SIMULATION OF NON-LINEAR BENDING BEHAVIOUR OF ULTRA-THIN WOVEN COMPOSITES

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Degree of Master of Science

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Dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science

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DECLARATION

I declare that this is my own work and this Dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The above candidate has carried out research for the Degree of Master of Science Dissertation under our supervision. We confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. H. M. Y. C. Mallikarachchi

Signature of the Supervisor: Date: 05/05/2025

Name of Supervisor: Dr. H. M. S. T. Herath

Signature of the Supervisor: Date: 05/05/2025

I would like to dedicate this thesis to my loving parents my sister and all the friends and colleagues who helped me through this journey. . . .

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Abstract

Ultra-thin woven fibre composites are commonly used to design self-deployable space structures subjected to large deformations. Accurate prediction of their folding and deployment behaviour is crucial for optimising space structures. Recent studies have suggested that in thin woven composites made of one to two layers, the material exhibits a significant reduction in bending stiffness at high curvatures, resulting in a non-linear moment-curvature response, but the phenomenon lacks comprehensive evidence. This study confirms the reported bending stiffness reduction by capturing the complete moment-rotation response from its initial stiffness to failure via a single experimental procedure conducted on coupons. Several approaches are used to construct the bending response from the experimental studies, and their effectiveness is evaluated. The observed experimental response is then captured using a representative unit cell-based homogenised numerical model which is proposed by previous researchers. The model is used to assess the effects of geometrical non-linearities and the material non-linearities of tows on the bending response. The meso-mechanical bending response aligns well with the experimental values. The meso-scale bending response is incorporated into macro-scale simulations via a user-defined section stiffness. Comparison of simulated results with column bending test results obtained through physical experiments shows that the proposed model is capable of accurately predicting the non-linear bending response. The study shows a significant variation in bending stiffness reduction at large curvatures when updating the stiffness matrix in comparison to the simulation performed only with a constant stiffness matrix. Incorporating this change of stiffness is critical for predicting the amount of energy stored for deployment as well as the force required for folding the structure.

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List of Abbreviations

ACS3	Advanced Composite Solar Sail 3
CBT	Column Bending Test
CLT	Classical Lamination Theory
CT	Computed Tomography
DIC	Digital Image Correlation
DSS	Deployable Space Structures
FPB	Four-Point Bending
HSC	High-Strain Composites
LD-FPB	Large Deformation Four-Point Bending
MSAT	Mobile Satellite System
NASA	National Aeronautics and Space Administration
RUC	Representative Unit Cell
SVMBIR	Super Voxel Model-Based Iterative Reconstruction
UTM	Universal Testing Machine
XRCT	X-Ray Computed Tomography

List of Symbols

A Extensional stiffness matrix
B Coupling stiffness matrix
D Bending stiffness matrix
E Young's modulus
G Shear modulus
M Bending moment
N In-plane force resultant
P Applied load
V_f Fiber volume fraction
ε Strain
κ Curvature
ν Poisson's ratio
σ Stress
ϕ Rotation angle
θ Angle
δ Displacement
Δ Difference or increment