INVESTIGATION OF CREASES IN ULTRA-THIN MEMBRANES

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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 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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D. M. S. P. Dassanayake

The above candidate has carried out research for the Master′s thesis under my supervision.

.... Date :

Dr. H.M.Y.C. Mallikarachchi

Abstract

The use of thin membranes is widespread in a variety of applications in a range of industries owing to the lightweight nature and small packaged volume attainable by them. When facilitating the storage of large areas of membranes by folding−specifically in aerospace applications, the resulting creases alter the physical state and material properties of the overall membrane structure. Even though numerical modelling is preferred as a viable tool in replicating space environments on earth in the form of reduced gravity and air drag, the idealisations utilised in these analyses require validation via small-scale experiments. The significance of this process is highlighted due to past endeavours which failed to idealise the crease mechanics accurately, leading to inaccurate predictions and eventual failure in complete missions. Moreover, the use of virtual testing in this regard is limited by the unavailability of accurate experimental data.

In this research, an attempt has been made to characterise the crease mechanics of multiple creased thin Kapton 100 HN poyimide membranes using an experimental study. A combination of specimens consisting of two and three creases have been analysed in this regard, and moment−angle responses were plotted using results of physical experiments. The results indicated different crease stiffnesses for each crease in a parallel-creased specimen, with the highest stiffness observed for a crease nearest to the pinned support. However, all the stiffness values obtained herein were observed to be of a lower order than the simulation and physical experimental results obtained by previous researchers for membranes with a single crease, which could be attributed to the precise measurements taken during the experimental study and the incorporation of the effect of self-weight of the membrane into its moment−rotation response, which was neglected in earlier studies. The time dependence of the opening behaviour was also studied, and it was identified that the membrane achieves a constant opening angle in a shorter time duration on being loaded.

An improved experimental setup was designed and developed, on identifying the limitations and inaccuracies observed in the experimental setup devised by previous researchers. This ensured controlled displacement being offered to the membrane for capturing its deployment behaviour over a wider regime of loading, along with precise force measurement. The setup included additional measures to facilitate its usage for specimens of a wider range of dimensions, and to ensure proper alignment of the membrane, thereby enhancing the accuracy of the results obtained via the physical experiments which would then be utilised for idealisation schemes of deployment simulations in virtual environment.

Crease stiffness determined for single-creased membranes utilising the improved setup was implemented in Abaqus/Explicit finite element package for the purpose of predicting the deployment behaviour of membrane structures with multiple creases accordingly. The crease-line was represented with connector elements specifying the rotational elasticity, and was observed to have negligible effect on the deployment which contradicts the experimental observations. Hence, further investigations are required for assessing the accuracy of this claim.

A quasi-static simulation was carried out for a simple creased unit based on traditional “Waterbomb” base for predicting the deployment behaviour consisting of intersecting creases. The simulation developed in Abaqus/Explicit environment was able to capture the deployment response observed in the physical experiments, in terms of maximum deployment ratio and shape on incorporating the effect of gravity to the simulation.

Keywords : *ultra-thin membranes, crease mechanics, rotational stiffness, multiple parallel creases, finite element simulations*

Dedication

To my parents, whose unyielding love, support and encouragement has enriched my soul and inspired me to pursue and complete this research.

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Nomenclature

List of Abbreviations

ARGOS	Active Response Gravity Offload System
DLR	German Aerospace Centre (Deutsches Zentrum für Luft- und Raumfahrt)
ESA	European Space Agency
IKAROS	Interplanetary Kite-craft Accelerated by Radiation of the Sun
JAXA	Japanese Aerospace Exploration Agency
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
PDT	Pacific Daylight Time
UTC	Coordinated Universal Time

List of Symbols

$\hat{V}_i^j$	Vector in the i^{th} direction for node j
ν	Poisson's ratio
ω_{max}	Highest Eigenvalue of the model
ϕ	Neutral angle
ρ	Material density
θ	Current crease opening angle
ξ	Fraction of critical damping in the fundamental frequency mode

c_d	Dilatational wave speed
c_v	Viscous damping coefficient
D_f	Fully deployed dimension of creased structure
E	Modulus of elasticity
E_i	Internal energy of the system (elastic, inelastic and artificial strain energy)
E_{ke}	Kinetic energy
E_{total}	Total energy of the system
E_{vd}	Energy absorbed by viscous dissipation
E_{wk}	Work done by external forces
F	Tensile load
k	Crease-line stiffness
k_o	Crease-line stiffness during crease actuation (and panel bending)
k_r	Crease-line stiffness during self-opening
l	Length of a membrane panel
L^*	Non-dimensional length
l_h	Horizontal distance from the crease-line to the loaded tip
l_{min}	Minimum length of the finite element
M	Resistive moment at the crease-line
M_c	Kinematic moment in the connector
t	Thickness
w	Width of the membrane coupon