PREDICTING NON-LINEAR BENDING BEHAVIOUR OF ULTRA-THIN WOVEN FIBRE COMPOSITES

Hasitha Sithadara Wijesuriya

188035A

Degree of Master of Science

Department of Civil Engineering

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Thesis submitted in partial fulfilment of the requirements for the degree of
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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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....   Date :

Dr. H.M.Y.C. Mallikarachchi

Abstract

Ultra thin woven composites are extensively used in deployable space structures, particularly on deployable booms which are responsible to deploy and hold key components in space missions. Due to high weight sensitivity of these applications, it is essential to achieve the maximum structural efficiency to reduce the payload. However the flexural behaviour of these thin textile composites is still troublesome under high curvatures. Hence it limits the optimization of deployable structures to highest degree possible.

Numerical modelling of these structures is considered as a promising tool in designing, considering the time consuming and costly nature of physical testing. Yet, most of the numerical models aimed at the macroscopic behaviour, suffer from lack of accurate behavioural characteristic of non-linear geometric regime.

This study is an attempt made to address the above problem by building virtual simulation techniques through micromechanical modelling. For this work a homogenized Kirchhoff Love plate model was developed with the identified unit cell of two-ply plain weave composite. The geometry was imported from TexGen textile modelling package and FEA simulation was done by ABAQUS commercial finite element package.

A new logical framework was proposed to describe the behavioural characteristics of the tows at the interlacing points by means of cohesive behaviour. Material definition for cohesive interaction was included through traction separation law maximum principal stress criterion for damage initiation. Required traction coefficients were extracted by a discrete FEA simulation due to unavailability of experimental data.

The developed model was executed in the linear regime and then extended to non-linear geometric regime to predict the flexural behaviour under high curvatures and it shows bending stiffness reduction as expected. Thus the proposed simulation technique can be utilized in designing process of deployable booms made of thin woven composites through the multiscale modelling approach after verifying the accuracy with experiments.

Keywords : *ultra-thin fibre composites, woven composites, non-linear bending behaviour, representative unit cell, ABD matrix, cohesive behaviour, traction separation, damage criterion*

Dedication

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

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Nomenclature

List of Abbreviations

C3D6	3D continuum six-node wedge elements
C3D8	3D continuum eight node brick elements
DLR	German Aerospace Center (Deutsches Zentrum fr Luft- und Raumfahrt e.V.)
DSL	Deployable Structures Laboratory
ESA	European Space Agency
LEFM	Linear Elastic Fracture Mechanics
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding
NASA	National Aeronautics and Space Administration
PBC	Periodic Boundary Conditions
RUC	Representative Unit Cell
XFEM	Extended Finite Element Modelling

List of Symbols - Roman

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
G_{12}	Shear stiffness
G_{23}	In-plane shear stiffness
K_{nn}	Traction stiffness in normal direction
K_{ns}	Coupling of traction stiffness in normal and shearing direction
K_{nt}	Coupling of traction stiffness in normal and tearing direction
K_{ss}	Traction stiffness in shearing direction
K_{st}	Coupling of traction stiffness in shearing and tearing direction
K_{tt}	Traction stiffness in tearing direction
M	Out-of-plane moment resultant
N	In-plane force resultants
P	Force just before the failure in platen folding test
$S22$	Normal stress of 2 plane in 2 direction
t_n	Traction stress in normal direction
t_s	Traction stress in shearing direction
t_t	Traction stress in tearing direction
u	Displacement in X direction
v	Displacement in Y direction
V_f	Fibre volume fraction
W	Aerial weight of fabric/film
w	Displacement in Z direction
w_s	Width of the specimen

List of Symbols - Greek

α_0	Stiffness reduction factor
δ_n	Separation in normal direction
δ_s	Separation in shearing direction

δ_t	Separation in tearing direction
Δl	Weave length of RUC
δ	Distance between two plates - platen folding test
γ	Shear stress
κ_x	Curvature around X axis
κ_y	Curvature around Y axis
κ_{xy}	Twisting curvature
κ	Out-of-plane curvature
ρ	Density
υ_{12}	Poisson's ratio
υ_m	Poisson's ratio of matrix
ε_x	Strain in X direction
ε_y	Strain in Y direction
ε_{xy}	In-plane shear strain
ε	In-plane strain