

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

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Degree of Master of Science

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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 :

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The above candidate has carried out research for the Masters thesis under my supervision.

..... 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 für 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
$S_{22}$	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

$\alpha_0$	Stiffness reduction factor
$\delta_n$	Separation in normal direction
$\delta_s$	Separation in shearing direction

$\delta_t$	Separation in tearing direction
$\Delta l$	Weave length of RUC
$\delta$	Distance between two plates - platen folding test
$\gamma$	Shear stress
$\kappa_x$	Curvature around X axis
$\kappa_y$	Curvature around Y axis
$\kappa_{xy}$	Twisting curvature
$\kappa$	Out-of-plane curvature
$\rho$	Density
$\nu_{12}$	Poisson's ratio
$\nu_m$	Poisson's ratio of matrix
$\varepsilon_x$	Strain in X direction
$\varepsilon_y$	Strain in Y direction
$\varepsilon_{xy}$	In-plane shear strain
$\varepsilon$	In-plane strain