QUASI-STATIC AXIAL CRUSHING BEHAVIOUR OF COMPOSITE HEMI-SPHERICAL SHELLS

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By

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Experimental investigations were carried out to investigate the energy absorption capability and load-carrying capacity of hemi-spherical composite shells subjected to quasi-static axial compressive load. The hemi-spherical shell specimens were fabricated by hand lay-up fabrication process in which the fibre was mixed with the matrix. Two types of resins were explored (polyester and epoxy) two types of fibre were also studied (woven glass fibre and woven carbon fibre). Four different R/t ratios of hemi-spherical composite shells were investigated as well as four different shells cross section area (A) were studied. A description of typical crushing modes and mechanisms of energy absorption for hemi-spherical composite shells is presented. Results showed that epoxy resin has higher value of load- caring capacity and energy-absorption capability than polyester resin. The results also show that the carbon fibre has higher value of load-carrying capacity and energy-absorption capability than glass fibre. The results of R/t ratio and area

(A) of shells also show that the specific energy absorption capability of hemispherical shells increases with reducing both of the geometry values.

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

KELAKUAN PENGHAN CURAN PAKSIAN MIRIPSTATKIK BAGI KELOMPANG KOMPOSIT HEMISFERA

Oleh

MHFUD A. M. SALEH

March 2004

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

Fakulti: **Kejuruteraan**

Pkaian eksperimentasi yang telah dijalankan untuk mengkaji keupayaon tenaga penyerapan dan keupayoon membawa ebon komposit hemisfera dipawah beban quasi static paksian. Specimenkelompang" ini dibikin dengan menggunakan proses "be ngkalai tangant" di mana gentian telah dicampurkan dengan matriks. Dua jenis resin telah digunakan (polyester dan epoksi) dan gentian jenis jalinan juga telah dikaji (gentian kaca dan karbon teranyam). Empat nisbah R/t bagi "kelompang" komposit hemi-spherical telah disiasat dan empat luias keratan rentas "kelompang" juga telah dikaji. Satu penerangan mengenai ragam penghancuran tipikaldan mekanisma tenaga penyerapan bagi kelompang komposit hemisfera kelompang telah dilaporkan. Kelakuan "kelompan" hemisfera tersebut telah diuji dan dilaporkan mengenai keupagan membawa bebanbeban bawaan dan juga kapabiliti tenaga penyerapan yang mendadak. Keputusan menunjukkan bahawa damar epoksi mempunyia nilai keopayan membawa beban dan tenaga penyerapan yang tinggi berbanding dengan poliester, tetapi keputusan juga menunjukkan gentian karbon mempunyai nilai keupayoon membawa beban dan keupayantenya

penyerapan yang tinggi berbanding gentian kaca. Keputusan nisbah R/t dan luas (A) “kelompang” juga menunjukkan bahawa keupayoon penyeraapan tenaga spesifik bagi “ kelompang ” hemisfera meningkat dengan penguangan kedua-dua nilai geometri kelompang tersebut.

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Mhfud A. M. Saleh

I certify that an Examination Committee met on 5th March 2004 to conduct the final examination of Mhfud Ahmed Saleh on his master of science thesis entitled "Quasi-Static Axial Crushing Behaviour of Composite Hemi-Spherical Shells" 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 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.

MHFUD A. M. SALEH

Date:

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NOMENCLATURE

t	Average thickness of the shell
Z	Depth of the shells
D	Inner minor radius
L	Span of the spherical shell
R	Mean radius of the spherical shell
A	Cross-section area of the spherical shell
ρ	Density of the composite material
E_{11}	Longitudinal modulus
E_{22}	Transverse modulus
G_{11}	In plane shear modulus
σ_{11}	Longitudinal stress
ε_{11}	Failure strains
ν_{12}	Poisson's ratio
P_i	Initial crush failure load
P_m	Mean crush failure load
P_h	Highest load
E_s	Specific energy absorbed
E_{NS}	Normalised Energy Absorption
CFE	Crush force efficiency
SE	Stroke efficiency
IFI	Initial failure indicator

$\left[D\right]$	Laminate bending stiffness
$\left[\bar{Q}\right]^{k}$	Kth-layer reduced stiffness matrix

CHAPTER- I

INTRODUCTION

The increasing deployment of composite structures in engineering applications, many of which are being designed as the primary load-carrying parts in hostile environments, has given greater attention to the long-term behaviour of composite components. Accordingly, there is an urgent need in the engineering community for a predictive tool of the durability, reliability, energy absorber, and safety of composite systems. In the design of modern structures, the damage tolerance of a structure needs to be quantified.

Composite structures are well suited for design with emphasis on damage tolerance due to the ability of continuous fibre composites to arrest cracks and prevent self-similar crack propagation. However, a number of design parameters such as fibre orientation patterns, choices of constituent material combinations, ply drops and hybridization, and render a multiplicity of design options for composite structures. Only by a priori quantification of progressive damage in a composite structure and its fracture characteristics, it is feasible to achieve a damage tolerant design. Compared with homogeneous materials, damage initiation and progression characteristics of fibre composites are much more complicated.

Energy absorber device is used to absorb impact energy in the event of a crash to reduce the net deceleration of the vehicle which might cause serious damage to the occupants. Materials such as carbon fibre/epoxy are inherently brittle and usually exhibit a linear elastic response up to failure with little or no plasticity. Thus composite structures are vulnerable to impact damage and have to satisfy certification procedures for high velocity impact from the sudden accidents. Conventional metallic structures absorb impact and crash energy through plastic deformation and folding. Modern explicit FE codes are able to model these effects and are being successfully applied to simulate the collapse of metallic aircraft and automotive structures.

High-energy absorbency per unit mass is possible with composite materials if proper failure mechanisms are initiated and maintained during the crash event. Whereas metals absorb energy primarily through plastic deformation, composite materials absorb energy through a variety of failure mechanisms. For example, Kevlar reinforced composites absorb energy through a buckling failure mechanism similar to the accordion buckling modes of metal structures. Carbon fibre and glass fibre-reinforced composites absorb energy through successive failures involving delamination, intraply cracking, and fibre fracture. Because energy absorbency of a composite structure is directly dependent on the failure mode that occurs and the failure mode is a function of the laminate stacking sequence, the loading history and environment, proper characterization ought to include off-axis crush tests.

As well known an initial geometry used by researchers to study the energy absorption capabilities of composite materials was the tube. This geometry is self-stabilizing and allows testing of relatively thin-section laminates. However, the lack of edges along its length reduces the complexity of the boundary conditions and provides consistency throughout the cross section.

In passenger vehicles, the ability to absorb impact energy and be survivable for the occupant is called the “crashworthiness” of the structure. This absorption of energy is through controlled failure mechanisms and modes that enable the maintenance of a gradual decay in the load profile. The crashworthiness of a material is expressed in terms of its specific energy absorption that is characteristic to that particular material. It is defined as the energy absorbed per unit mass of material. In the crashworthiness of automotive structures, the primary issues to the automotive industry are the overall mechanisms, e.g., fibre fracture, matrix crazing and cracking, fibre-matrix debonding, delamination, and inter-ply separation, and sequence of damage are highly dependent on lamina orientation, crush speed, triggers and geometry of the structure. Much of the experimental work to study the effects of fibre type, matrix type, and fibre architecture and specimen geometry on the energy absorption of composite materials has been carried out on axisymmetric tubes. Tube structures are relatively easy to fabricate and close to the geometry of the actual crashworthy structures. These tubes were designed to absorb impact energy in a controlled manner by providing a trigger to initiate progressive crushing. A trigger is a stress concentrator that causes failure to initiate at a specific location within a structure and propagate through the body in a controlled predictable manner. The most widely used method of triggering is chamfering one end of the tube. The brittle fibre reinforced composite tubes crushed in the fragmentation and splaying modes while progressive folding was exhibited by ductile fibre reinforced composite tubes. Both material and structural damage processes need to be well understood to accurately model and design crashworthy automotive composite structures. In the progressive crushing of composite tubes, many different failure mechanisms contribute to the overall energy absorption of the structure. To isolate the damage mechanisms and quantify the energy absorption contributed by the splaying mode.

Problem Statement

To ensure passengers safety or at least to alleviate severe impact during collision, a highly reliable system is required. In such design and for gross deformation, the overall stability of the energy absorber device is important. However, the tubular composite energy absorber devices crush behaviour is often unstable, with energy absorption rising and falling erratically. The instabilities are one of the more critical problems in using composites tubular devices for crash energy management. To overcome this instability behaviour was the main reason behind this study. Therefore, the primary aim of this study is to explore the ability of composite hemispherical shells as collapsible energy absorber devices.

1.2 Objectives

The overall aim of the present project is to introduce the hemispherical shells to the field of collapsible energy absorber devices. The main specific objectives are as following:

1. To investigate the materials type (matrix& fibre reinforced) effect on the energy absorber capability, failure modes and load carrying capacity of hemi spherical composite shells
2. To examine the effect of the hemi spherical shells aspect ratio (R/t) on the energy absorber capability and failure modes.

3. To examine the relationship between the cross-section area and the energy absorber capability and failure modes of hemi spherical composite shells.

1.3 Importance of the Study

Composite hemispherical shells can be used in many applications such as energy absorber devices in aeroplanes, spacecraft and automotive vehicles, packaging and cushion goods, closure of compressed natural gas and submarines. This study could be useful in a manner to introduce the spherical geometry to the field of energy absorber devices.

1.4 Thesis Layout

Following this introduction chapter, Chapter 2 presents the literature reviews of the energy absorber capability of composite materials, energy shapes and the parameters that affects the energy absorption capability of composite structures. The overall methodology of the current study is presented in Chapter 3. The details of experimental work as well as fabrication and testing procedure are given in Chapter 4. Chapter 5 presents the result and discussion. Finally, in Chapter 6 includes the conclusion drawn from this study as well as the future recommendations are giving.

CHAPTER- II

LITERATURE REVIEW

In this chapter, literatures related to energy absorbers of composite structure, concentrating on hemi-spherical composite shells are reviewed. Factors that affect the energy absorption capability of composite structures are also discussed. In addition, the test methods, crushing modes and mechanisms of composite structure are explained.

2.1 Energy Absorbers

During the last part of the last century, a number of impact engineering problems were studied, especially in the field of the dynamic response of structures in the plastic range. This contributed towards a better understanding of the modes of failure and the energy dissipation patterns during impact in such structures. Such information is important in order to be able to design safer structures and also in evaluating existing ones for specific uses, therefore reducing losses in human and material resources. Application of this field of engineering is now available for use in a wide variety of situations, which include such aspects as crashworthiness of vehicles (cars, lifts, aircraft, ships, etc) [1,2], crash barrier design [3], safety of nuclear reactors [4], collision damage to road bridges [5] and offshore structures and oil tankers [6].

2.2 Energy absorbers Systems

An energy absorber is a system that converts, totally or partially, kinetic energy into another form of energy. Energy converted is either reversible, like pressure