UNIVERSITI PUTRA MALAYSIA

BEHAVIOUR OF CORRUGATED COMPOSITE TUBE UNDER COMPRESSIVE LOAD USING FINITE ELEMENT METHOD

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Thesis Submitted to the School of Graduate Studies Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Master Science

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Chairman: **Assoc. Prof. Dr. Ahmad Samsuri b. Mokhtar, Ph.D**

Faculty: **Engineering, UPM**

This work focuses on studying the effect of composite corrugated tubes' crushing behaviour and to identify the optimised energy-absorption orientation of composite material lamination subjected to the axially compressive load. Parametric study was conducted to investigate the effect of the corrugated angles and fibre orientations on the energy absorb using the E-Glass fibre/epoxy Corrugated Cylindrical Composite Tubes (CCCT) in woven roving form. Twenty different orientations ([0/0/0], [30/0/0], [0/45/0], [60/0/0], [30/0/30], [30/45/0], [60/0/30], [45/0/45], [60/45/0], [60/0/60], [30/30/30], [30/45/30], [60/30/30], [30/45/45], [60/45/30], [30/60/60], [45/45/45], [60/45/45], [60/45/60], [60/60/60]) of E-Glass fibre/epoxy in woven roving laminations were fabricated for this purpose. Nevertheless, only three randomly chosen corrugated angles (5 degrees, 20 degrees & 35 degrees) were used for finite element analysis. Typical failure histories of their failure mechanisms are presented and discussed. Results showed that the crushing behaviour and the energy-absorption level of composite corrugated tube are found to be different when changes are made to the orientation of lamination of the composite material. CCCTs

with the lowest corrugation angles resulted with highest initial crushing load and the highest average crushing load, and vice-versa. Meanwhile, CCCTs with the low corrugated angle requires thorough study before being used as an energy absorption device because their initial crush load that is too much greater than the average crush load itself. However, the best energy absorbing CCCT for this work should have the highest possible energy absorbed per unit mass (*Es*) while compensating for least possible differences between initial crush load and average crush load. With this criterion, CCCT with a corrugated angle of 20 degrees and [60/0/60] lamination orientation fulfilled the requirement. At the same time, the result of this work also shows that the average *Es* for CCCT with a lower corrugated angle is higher than the CCCT with a higher corrugated angle. Subsequently, the usage of 5, 20 and 35 degrees corrugated angles has generally covered the range of corrugated angles from 0 degree to 45 degrees because as the corrugated angle of CCCTs increases, the average *Es* of CCCT will reduce and will no longer significant in this project. CCCT with a corrugated angle of beyond 45 degrees will cause the woven roving composite material of CCCT to perform beyond the intended strength of direction. In addition, corrugated angles between 45 degrees and 90 degrees are similar to corrugated angles from 0 degree to 45 degrees. Thus, no study on CCCTs with corrugated angle beyond 45 degrees is required.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KELAKUAN TIUB KOMPOSIT BERLIPAT DIBAWAH DAYA MAMPATAN MENGGUNAKAN KAEDAH UNSUR TERHINGGA

Oleh

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Desember 2008

Pengerusi: **Assoc. Prof. Dr. Ahmad Samsuri b. Mokhtar, Ph.D**

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Kerja penyelidikan yang telah dijalankan tertumpu kepada kajian terhadap kelakuan renyukan tiub komposit yang berlipat disebabkan oleh daya mampatan dan penentuan orientasi lamina bahan komposit bagi mendapatkan serapan tenaga yang optimum. Kajian parametrik telah dilakukan untuk menyiasat kesan sudut lipatan dan orientasi fiber terhadap serapan tenaga dengan menggunakan tiub silinder gelas fiber jenis E yang berlipat. Dua puluh orientasi lamina ([0/0/0], [30/0/0], [0/45/0], [60/0/0], [30/0/30], [30/45/0], [60/0/30], [45/0/45], [60/45/0], [60/0/60], [30/30/30], [30/45/30], [60/30/30], [30/45/45], [60/45/30], [30/60/60], [45/45/45], [60/45/45], [60/45/60], [60/60/60]) gelas fiber jenis E dikaji bagi tujuan tersebut. Walaubagaimanapun, hanya tiga sudut lipatan yang dipilih (5 darjah, 20 darjah dan 35 darjah) dan digunakan untuk analisis unsur terhingga. Perilaku kegagalan bagi mekanisme kegagalan dibentangkan dan dibincangkan. Hasil kajian yang diperolehi menunjukkan kelakuan renyukan dan paras serapan tenaga tiub komposit yang berlipat adalah berbeza mengikut perubahan yang dibuat ke atas orientasi lamina

bahan komposit. Tiub jenis CCCT dengan sudut lipatan yang terendah menghasilkan daya renyukan awalan dan daya renyukan purata yang tertinggi begitu juga sebaliknya. Sementara itu, tiub jenis CCCT dengan sudut lipatan yang rendah memerlukan kajian yang mendalam sebelum ia digunakan sebagai alat serapan tenaga kerana daya renyukan awalannya yang tinggi melebihi daya renyukan purata. Walaubagaimanapun, CCCT yang paling baik untuk dijadikan bahan serapan tenaga dalam kajian ini adalah CCCT yang mempunyai serapan tenaga yang setinggi mungkin dan mempunyai perbezaan di antara daya renyukan awalan dan daya renyukan purata yang serendah mungkin. Dengan itu, CCCT yang bersudut lipatan 20 darjah dan berlapis arah [60/0/60] adalah pilihan yang paling sesuai untuk kriteria ini. Pada masa yang sama, hasil kajian ini juga menunjukan bahawa purata serapan tenaga (*Es*) untuk tiub jenis CCCT dengan sudut lipatan yang rendah adalah lebih tinggi daripada tiub jenis CCCT dengan sudut lipatan yang tinggi. Oleh itu, kajian kegunaan tiub jenis CCCT dengan sudut lipatan 5, 20 and 35 darjah secara am telah dapat merangkumi tiub jenis CCCT dengan sudut lipatan di antara 0 darjah hingga ke 45 darjah. Ini adalah disebabkan oleh sudut lipatan yang bertambah tinggi, di mana purata *Es* tiub CCCT akan berkurangan dan keadaan sedemikian tidak lagi menjadi penting dalam kajian ini. Tiub CCCT dengan sudut lipatan melebihi 45 darjah akan mengakibatkan fiber komposit pada tiub CCCT ini berfungsi di luar kawasan kekuatannya dari arah yang sepatutnya. Tambahan pula, sudut lipatan di antara 45 darjah dan 90 darjah adalah sama seperti sudut lipatan di antara 0 darjah dan 45 darjah. Oleh yang demikian, kajian terhadap CCCT dengan sudut lipatan yang melebihi 45 darjah adalah tidak diperlukan.

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It would not have been possible to write this thesis without the collaboration and support of a number of people. The first person I would like to thank is Dr. Rizal b. Zahari for inspiring me with many ideas and information regarding my master project. Without his invaluable guidance, this thesis would never have been completed.

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Most of all, I want to thank my wife for supporting me by all means while I was writing this thesis. Without her unwavering support and understanding I could never have accomplished it.

I certify that a Thesis Examination Committee has met on 5 December 2008 to conduct the final examination of Ng Seet Wai on his thesis entitled "Behaviour Of Corrugated Composite Tube Under Compressive Load Using Finite Element Method " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science in Aerospace Engineering.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledge. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

_____

Name: Ng Seet Wai

Date: 23 December 2008

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NOMENCLATURES

	DESCRIPTIONS	UNITS
2D	Two-dimensional	-
3D	Three-dimensional	-
BBP	Braided Pultruded Process	-
CCCT	Corrugated Cylindrical Composite Tubes	-
CFRP	Carbon Fibre Reinforced Plastic	-
E	Young Modulus	GPa
E_s	Energy absorbed per unit mass	kJ/kg
FEA	Finite Element Analysis	-
G	Shear Modulus	GPa
MA	Moveable rigid anvil	-
P_i	Initial crushing load	kN
P_m	Average crushing load	kN
QUAD	Quadrilateral elements	-
SA	Stationary rigid anvil	-
TRIA	Triangle elements	-
l	Fibre length	m
l_c	Critical fibre length	m
l_t	Load-transfer length	m

σ	Stress	kPa
σ_f	Fibre stress in axial direction	kPa
σ_{f0}	Stress on the fibre end	kPa
$\in$	Strain	kPa
τ	Shear stress	kPa
τ_y	Matrix yield stress in shear	kPa

1. INTRODUCTION

This chapter serves as the introductory page on this thesis. The major focus in this chapter is for the discussion on the subject matter and the overall objectives of this project. In this chapter, issues of interest, objectives and the overview of the thesis are discussed.

Background and Problem Statement

Due to the human desire in designing high speed transport vehicles to reduce travelling time, the survivability of occupants in the vehicles had became the major concern to vehicles designers. Regardless of air, sea, and ground vehicles, the design features were increasingly driven by minimum weight considerations to increase carrying capacity and at the same time, tolerates for passenger safety. Upon introducing safety features in vehicles, which include the seat belts, safety helmets, vehicle crash protective bars, etc., has created an increased interest in the research and development of lightweight transportation vehicles. The primary goal to the lightweight vehicle is to achieve the superior strength-to-weight ratio and to improve the fuel economics of vehicles. This ideology had brought for the change of types of materials used from metallic to composite material. When composite structures or components are perfectly designed and fabricated, a very low stress loading, lightweight and high crashworthiness performance could be achieved. This will served as a high energy-dissipating device to most of the vehicle components.

Eventually, the researches in composite crushing behaviour and energy absorption of composite components with customised shapes and geometries

serves as the primary but vital steps in producing the desired "Near Perfect" components.

Importance of Study

Due to the simplicity in manufacturing and cost efficiency of hollow tubes as compared to solid tubes, hollow tubes are favourable for the used as structural components in today's world. Subsequently, cylindrical shape tubes were chosen for this research mainly due to no sharp edges along the tube body that eventually serves as weak buckling points. Thus, giving optimal longitudinal strength.

The study at the crushing & behaviours of the desired orientations of fibre lamination for axially loaded tubes using FEA software is beneficial as follows;

- Optimisation of designed of crushing device with optimal geometrical shapes and fibre orientations.
- Identification of the possibility of such designed prior to experimental approach. Time and cost saving as compared to prototypes building for trial-an-error experimental approach.

Aims & Objectives

The objectives of this project are:

- To investigate the effect of varying the corrugated angles on the crushing behaviour of CCCT under compression using FEM.
- To determine the optimal orientations of composite (woven roving glass fibre/epoxy) laminas of several commonly used Corrugated Cylindrical

Composite Tubes (CCCT) when axial load applied onto one end of the tube using FEA (ABAQUS) method.

Method Statement

This research focuses in studying the effect of composite material (woven roving glass fibre/epoxy) fabrication orientation in Corrugated Cylindrical Composite Tubes (CCCT) on energy absorption capacity, failure mechanism, and failure mode using the Finite Element Analysis (FEA) simulation method.

In the beginning of the study, finite element models were built in the ABAQUS/CAE. Referring to Elgalai et al. (2004) work as the based study for this thesis; several corrugated tubes with reference to the journal were built for the study. Axially compressive loads were simulated and applied onto the selected tubes in the software environment. These corrugated tubes models were then be analysed using ABAQUS/Explicit for validation.

Upon validation of several cases using the work, the study of several selected corrugated tubes with corrugated angle of 5, 20 & 35 degrees were used for the study. 20 corrugated tubes formed by 20 respective different orientations of E-Glass fibre/epoxy in woven roving form were simulated for axially compressed loading. The energy absorption capacity, failure mechanism, and failure mode of the composite corrugated tubes were then be analysed and discussed.