UNIVERSITI PUTRA MALAYSIA

CRUSHING BEHAVIOUR OF WOVEN ROVING LAMINATED CONICAL SHELLS USING SLIPPING SOLID CONES

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By

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This project examines experimentally the energy management during the slipping of solid steel cone into composite conical shell. Quasi-static crushing test was carried out with different low speed rate. The cone vertex angles used were 8, 16, 24, 32 and 40 degrees. The cone height and bottom diameter were kept constant for all cases as 100 mm and 76.2 mm, respectively. Force-stroke curves and deformation histories of typical specimens are presented and discussed.

Experimental results show that the cone vertex angle and loading condition affects the load carrying capacity and the energy absorption capability of the conical shell. The axially loaded conical shells between two platens have better load carrying capacity and energy absorption capability compared to the conical shells subjected to slipping. The tearing failure mode is longitudinal fibres and occurs near the contact area between the solid steel cone and the conical shell wall (out-of-plane tearing mode). Furthermore, the

structure subjected to plated test crushed at the small end in splaying failure-crushing mode.

Based on experimental results obtained from this investigation, it could be concluded that at first-crush stage the energy is dissipated in the form of friction and the conical shell responded to slipping force in an elastic manner, while the post crush stage is dominated by the tensile tearing failure followed by longitudinal and transverse shear cracking failure.

The developed FORTRAN computer program approximately predicts the initial failure load. The discrepancy between the analytical solution prediction and the experimental results is due to the assumption made in FORTRAN computer program.

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

KELAKUAN PENGHANCURAN BAGI KELOMPANG KON BERLAPIS ROVING TENUN MENGGUNAKAN KEGELINCIRAN KON-KON PADU

Oleh

BASHIR S. ELMABROUK

Ogos 2003

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

Fakulti: **Kejuruteraan**

Projek ini secara eksperiman berkaitan penggunaan tenaga semasa gelinciran besi pejal kepada bentur komposit konical kiub. Ujian renghancanran Quasi-static dilakukan pada kadar kelajuan reudah yang berbeza. Sudut vertex kon yung digunakan adalah 8,16,24,32 dan 40 darajah. Keliuggian kon dan diameter bawah kon adalah konstan pada semua kas pada 100mm dan 76.2mm. Lengkung stroke-daya dan kecacatan spesimen di bincangkan.

Keputusan eksperimen menunjukkan sudut kon vertex dan beban mempengaruhi kapasiti bebanan dan kebolehan penyerapan tenaga kiub konikal. Kiub konical yang di letakkan beban secara tegak diantara dua gandar mesin mempunyei kapasiti bebanan dan penyerapan tenaga yang lebih baik berbanding kiub konical yang gelincir. Mad kegagatan koyakan adalah fiber yang membujar dan berlaku berdekatan kawsan sentuh diantaru kon besi pejar dan dindiue kiub konical (mod koyakan luar satah). Tambahan lagi, struktur

pada platugian hancur pada hujung yang kecil pada mod kegagalan-peghaueuran melebar.

Berdasarkan pada keputusan eksperimen yang di dapati, boleh di rumuskan pada peringkat penghancuran pertama tenaga hilanc dalam betuk geseran dan konical kiub bertindak balas tarhadap daya gelinciran secara elastik, manakalaperingkat pengnangcuran di dominasi oleh kegagalan koyakan tensil diikuti oleh kegagalan retakan ricihan melitang dan menegak.

Program komputer FORTRAN meramalkan tegaglan beban yang awal. Perpezaan diantararamalah penyelesaian analitikal dan keputusan eksperimen adalah disebabkan oleh andaian yang dibuat didalam program komputer FORTRAN.

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BASHIR S. ELMABROUK

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NOMENCLATURE

E_s	Crushing energy absorbed per unit mass
E_v	Crushing energy absorbed per unit volume
P_m	Average crushing force
Pi	Initial crushing force
P_{P1}	Stands for the first peak force
P_{PH}	Stands for the highest peak force
IFI	Abbreviated the initial failure indicator
L	Maximum stroke
S	Slipping crush test
P	Plated test between two platens
A	Cross-section area
M	Weight of the structure
H	Height of the structure
β	Cone Vertex angle
CFE	Crush force efficiency
SE	Stroke efficiency
D, d	Maximum and minimum diameters of the cone, respectively
WRL	Woven Roving Laminated
Vi,	Crushing speeds (i=1-4)

CHAPTER 1

INTRODUCTION

One of interesting aspects of composite material is the freedom to select the precise from the material to suit the application. Moreover, composite materials offer the stiffness of conventional metal at a lower weight. However, with the increasing demand of advanced composite material in wide range of engineering application, it requires test data, which the designers could rely upon in the designing process. Crashworthiness ensures vehicle structural integrity and its ability to absorb crash energy with minimal attention of survivable space. Accordingly one of these applications in the energy absorbing devices, which optimise the crashworthiness design factors of vehicles, the occupant safety should be the crucial design factor in favour of other factors, although it is well known that crashworthiness design factors are often in conflict. Moreover the material used for these applications should have the required rigidity, strength, and survivability. Furthermore There is need understood that the amount of energy that a vehicle absorbs during collision is a matter of concern to ensure passengers and pedestrians safety.

Motor vehicle accidents are inevitable due to human and environmental factors. Automobiles manufacturers, by employing proper safety design and manufacturing techniques, can prevent the death and serious injuries that result from motor vehicle accidents. Accordingly, one of these techniques is the energy absorber device, which design to prevent vehicle's occupants from the effects of sudden impact [1].

However, maximum energy is believed that to be absorbed by progressive crush that involves extensive deformation and fibre micro fracture in a small zone that moves progressively through the structure. Most of the studies to examine the energy absorption capabilities of composite material have been directed towards the axial or lateral crushing analysis.

The importance of improved safety and crashworthiness in automotive vehicles is evident through increased design requirements. The reason behind using thin walled shells is that they could withstand their axial loading in a membrane manner rather than through bending [2]. Increased demand of laminated composite shell has created real need for further investigation on the crushing behaviour of composite shell. Composite conical shells are common structural components that can be used for wide variety of applications. Some of these applications include closures in tanks and pressure vessels, hoppers in cylindrical structures, together with cylinders and spheres; they may be regarded as elementary shells geometries and submarine and submersible pressure hulls.

Several studies have shown that composite structure like tubes, cones and domes have considerable energy absorption potential that is comparable to and in some cases better than metal structures [3]. In addition to the reduction in weight, composites have the advantage of good manufacturing quality, styling enhancements and improved corrosion and dent resistance. However, studies involving their analysis are rather limited. This is primarily due to large number of variables involved. Axial crushing of metallic tubes has long been the subject of extensive research. In the time being many authors have considered the axial compression of the composite tubes [3-5]. The present project has been performed with the objective of the developing an understanding of mechanisms responsible for energy absorption in slipping solid steel cone into woven roving glass/epoxy conical shells and axial crashing between two flat platens.

In this project, experimental investigation into the crushing behaviour of the woven roving laminated conical shells has been conducted. The axial crushing between two platens and slipping solid cone into the woven roving laminated conical shells were performed.

The developed FORTRAN computer program approximately predicts the initial failure load for woven roving laminated conical shells subjected to quasi-static axial crushing load between two platens.

1.1 Objectives of Project

The main objectives of present study can be summarised as following:

1. To study the performance of the woven roving glass/epoxy circular conical composite shells specimens with different vertex angle.

2. To investigate the effects of crushing speed changing on crashworthiness performance of woven roving glass/epoxy composite circular conical shells.
3. To examine the effect of loading condition slipping and plated tests on the crushing behaviour of the conical shells.

1.2 Thesis Layout

This thesis is divided into six chapters. The next chapter, Chapter 2 presents a review of literature that related to the composite materials, reinforcement, composite forms, mechanism of composites, crushing process, effect of crushing speed and energy absorption characteristics of composite structures will be discussed. Chapter 3 explains with systematic description of the methodology to carryout the work. The results from experiments are discussed in details and analysed in Chapter 4. In Chapter 5 analytical solution by FORTRAN program will be presented and discussed. General conclusions and discussion are presented in Chapter 6.

1.3 Significance of the study

This study is important because of the following:

- The generated data from this study can be useful in the design of energy absorber elements made from composite materials.

- Conical shells made of metal are frequently used as energy absorber elements; the use of composite conical shells instead of metal conical shells can result in much technical and economical advantage.
- The efficient use of composite conical shells as energy absorber depends on the understanding of their crushing behaviour.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the review of literature on composite material and crushing process is done. Attention is directed toward, the mechanics of composite material, crushing modes, and the energy absorption in composite materials. In addition the effect of geometry and crushing speed, which influence the crushing behaviour of composite conical shells are also discussed

2.1 Introduction

Robert M. Jones 1975 defined that the word "composite" in composite material signifies that two or more materials are combined on a macroscopic scale to form a useful material. Different materials can be combined on a microscopic scale, such as in alloying, but the resulting material is macroscopically homogeneous. The advantage of composites is that they usually exhibit the best qualities of their constituents and often some qualities that neither constituent possesses [6]. Composite is a material that is composed of two or more distinct materials as shown in Figure 2.1 thus a composite is heterogeneous. To a certain extent this definition depends upon the level of analysis, as all materials are considered heterogeneous if the scale of interest is sufficiently small. Fibrous composite are material in which one stage acts as a reinforcement of a second stage. The second material is called matrix [7].

The most general definition of a composite material is very closely related to dictionary definition of the word composite, meaning made up of different parts or materials. Composite material are constructed of two or more materials, commonly referred to as constituents, and have characteristics derived from the individual constituents. Depending on the manner in which the constituents are put together, the resulting composite materials may have the combined characteristics of the constituents [8].

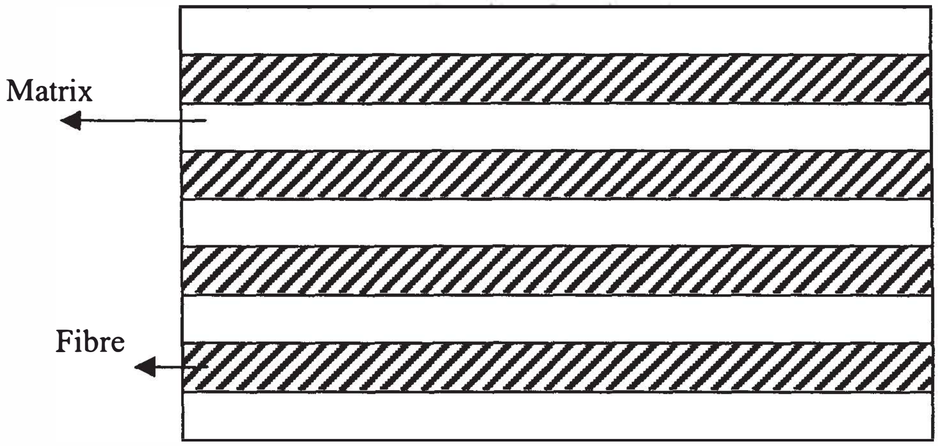

Figure 2.1 Composite materials

Modern composite material typically utilizes a reinforcement phase and a binder phase, in many cases with more rigid and higher-strength fibres in more compliant matrix, although this is not universally the case. Modern applications started with glass fibre, followed by more recent high-performance fibres such as carbon, aramid, boron, silicon carbide and others.

2.2 Fibrous Composites

It is well recorded that are becoming the material for the future. This is because they have very high specific stiffness compared with conventional and bulk composites. This is because of preferential orientation of molecules along the fibre direction and because of the reduced number of defects present in a fibre as apposed to the bulk material [9]. Serope et al summarized the common synthetic polymeric fibres used in engineering application are generally glass, carbon, aramid, or boron.

There are several principal types of glass fibres.

1. E-glass is a borosilicate glass developed for better resistance to water and mild chemical concentrations.
2. S-glass type, is most common for structural application, offering higher strength and stiffness but at great cost;
3. E-CR type, a more recently developed, high-performance glass fibre, offering higher resistance to elevated temperatures and acid corrosion than does the E glass [11].

It is also interesting to mention that the E-glass fibre, which has been used as reinforcement material to fabricate the specimens in this project, will be highlighted in the following section.

2.2.1 E- Glass Fibre

Glass fibres are the most common of all reinforcing fibres for polymeric (plastic) matrix composite (PMC). The principal advantages of glass fibres are low cost, high tensile, strength, high chemical resistance and excellent insulating properties. The disadvantages are relatively high specific gravity (among the commercial fibre), sensitivity to abrasion with handling (which frequently decreases its tensile strength), relatively low fatigue resistance and high hardness (which causes excessive wear on moulding dies and cutting tools) [11].

Serope et al also indicated that glass fibres are the most widely used and the least expensive of all fibres. The composite materials are called glass-fibre reinforced plastic (GFRP) and many contain between 30% and 60% glass fibres by volume. Glass fibres are made by drawing molten glass through small openings in a platinum die [11].

2.2.2 Matrices

The matrix resin generally accounts for 30 to 40 percent, by volume, of a composite material. Polymers used as matrix materials are commonly referred to as resin. In addition to maintaining the shape of the structure of composite, aligning the reinforcements, and acting as a stress transfer medium, the matrix protects the fibre from abrasion and corrosion [12]. The two basic classes of resins are thermosets and thermoplastics. The two resins systems have different thermal