HOMOGENIZED RESPONSE OF ULTRA-THIN WOVEN FIBRE COMPOSITES UNDER FLEXURAL LOADING

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Degree of Master of Science

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Declaration of the Candidate and Supervisor

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Abstract

Design of large space structures is restricted due to the limited storage capacity of launch vehicles. Deployable structures made with ultra-thin woven fibre composites eliminates this bottleneck due to self-deploying nature. These structures can self-deploy using the strain energy stored during elastic folding. Popularity of self-deployable structures got increased due to their high strength, lightweight, and good packaging properties. However, thin woven fibre composites undergo large deformation during folding process due to the formation of high curvature, which causes reduction in bending stiffness. Hence, it is crucial to understand the mechanical behaviour of these structures before implementing, in order to avoid unnecessary failures. Numerical modelling techniques have become popular in this research area due to the advancement of computational methods to obtain the mechanical properties of thin woven fibre composites. Homogenised Kirchhoff plate-based representative unit cell modelling technique with solid elements is considered in this research. Corresponding ABD stiffness matrices are obtained with using virtual work principle, where the repetitive nature of woven fibre composites is represented by periodic boundary conditions.

First, a series of micro-mechanical analyses is carried out to observe the influence of the relative positioning of tows on the mechanical properties of thin woven fibre composites. Various phase shifts between the plies have been considered in this research which might be originated from the inter-ply misalignment during the manufacturing stage. The outcomes of this parametric study clearly depict the variation in in-plane and out-of-plane properties extracted from the ABD stiffness matrices and describe the potential causes for the detected deviations between experimental and numerical results.

Next, a resin embedded unit cell model is developed to predict the non-linear bending behaviour with degree of deformation. Initially, a geometrically linear analysis is carried out and then the analysis is extended to non-linear region to observe the moment-curvature response. Linear analysis results of extensional stiffness and Poisson’s ratio showed good agreement with the experimental results extracted from the literature. However, the out-of-plane properties and shear stiffness values were overpredicted. Similarly, non-linear analysis overpredicted the bending stiffness throughout the considered curvature range. Hence, the resin embedded unit cell model needs further improvements and modifications to accurately predict the out-of-plane properties, and capture the reduction in bending stiffness.

Keywords: woven fibre composites, phase shift, representative unit cell, ABD matrix, non-linear bending behaviour

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List of Abbreviations

Abbreviation	Description
NASA	National Aeronautics and Space Administration
ESA	European Space Agency
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
DLR	German centre of aviation and space flight
PBC	Periodic Boundary Conditions
RUC	Representative Unit Cell
FEM	Finite Element Modelling
CLT	Classical Lamination Theory
MPC	Multi Point Constraint
C3D6	Three-dimensional continuum six-node triangular prism elements
C3D8R	Three-dimensional continuum eight-node linear brick elements, reduce integration hourglass control elements
CAD	Computer Aided Drawing
BVP	Boundary Value Problem

List of Symbols

Roman Letters

Symbol	*Description*
1K	Thousand filament tow
A	Cross-sectional area of tow
A	Tow thickness
E_1	Longitudinal stiffness
E_2	Transverse stiffness
E_m	Stiffness of matrix
E_{1f}	*Longitudinal stiffness of the fibre*
E_{2f}	Transverse stiffness of the fibre
G_{12}	Shear stiffness
G_{23}	In-plane shear stiffness
G_{12f}	Shear modulus of the fibre
G_m	Shear modulus of the matrix
M	Out-of-plane moment resultant
N	In-plane force resultants
t	Thickness of the laminate
u	Displacement in the X direction
v	Displacement in the Y direction
V_f	Fibre volume fraction
W	Aerial weight of fabric/film
w	Displacement in the Z direction
Subscripts x,y	In-plane directions of loading
Subscripts 1,2	In-plane directions of material

Greek Letters

Symbol	*Description*
ΔL	Weave length of RUC
γ	Shear stress
κ	Out-of-plane curvature
κ_x	Curvature along the X axis
κ_y	Curvature along the Y axis
κ_{xy}	Twisting curvature
ν_{12}	Poisson's ratio
ν_m	Poisson's ratio of resin
ε	Mid-plane strain
ε_x	Strain in the X direction
ε_y	Strain in the Y direction
σ	Equivalent normal
θ	Rotation