CHARACTERIZING MESO-MECHANICAL PROPERTIES OF ULTRA-THIN PLAIN WOVEN FIBRE COMPOSITES UNDER LARGE DEFORMATIONS

Weerasinghe W. U. D

228064H

Master's in Civil Engineering (Major component by Research)

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

May 2025

CHARACTERIZING MESO-MECHANICAL PROPERTIES OF ULTRA-THIN PLAIN WOVEN FIBRE COMPOSITES UNDER LARGE DEFORMATIONS

Weerasinghe W. U. D

228064H

Dissertation submitted in partial fulfillment of the requirements for the degree
Master's in Civil Engineering (Major component by Research)

Department of Civil Engineering
Faculty of Engineering

University of Moratuwa
Sri Lanka

May 2025

DECLARATION

I declare that this is my own work and this Dissertation 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. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date: 13/05/2025

The supervisors should certify the Dissertation with the following declaration.

The above candidate has carried out research for the Master's in Civil Engineering (Major component by Research) Dissertation under our supervision. We confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. Chinthaka Mallikarachchi

Signature of the Supervisor: Date: 14/05/2025

Name of Supervisor: Dr. Sumudu Herath

Signature of the Supervisor: Date: 14/05/2025

DEDICATION

This thesis is dedicated to my family, whose unwavering support, love, and encouragement have been my greatest source of strength throughout this journey. To my parents, who have instilled in me the values of hard work, perseverance, and curiosity, and who have always believed in my dreams. To my mentors and professors, whose guidance and knowledge have been invaluable, helping me shape my path in the field of engineering. Finally, to my friends and colleagues, who have shared this journey with me, providing support and camaraderie. This work is a testament to all of you, whose belief in me made this accomplishment possible. Thank you for being part of this journey.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to my supervisors, Prof. Chinthaka Mallikarachchi and Dr. Sumudu Herath, whose guidance, support, and mentorship have been invaluable throughout this research. Their expertise, encouragement, and constructive feedback have played a pivotal role in the successful completion of this work.

Also, I am grateful to the progress review and final evaluation committee for their valuable comments and support throughout the research.

Special thanks to the Deployable structures research group for giving me motivation and guidance throughout the research.

I am also grateful to the faculty and staff at the Department of Civil Engineering, University of Moratuwa, for providing a stimulating and supportive environment that has nurtured my academic and professional growth. Special thanks to my colleagues and friends for their camaraderie, insightful discussions, and encouragement during challenging moments.

I am profoundly appreciative of the support provided by my family, whose belief in my abilities has been my greatest motivation. Their unwavering support and encouragement have been a constant source of strength.

This research would not have been possible without the financial support of the National Research Council, provided through grant no. 2020-080. I am sincerely thankful for this funding, which has been essential in enabling the resources and facilities necessary to undertake this study.

Finally, to everyone who has contributed to this journey in ways big and small, I offer my heartfelt thanks. This accomplishment is a testament to your support and belief in my work.

Thank you all.

ABSTRACT

Ultra-thin woven fibre composite structures offer high strength-to-weight ratios and flexibility, making them highly used for aerospace and other applications requiring lightweight, durable materials. However, understanding and predicting the mechanical behaviour of these composites under large deformations, particularly their flexural response and bending stiffness, remains a challenge. This study presents a comprehensive investigation into the meso-mechanical properties of ultra-thin plain woven composites under conditions of extreme curvature. Using finite element modelling, this research focuses on accurately capturing the bending behaviour and assessing the impact of inter-tow slipping and material non-linearity, which are pivotal in understanding the reduction in bending stiffness observed at high curvatures.

A detailed numerical model based on a Representative Unit Cell approach was developed in Abaqus software, incorporating Periodic Boundary Conditions to reflect the composites meso-structural attributes. To simulate realistic conditions, both geometrical and material non-linearities were introduced. This approach enabled a robust analysis of cohesive interactions between fibre tows and the resin matrix, which are crucial for replicating the observed reduction in bending stiffness at higher curvatures. The FE model was calibrated and validated against experimental results from the literature, showing strong agreement with empirical data and confirming the model's predictive capabilities.

Results indicate that interfacial interactions, coupled with material non-linearity, play significant roles in the mechanical response of these composites, particularly under large bending strains. The study successfully captures these phenomena, providing a framework for further parametric studies and highlighting the necessity of meso-scale modelling for such complex materials. The findings offer valuable insights for optimizing the design of ultra-thin woven composites for use in deployable aerospace structures and other applications, contributing to the development of more efficient and reliable structural components.

Keywords: Thin woven composites, Meso-mechanical modeling, tow non-linearity, Inter-tow slipping

TABLE OF CONTENTS