SIMULATION OF CLOSED CROSS SECTION DUAL MATRIX COMPOSITE BOOMS

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Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

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Thesis submitted in partial fulfilment of the requirements for the degree Master of Science in Civil Engineering

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DECLARATION

I declare that this is my own work and this thesis 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.

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Dr. H.M.Y.C. Mallikarachchi

ABSTRACT

The necessity of deployable mechanisms in the field of aerospace is inevitable due to volume limitations in the launch vehicles. Use of mechanical hinges with motors and springs for actuation make the structure heavy and complex. Alternatively, elastically deformable thin shell structures have become popular due to their light weight, ability to self-deploy using energy stored during folding and eliminating complex hinge mechanisms.

Self-deployable booms made of fibre composites are widely used in the space industry. Design of booms made with traditional epoxy matrix are limited by the low failure curvatures. The dual-matrix composite with soft elastomers in the folding region has been identified as a better alternative which allows for high curvature folds of as much as 180^o. However, the behaviour of folding and deployment of dual-matrix composites has not been studied in detail.

This thesis presents a detailed study of finite element simulations of folding and deployment of a dual-matrix composite boom made of 3-ply plain-weave glass fibre laminates having a soft silicone matrix in the intended hinge region and rigid epoxy matrix elsewhere. Folding and deployment simulations were carried out under quasi static conditions using the commercial finite element package Abaqus/Explicit. The limitations and the necessary checks to obtain a robust solution are discussed in detail.

Moment-rotation relationship is used to characterize the deployment behaviour under quasi-static conditions, because it gives an indication whether the structure can self-latch and achieve the intended configuration during deployment. Initially a stable folded configuration was simulated from the unstressed configuration of the dual-matrix composite boom and then deployment was simulated by gradually decrease the relative rotation between two ends of the boom until it becomes zero.

Reduction in the bending stiffness of silicone matrix under high curvature significantly influencing the folded configuration of dual-matrix composite booms. A detailed study on the cross sections of the folded configurations reveals that a modified bending stiffness has to be used for simulations. 10% of original bending stiffness which corresponds to high curvature conditions was used for silicone region throughout the simulation.

The simulated response was compared against physical experiments carried out by Sakovsky et al. (2016) for validation. Simulation is capable of capturing both overall and localized deform configurations as well as the steady-state moment in the moment-rotation response. However it underestimates the peak moment because the modified bending stiffness leads to a weaker response. Further analysis was carried out using different bending stiffness modifications to understand the significance of the stiffness variation of silicone matrix. Also an attempt was made to understand the potential of dual matrix composite booms which is having a closed cross section by comparing with an equivalent tape spring hinge.

Key words: dual-matrix composite boom, self-deployable structures, quasi-static simulations, moment-rotation response

DEDICATION

To my parents, without whom none of this would be possible.

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NOMENCLATURE

List of symbols

ABD_E	constitutive matrix for epoxy matrix in coordinate system x and y
ABD_S	constitutive matrix for silicone matrix in coordinate system x and y
A_{ij}	coefficients of upper-left 3 x 3 submatrix of ABD, N/mm
B_{ij}	coefficients of upper-right 3 x 3 submatrix of ABD, N
D_{ij}	coefficients of lower-right 3 x 3 submatrix of ABD, Nmm
c_d	dilatation wave speed, mm/s
c_v	viscous pressure coefficient, Ns/mm^3
E	modulus of elasticity, N/mm^2
E_i	internal energy, mJ
E_{ke}	kinetic energy, mJ
E_{total}	total energy, mJ
E_{vd}	viscous dissipation, mJ
E_{wk}	work done by external forces, mJ
l_{min}	shortest length of finite element, mm
M	moment per unit length stress resultant, N
N	force per unit length stress resultant, N/mm
n	unit surface normal
p	viscous pressure, N/mm^2
p_b	bulk viscosity pressure, N/mm^2
v	velocity vector mm/s
α	time scaling factor
ε	mid-plane strain mm/mm
$\dot{\epsilon}_{vol}$	volumetric strain rate, 1/s
ν	Poisson’s ratio
ρ	density, kg/m^3
θ	rotation, radian
ξ	fraction of critical damping in highest frequency mode
Δt	stable time increment

List of abbreviations

CLT	Classical Lamination Theory
CFRP	Carbon Fibre Reinforced Polymer
CTM	Collapsible Tube Mast
FFT	Flattenable Foldable Tubes
FRP	Fibre Reinforced Polymer
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding
MSAT	Mobile SAT system
STEM	Storable Tubular Extensible Member
TRAC	Triangular Rollable And Collapsible