# CRUSHING BEHAVIOR OF WOVEN ROVING GLASS-EPOXY ELLIPTICAL COMPOSITE CONES

**By**

**MOHAMED M. AL-KATEB**

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

**February 2004**

# A special Dedication To

# My family

*Mohamed*

Malaysia, 2004

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master Science

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**Chairman: Associate Professor Abdel Magid Salem Hamouda, Ph.D.**

**Faculty : Engineering**

Structure made from composite materials offers important characteristics such as weight reduction, design flexibility, and safety improvement. These composite materials provide higher or equivalent crash resistance as compared to their metallic counterparts and therefore find use in crashworthiness applications. The design of various transport vehicles such as automobiles and aircraft for crashworthiness requires collapse resistance of structural component and energy absorption characteristics during collision.

This work examines the effects of composite elliptical cone vertex angles on crushing behaviour, energy absorption subjected to quasi-static compressive load, and the capability of natural fibre composite as filler material. The composite elliptical cone walls were fabricated from woven roving glass fibre with orientation of [0/90] and epoxy. Since natural fibre composite materials are increasingly being utilised in automotive parts for their relatively high strength and stiffness to weight and cost ratios, chopped oil palm frond fibres mixed with resin in the form of foam were used

in this study as fillers. The composite elliptical cones with vertex angles varying from 0º to 24º in 6 increments fabricated for axial compression tests with the cone bottom end dimension of $a_b$ = 74mm (inner major radius) and $b_b$ = 53mm (inner minor radius); 165mm high and 5mm thick were fixed for all the specimens. Different cone vertex angles (β) of the elliptical cone resulted in different dimension of cone top end i.e. $a_t$ (inner major radius) and $b_t$ (inner minor radius). The composite elliptical cones fabricated and tested were of six layers.

Thirty specimens were fabricated, fifteen of which were filled with chopped oil palm frond fibres. The load-deformation and the energy-deformation relations as well as the deformation history and failure modes for the composite elliptical cones with various vertex angles tested under quasi-static axial crushing load are presented and discussed. The load-deformation curves presented were obtained from averaging the load-deformation points for three replicated tests with identical elliptical cone and testing conditions. In addition, the effects of cone vertex angles, filling on the load carrying capacity and the energy absorption capability are discussed.

The results showed that the quasi-static axial crushing behaviour of elliptical woven roving laminated composite cones is strongly affected by their structural geometry, the specific energy absorbed by the composite elliptical cones with the vertex angles of 6º, 12º, 18º, and 24º, both the empty and the filled with natural fiber, which is more than that in an elliptical cone with the vertex angle of 0º (the elliptical tube) at any given deformation.

On the other hand, empty core elliptical composite cones were better in specific energy absorption than those filled with natural fibre. The specific energy absorption for elliptical composite cone showed positive correlation i.e., the more the angle increases the more energy is absorbed. In this regard, the empty elliptical composite cone with 24º angle exhibited the best energy absorption capability.

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

**KELAKUAN PELANGGARAN BAGI KON KOMPOSIT ELIPS PELEKAT KACA ANYAMAN BERGERAK**

**Oleh**

**MOHAMED M. Al-KATEB**

**Februari 2004**

**Pengerusi :** **Profesor Madya Abdel Magid Salem Hamouda, Ph.D**

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Struktur yang diperbuat dari bahan komposit memberikan beberapa ciri penting seperti pengurangan berat, keanjalan reka bentuk dan peningkatan keselamatan. Bahan komposit ini menunjukkan daya tahan pelanggaran yang sama atau lebih tinggi jika dibandingkan dengan bahan logam, yang mengarahkan penggunaannya pada keadaan yang memerlukan ciri-ciri ini. Reka bentuk beberapa kenderaan pengangkutan seperti kereta dan kapal terbang untuk daya tahan pelanggaran perlu mempamerkan ciri-ciri seperti ketahanan komponen struktur pada kemusnahan serta mampu menyerap tenaga semasa sesuatu pelanggaran.

Kajian ini dilakukan untuk melihat kesan sudut-sudut verteks kon komposit elips terhadap pelanggaran, penyerapan tenaga yang diperlakukan dengan berat tekanan separa statik dan kemampuan komposit gentian asli sebagai bahan pengisian. Dinding-dinding kon komposit elips dibina dari pada gentian kaca anyaman bergerak dengan berorentasi [0/90] dan pelekat. Oleh kerana pengunaan bahan-bahan komposit

gentian asli meningkat dalam bahagian-bahagian kenderaan untuk kekuatan dan kekerasan yang tinggi terhadap nisbah-nisbah berat dan kos, maka gentian pelepah kelapa sawit yang dhancurkan dan dicampur dengan damar menjadikan bentuk busa digunakan dalam kajian ini sebagai bahan pengisian. Kon-kon komposit elips dengan beberapa sudut-sudut verteks dari 0º hingga 24º dalam 6 tambahan dibina untuk ujian mampatan paksian pada bahagian hujung bawah kon berdimensi $a_b$ = 74mm (jejari major dalaman) dan $b_b$ = 53mm (jejari minor dalaman) serta ketinggian 165mm dan ketebalan 5mm dilakukan pada semua spesimen. Perbezaan sudut-sudut verteks eliptik kon dihasilkan dari perbezaan dimensi bahagaian hujung atas kon iaitu $a_t$ (jejari major dalaman) dan $b_t$ (jejari minor dalaman). Kon-kon eliptik komposit yang dibina dan diuji mengandungi enam lapisan.

Tiga puluh spesimen dibina yang mana lima belas adalah dipenuhi dengan gentian pelepah kelapa sawit yang di hancurkan terpenggal. Hubungan antara beban-uboh bentuk dan tenaga- uboh bentuk serta sejarah uboh bentuk dan ragam kegagalan untuk kon-kon komposit elips dengan beberapa sudut verteks yang diuji pada berat penghancuronpaksian mirip statik dibentangkan dan dibincang. Lengkuk daga-ubahbentuk dibentangkan ini adalah dari purata nilai-nilai daga-ubah bentuk untuk tiga ujian replikasi dengan kon eliptik dan keadaan ujian yang seiras. Sebagai tambahan Kesan sudut verteks kon, pengisian dalam keupayaan tekanan berat dan keupayaan penyerapan tenaga juga dibincangkan.

Keputusan-keputusan menunjukkan bahawa kelakuan perghancuran paksian mirip statik bagi kon- kon komposit elips yang dibina dari gentian kaca anyaman bergerak didapati tinggi oleh geometri struktur, tenaga spesifik yang diserap oleh kon- kon komposit elips dengan sudut-sudut verteks 6º, 12º, 18º, dan 24º, serta kon-kon kosong dan dipenuhi dengan gentian asli yang lebih dari kon eliptik dengan sudut verteks 0º (tiub elips) pada sebarang perubahan bentuk.

Sebaliknya, kon-kon komposit elips kosong adalah lebih baik pada penyerapan tenaga spesifik daripada yang dipenuhi dengan gentian asli. Penyerapan tenaga spesifik untuk kon eliptik komposit menunjukkan sekoitan positif iaitu jika sudut bertambah tenaga yang diserap juga bertambah. Dalam hal yang sama, kon komposit elips dengan sudut 24º mempamerkan keupayaan penyerapan tenaga yang terbaik.

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Mohamed M. Al-kateb

**Approval Sheet No.1**

I certify that an Examination committee met on to conduct the final examination of Mohamed M. Al-Kateb on his Master thesis entitled "An Experimental Study of Woven Roving Glass/Epoxy Elliptical Composite Cones" in accordance with University Pertanian Malaysia (High Degree) Act 1980 and University Pertanian Malaysia (High 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 the 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 institutions.

**MOHAMED M. AL-KATEB**

Date:

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| A | Test area |
| h | Height of the cone |
| t | Thickness of the cone wall |
| $a_t$, $b_t$ | Inner major and inner minor radius of top end, respectively |
| $a_b$, $b_b$ | Inner major and inner minor radius of bottom end, respectively |
| $\beta$ | Cone vertex angle |
| $P_m$ | Average crush failure load |
| $P_i$ | Initial crush failure load |
| $P_{cr}$ | Critical load |
| $P_{HP}$ | Highest Crush failure load |
| $P_{IP}$ | First peak crush failure load |
| $\sigma_m$ | Crush stress |
| $\varepsilon$ | Crush strain |
| $\upsilon$ | Axial Poisson's Ratio |
| $E_{11}$ | Effective axial modulus |
| $E_{22}$ | Effective transverse modulus |
| $E_{33}$ | Transverse young's modulus |
| K | Bulk modulus |
| $\rho$ | Mass density of the structure |
| $W_T$ | Total work done |
| S | Instantaneous deformation |
| CFE | Crush force efficiency |
| SE | Stroke efficiency |
| IFI | Initial failure indicator |

$E$ Total energy absorbed

$E_S$ Specific energy absorbed

$E_{NS}$ Normalised Specific energy absorbed

$E_V$ Volumetric energy absorbed

WRLW Woven roving laminated wrapped

FRP Fiber-reinforcement plastic

ECEC Empty composite elliptical cone

FCEC Filled composite elliptical cone

(CSCNFT) Composite Solid Circular Natural Fiber Tube

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# CHAPTER 1

## INTRODUCTION

Crashworthiness is today one of the important factor in the area of designing the transportation means such as automobiles, rail cars and aero planes. This is because it concerns to vehicle structural integrity and its ability to absorb crash as well as providing a protective shell around the occupants. In the last century extensive and credible studies have proven the high compete ability of composite materials in the filed of collapsible energy absorber devices.  It is also evident that composite materials meet design requirements by the vehicles manufacturers as well as customers demand for safe vehicle with low fuel consumption and high pay load. It is interesting to note that the low cost glass/epoxy composite can absorb up to twice the specific energy of steel [1], while the relatively high cost carbon/PEEK composite can absorb up to 7 times as claimed by Hamada, et al [2].  As a consequence more metals parts will be replaced by composite one for weight saving and increased reliability. However, the challenge is to find a suitable polymeric composite material with specific features for a suitable structural application.

The high efficiency of an impact energy absorber device may be defined as its ability to decelerate smoothly the occupant compartment to the rest within the allowable limit of 20g [3]. However, optimum energy absorbed management from practical collapsible energy absorber device is characterised by having a very small elastic energy and the area under its load-displacement curve is representing by rectangular form with long sides (i.e. a constant force). It is evident for all practical collapsible energy absorber devices that initially their resistance response records very high load till reach its full capacity after which definitely different degrees of unstable response takes place [4]. Due to the black and white design of energy absorber device, one can define the desirable energy absorber device as the one with suppressed energy absorption during the elastic or pre-initial crush failure stage not to exceed the safe allowable limits. Moreover, its post crush stage should have a very stable response during the post crush stage. In such design and for gross deformation, the overall stability of the energy absorber device is important as well as its energy absorbing capability and load carrying capacity.

It is well known that any type of failure mode leads to Euler-buckling resulted in global instability which is an inefficient energy absorbing mechanism should be avoided in designing the collapsible energy absorbing system. This is because Euler-buckling failure mode is unstable and associated with load-deformation behaviour rising and falling erratically [5]. This instability is one of the more critical problems in using fibre composites for crash energy device and can be caused by many factors. Mahdi, et al [6] stated that the initial crush failure load was found to have a significant effect on the behaviour of specific energy absorption-deformation relationship during the entire post-crush crush process of composite shell with empty core and squared ends (i.e. un triggered). They found that the energy absorption capability is reverse proportional to the high magnitude of initial crush failure load.