ANALYSING THE NON-LINEAR BENDING BEHAVIOUR OF ULTRA-THIN WOVEN COMPOSITES AT HIGH CURVATURES

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Deep space missions require self-deployable structures built of ultra-thin materials which can be carried to space in a limited space. Therefore, a growing demand for ultra-thin woven composites has been identified in space engineering applications. Understanding their mechanical behaviour is crucial for the effective optimisation of future structures because they experience extreme curvatures when in use in both folding and deploying mechanisms. It is more challenging to predict the overall mechanical behaviour of these composites due to their complicated geometry and nonlinear behaviour of its constituent parts. A common method to solve this problem is multiscale modelling, in which the system is simultaneously described by multiple models at varying scales. Micromechanical, mesomechanical and macromechanical scales are taken into consideration for woven fibre composites.

Physical experiments revealed that ultra-thin woven fibre composites show a significant drop in bending stiffness at higher curvatures. The first objective of the study focuses on checking whether there is a thickness reduction of the plies at high curvatures which can be a possible reason for the reduced bending stiffness at high curvatures. As the second objective, it is expected to introduce air voids in resin to capture the non-linear bending response of woven fibre composites observed under high curvatures.

Due to the deformation of the fibres and the weave structure at higher curvatures, woven fibre composites may exhibit variations in thickness. Resin matrices usually have lower stiffness compared to the reinforcing fibres. As a result, when the composite is subjected to higher curvatures, the fibres on the inner side of the curve may experience compression, leading to a reduction in thickness, while the resin matrix tends to flow and redistribute in response to the applied forces. The flow of resin can have both positive and negative effects on the thickness variation. On one hand, the ability of the resin to flow and redistribute can help accommodate the compression of the fibres and reduce the overall thickness reduction.

According to the obtained results from the Dry Fibre model and the Resin model, except for the mid-section of the Dry Fibre model, there is no significant thickness variation at other locations compared to the original thickness in both the Resin model and Dry Fibre model. Although there is a thickness reduction at the mid-section of the dry fibre model, at high curvatures thickness starts to increase again which is against the experimentally observed bending behaviour. So, according to the obtained thickness variation results from the two models, there is no clear connection between bending stiffness reduction and thickness variation.

To check the effect because of voids, Fibre Volume Fraction of the composite was used. The Fibre Volume Fraction is defined as the ratio of the volume of fibres present to the total volume of the layer. From the second objective, it was observed that there is a 6-8 % reduction in longitudinal stiffness, transverse stiffness, and shear stiffness with the void ratio. Variation in the Poisson's ratio with the void ratio is low compared to other mechanical properties.

Keywords: Deployable Structures, Woven fibre composites, Representative Unit Cell, Bending Stiffness, Fibre volume fraction

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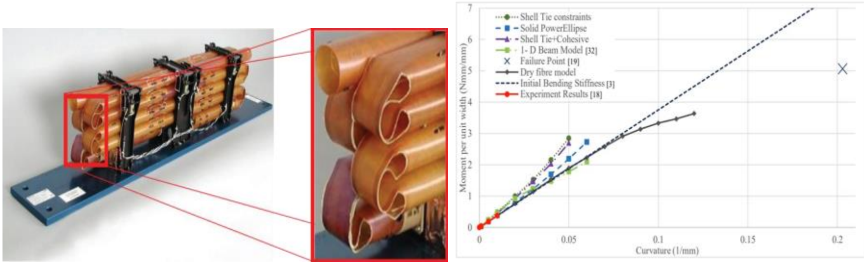
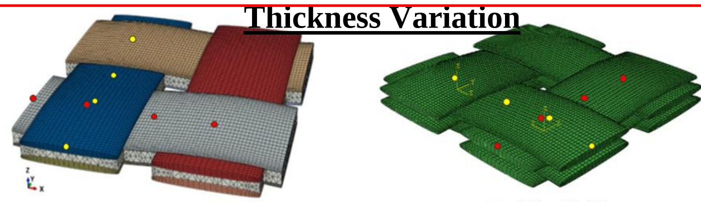
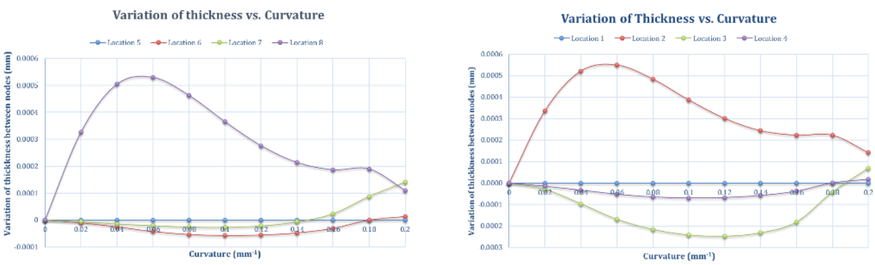


Non-linear bending behavior of woven fibre composites at high curvatures

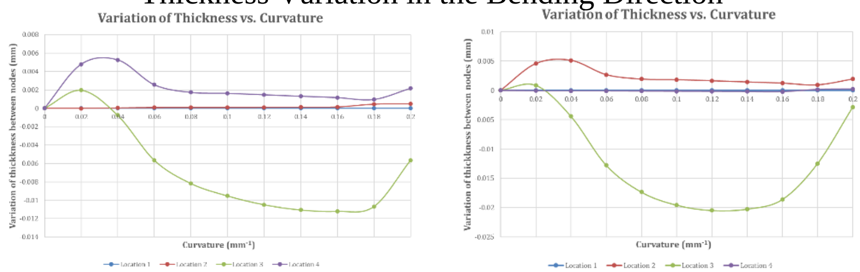
Thickness Variation



Resin Model *Dry Fibre Model*



Thickness Variation in the Bending Direction



Thickness Variation in the Transverse Direction

Change in Mechanical Properties of Woven Fibre Composites with Void Ratio

Property	Property Value		Change, %
	Void Ratio, 0 %	Void Ratio, 20 %	
Fibre volume fraction, V_f	0.6183	0.5745	-7.08
Longitudinal stiffness E_1 (N/mm^2)	145360	135300	-6.92
Transverse stiffness $E_2 = E_3$ (N/mm^2)	10390	9600	-7.60
Shear stiffness $G_{12} = G_{13}$ (N/mm^2)	3367	3095	-8.08
Poisson's ratio, $\nu_{12} = \nu_{13}$	0.28	0.29	3.57