INFLUENCE OF NUMBER OF PLIES ON FLEXURAL BEHAVIOUR OF ULTRA-THIN WOVEN COMPOSITES

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Deep space missions necessitate the development of weight-sensitive structures capable of supporting multiple operational configurations. The high strength-to-weight ratio and flexible material properties of woven fibre composites make them ideal for aerospace structures. Epoxy laminates reinforced with carbon fibre are often used in primary and secondary aircraft structures. Woven fibre composites have greater advantages compared to unidirectional fibre lamina. The number of fibres in a yarn and the type of weave determine the material properties. The high curvature experienced by space structures during folding and deployment points out the critical importance of understanding their bending behaviour for optimising future designs. Experimental studies show a significant reduction in the bending stiffness of ultra-thin woven composites when subjected to high curvatures according to the literature. The in-plane properties of woven laminates have been estimated through the development of numerous micromechanical analytical methods. Although in-plane properties can be accurately determined through Classical Lamination Theory (CLT) for thin woven composites, the flexural properties tend to over-predict by 200 – 400%.

This paper introduces micro-mechanical models to capture the impact of ply count on the mechanical characteristics of thin woven fibre composites. Accordingly, this study expresses a geometric model with solid elements that simulate the effect of the two waviness with increasing plies in a Representative Unit Cell (RUC) to analyse the bending stiffness reduction near failure. The study focuses on a plain-woven carbon fibre composite having fibres arranged in an in-phase configuration. A finite element pre-processor, TexGen software, is used to generate the representative unit cell geometry. This generated RUC model is then imported into the commercial finite element software Abaqus/Standard to simulate the mechanical behaviour. The numerical results are validated with experimental results obtained from the literature.

In addition, the study aims to investigate the behaviour of results derived from CLT under varying numbers of plies. The reduction in bending stiffness between CLT predictions and finite element (FE) simulations across all ply configurations varies from approximately 500% for single-ply laminates to 90% for three-ply laminates while 150% for two-ply laminates, highlighting the efficacy of the CLT approach in accurately predicting bending properties with increasing number of plies. One reason for this deviation is that CLT does not account for the inherent waviness of woven fibre composites, which generally exhibit a sinusoidal wave pattern. This waviness is reduced with an increasing number of plies, leading to a closer alignment between CLT and FE results.

Keywords: ABD matrix, Micro-mechanical modelling, Thickness effect, Woven fibre composites

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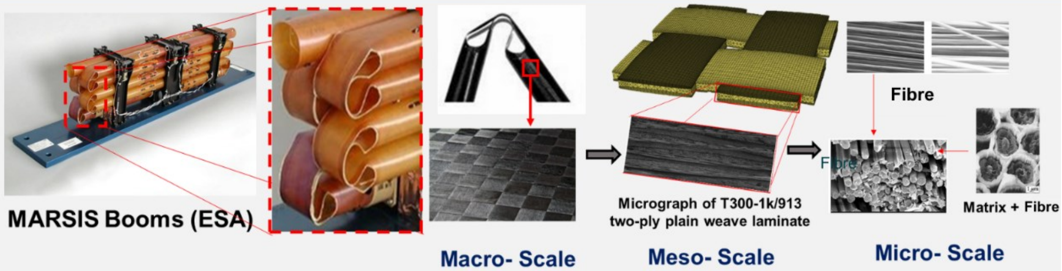
Background

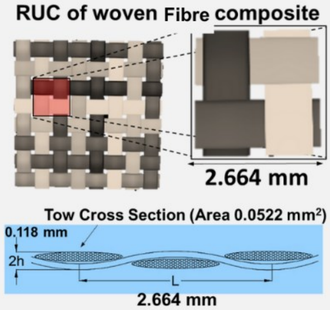


Multiscale Modelling

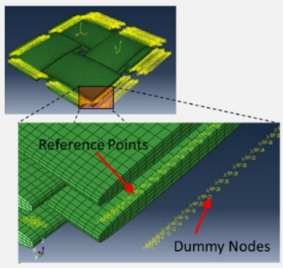
Research Methodology

Meso-Mechanical Modelling

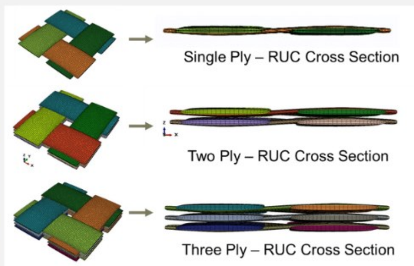
RUC of woven Fibre composite



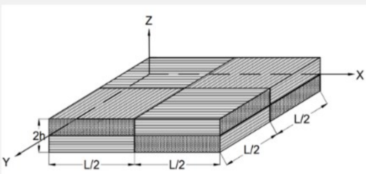
Abaqus/Standard



RUC Models - Varying Number of Plies



Classical Lamination Theory Approach



Simplified model of a single ply laminate

Sub Stiffness Matrix

$$A_{ij} = nh(Q_{ij}^{0} + Q_{ij}^{90})$$

$$B_{ij} = 0$$

$$D_{ij} = n^3 \frac{h^3}{3}(Q_{ij}^{0} + Q_{ij}^{90})$$

ABD Matrix

$$\begin{pmatrix} N \\ M \end{pmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{pmatrix} \varepsilon \\ \kappa \end{pmatrix}$$

Output

Results

Property	Experimental Value	FEM	CLT
D11	37.84	39.6	84.56
1/a11	12833	10000	17349
1/a66	833	333	797
V12	0.11	0.001	0.22