UNIVERSITI PUTRA MALAYSIA

AXIAL AND LATERAL QUASI-STATIC CRUSHING BEHAVIOUR OF SEGMENTED AND NON-SEGMENTED COMPOSITE TUBES

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ITMA 2003 1

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By

AL-HADI A. SALEM ABOSBAIA

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

April 2003

Dedication

A Special Dedication To

My family

Hadi

Malaysia, 2003

Abstract of thesis submitted to the Senate of Univeriti Putra Malaysia in partial fulfilment of the requirements for the degree of Master of Science

AXIAL AND LATERAL QUASI-STATIC CRUSHING BEHAVIOUR OF SEGMENTED AND NON-SEGMENTED COMPOSITE MATERIAL TUBES

By

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April 2003

Chairman: **Dr. Elsadig Mahdi Ahmed**

Institute: **Advanced Technology**

Considerable research interest has been directed towards the use of composite for crashworthiness applications, because they can be designed to provide impact energy absorption capabilities which are superior to those of metals when compared on weight basis. The use of composite circular tubes in structural applications is becoming more widespread throughout the automotives, aircraft industry.

This work examines the effect of segmentation on the crushing behaviour, energy absorption and failure mode of composite circular tubes. The segmented composite tube consists of more than one material, each with its own specific functions. Through out this study, segmented and non segmented composite tubes with different sequences were experimentally investigated under axial and lateral loading conditions. The effect of fibre reinforcement type and segments sequence on energy absorption and load carrying capacity were also presented and discussed.

Load-displacement curves and deformation histories of typical specimens are presented and discussed. The results showed that non-segmented composite tubes were found to be very brittle (i.e. tissue mat glass fibre/epoxy tubes), and show very low initial failure crush load value of 1.89kN, as well as low specific energy absorption value of 0.065kJ/kg under axial crushing. Whereas, the carbon fabric fibre reinforced plastic (CFRP) tubes showed highest load-carrying capacity among the tested specimens with initial failure crush load value of 18.85kN as well as specific energy absorption value of 19.27kJ/kg.

On the other hand, segmented composite tubes including the tissue mat glass fibres were found to suffer from low energy absorption and the catastrophic failure mechanism initiated at the part made of tissue mat glass fibre/epoxy. Segmented Composite tubes from carbon fabric fibre and cotton fabric fibres exhibited good specific energy absorption value of 13.53kJ/kg as well as stable load-carrying capacity under axial loading. A change in segmentation sequence affects the crush loads significantly just for double fibre segmented composite tubes under lateral loading.

The axial loaded segmented composite tubes have better load carrying capacity and energy absorption capability compared to the laterally loaded segmented composite tubes, and the failure modes were quite different.

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

PENYIASATAN SECARA EXPERIMENTASI TERHADAP REMUKAN TIUB KOMPOSIT BERSEGMEN SECARA QUASI-STATIC AXIAL DAN LATERAL

Oleh

ALHADI A. SALEM ABOSBAIA

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Banyak penyelidikan kini berarah kepada penggunaan komposit bagi aplikasi “crashworthiness” disebabkan ia dapat di reka bentuk untuk menyediakan keupayaan tenaga hentaman impak, dimana adalah lebih tinggi daripada logam-logam apabila hendak dibandingkan dengan ciri berat. Kegunaan komposit tiub berongga di dalam aplikasi struktur telah mendapat perhatian meluas hingga ke industri automotif, udara dan aeroangkasa.

Kerja penyelidikan yang dilakukan ini meliputi kesan segmentasi terhadap kelakuan remukan dan mod tenaga penyerapan bagi tiub komposit berongga. Tiub komposit bersegmen mempunyai lebih dari satu bahan, setiap satu mempunyai cirri masing-masing. Kajian yang dibuat, segmen atau tidak bersegmen dengan cirri-ciri yang berlainan telah disiasat dibawah bebanan axial dan lateral. Kesan daripada jenis gentian tetulang dan ciri-ciri segmen terhadap tenaga penyerapan dan kapasiti beban

bawaan juga telah dibincankan. Lengkungan beban-anjakan dan sejarah deformasi bagi spesimen tipikal telah juga dibincangkan. Keputusan ujikaji telah menunjukkan bahawa tiub komposit tidak bersegmen adalah sangat rapuh (sebagai contoh: tikat tisu gentian kaca/tiub epoksi). Atau mempunyai tenaga penyerapan yang rendah (sebagai contoh: fabrik gentian kapas/epoksi).

Komposit tiub bersegmen pula, termasuk tikar tisu gentian kaca telah didapati mengalami kadar penyerapan tenaga yang rendah dan mekanisma kegagalan teruk pada bahagian yang diperbuat daripada gentian/epoksi tersebut. Komposit tiub bersegmen menunjukkna kadar penyerapan yang baik dan juga kapasiti beban bawaan yang stabil dibawah bebanan axial. Perubahan ciri segmentasi tiub komposit akan mempengaruhi beban remukan (DF) dibawah bebanan lateral.

Beban axial tiub komposit bersegmen mempunyai kadar beban bawaan dan keupayan kadar penyerapan tenaga keatas tiub komposit bersegmen yang dikenakan beban lateral tetapi pada sifat kegagalan yang berbeza.

ACKNOWLEDGMENTS

بسم الله الرحمن الرحيم

أن من يستحق الشكر حقا هو الله سبحانه وتعالى علي عظيم فضله وتوفيقه لي في إتمام هذا البحث المتواضع فله الحمد والشكر سبحانه وتعالى. كذلك شكر وتقدير ومحبه عظيمة الى أبي وأمي الأعزاء لدعائهما لي بالتوفيق والنجاح فبدون تعبهما وسهرهما عليّ طوال سنوات العمر الماضية لما وصلت الى هذه الدرجة. ولا يفوتني أن أخص بالشكر الى زوجتي الفاضلة علي ما بذلته من جهد وتعب طوال فترة دراستي.

First, I would like to express my sincere gratitude and deep thanks to my supervisor Dr. Elsadig Mahdi Ahmed for his kind assistance, support, advice, encouragement, and suggestions throughout this work and during the preparation of this thesis.

Furthermore, I would like to take this opportunity to express my deepest appreciation and gratitude to Associate Professor Dr. Abd El-Magid Salem Hamouda for his advice, valuable suggestion, and comments.

Also, I would like to thanks to Professor Dr. Barkawi Bin Sahari for his suggestions and constructive criticisms given at different stages of this study.

Finally, deep thanks to my best friend Ebrahem Alfegi for his support, and help during the fabrication of the experimental work.

Alhadi A. Absobaia

I certify that an Examination Committee met on 23th April 2003 to conduct the final examination of Alhadi A. Salem Abosbaia on his Master of Science thesis entitled "Axial and Lateral Quasi-Static Crushing Behaviour of Segmented and Non-Segmented Composite Tubes" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

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

ALHADI A. ABOSBAIA

Date: 16.06.2003

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NOMENCLATURE

A	Cross-section area
R	Radius of the tube
D	Diameters of the tube
H	Height of the tube
M	Weight of the tube
P_m	Average crush failure load
P_i	Initial crush failure load
P_{1P}	First peak crush failure load
P_{pi}	Highest first peak crush load
s	Instantaneous deformation
CFE	Crush force efficiency
SE	Stroke efficiency
E_s	Crushing energy absorbed per unit mass
MM	Multi failure modes
SM	Single failure modes
CT	Cotton fabric fibre
C	Carbon fabric fibre
GT	Tissue mat glass fibre
FRP	Fibre-reinforced plastic
SF	Single fibre
DF	Double fibre
TF	Triple fibre
IFI	Initial failure indicator
u	Crush distance
E_{11}	Young's modulus in 1 direction
υ_{12}	Poisson's ratio in 1-2 direction
G_{12}	Shear modulus
Q_{ij}	Reduced Stiffness
A_{ij}	Represents the extensional stiffness matrix
B_{ij}	Represents the coupling stiffness matrix
D_{ij}	Represents the bending stiffness matrix

N_x, N_y, Normal forces in x-direction, y-direction resultants

N_{xy}, Shear force resultants

M_x, M_y, Bending moment resultants

M_{xy} Twisting moment resultants

k^0 Curvature strain

σ_1^t Tensile failure stress in the 1 direction

σ_1^c Compressive failure stress in the 1 direction

σ_2^t Tensile failure stress in the 2 direction

σ_2^c Compressive failure stress in the 2 direction

τ_{12}^f Shear failure stress in the 1-2 plane

CHAPTER ONE

INTRODUCTION

Vehicle crashworthiness has been improved in recent years with attention mainly directed towards reducing the impact of the crash on the passengers. Efforts have been made in experimental research to establish safe theoretical design criteria for the mechanics of crumpling, providing the engineers with the ability to design vehicle structures so that the maximum amount of energy will dissipate while the material surrounding the passenger compartment is deformed, thus protecting the people inside.

During the last two decades, the attention given to crashworthiness and crash energy management has been centred on fibrous composite structures. The main advantages of fibre reinforced composite materials over conventional metals; however, are their high specific strength and stiffness, which can be achieved. It is also interesting to note that despite their relatively low strength and stiffness to weight ratio metal tubes are versatile construction components and are also efficient energy absorbing elements. In that manner, aluminium and paper honeycombs are rated as very efficient energy absorbers.

Moreover, with composites, the designer can vary the type of fibre, matrix and fibre orientation to produce composites with improved material properties. Besides the perspective of reduced weight, design flexibility and low fabrication costs of composite materials offer a considerable potential for lightweight energy absorbing structures, these facts attract the attention of the automotive and aircraft industry owing to the increased use of composite materials in various applications, such as frame rails and the sub-floor of an aircraft, replacing the conventional materials used

Previous investigations indicated that composite shells deform in a manner different to similar structural components made of conventional materials, (i e metals/polymers) since micro failure modes, such as matrix cracking, delamination, fibre breakage etc , constitute the main failure modes of these collapsed structures Therefore, this complex fracture mechanism renders difficulties to theoretically model the collapse behaviour of fibre-reinforced composite shells

Extensive research work has focused primarily on axial loading and bending of simple thin-walled composite structures The effect of specimen geometry on the energy absorption capability was investigated by varying the cross-sectional dimensions, wall thickness and length of the shell The effect of the type of composite material, laminate sequence, loading conditions and strain rate on the crashworthy behaviour of the components were also studied Environmental effects related to crash characteristics of composites have also been investigated

However, the behaviour of crushable composite energy absorber devices is often unstable, with energy absorption rising and falling erratically This instability is one of the more critical problems in using fibre composites for crash energy management It is interesting to note that specific energy absorption capability of composite devices is significantly influenced by the failure mechanism, which depends on many factors, such as material constituent, fibre architecture, fabrication process, geometry of elementary substructures and loading conditions.

It could be concluded from that axial crushing of non-trigger tubes (i.e. tube with constant thickness and straight wall) produces an unstable load-end shortening behaviour characterized by energy absorption rising and falling erratically. In previous work, the initial crush failure load was found to have a significant effect on the energy absorption during crush.

To achieve stable crush-deformation behaviour as well as to maximize the energy absorption capability of the composites structures, the sharpness and magnitude of the instability needs to be minimized or eliminated. Extensive experimental work concerning the axial collapse of thin-walled composite material tubes of various geometries and material under various loading conditions demonstrated a high energy absorbing capability of these materials.

The operating loads of laterally compressed tubes are for lower than those of axially compressed tubes and the energy absorbed by laterally loaded tube is about an order of magnitude less than what it can absorb under axial compression, however the energy absorbing capability of laterally compressed tubes can be increased by encouraging the tubes to deform in alternative modes which involve more plastic hinges. The stable crushing stage is generally more important because this is where much of the energy absorption takes place. Compliant material (i.e. cotton fabric

CTFRP) has used to achieve this stability, with low post crash stage. Whereas, when the stiff composite material is used (i.e. carbon fibre CFRP or tissue mat GTFRP), it exhibited high post crash stage with unstable behaviour.

The inspiration of the current work is to study the crashworthiness performance of segmented woven roving laminated composite tubes in terms of energy absorption capability and load carrying capacity subjected to quasi-static axial and lateral crushing load.

1.1 **Segmentation Concept**

Most of the existing data concerns with the failure mechanism and energy absorbing characteristics are obtained from the crushing investigation of composite circular tubes. Therefore, it was preferred to examine the effect of segmentation on their crushing behaviour. Tubes with same diameters were chosen to eliminate the influence of geometry so that the effect of segmentation remains.

1.2 **Objectives**

The main objectives of this work are:

1. To study the effect of loading conditions on crushing behaviour of segmented composite tubes.

2. To study the crushing behaviour for different arrangements of axial segmentation composite tubes.
3. To examine the energy absorption capability of axially segmented composite tubes.

1.3 Significance of the Study

It is interesting to study the effect of the segmentation on composite materials, and also to investigate the energy absorber devices using different materials as composite-composite materials. This study is important because of the following;

1. The present study is focused on introducing a new concept for collapsible energy absorber device.
2. This study may change the design philosophy of applying the hybrid energy absorber system.
3. The generated data from this study can be useful in the design of energy absorber elements made from composite materials.

1.4 Organization of Thesis

The thesis is organised as follows: Chapter one is an introduction of thesis and the objectives. Chapter two reviews of the literature of the fibre reinforced composite materials and studies on their use as energy absorption structure devices. Methodology used in this study has explained in Chapter three. Experimental results