EXPERIMENTAL INVESTIGATION AND FINITE ELEMENT ANALYSIS OF COMPOSITE CONICAL STRUCTURES SUBJECTED TO SLIP LOADING

By

HAKIM S. SULTAN ALJIBORI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfilment of the Requirement for the Degree of Doctor of Philosophy

November 2006

DEDICATION

To my affectionate parents, my brothers, my wife and my children: ***Ameer and Alzahraa***

For their love and support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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One of the main objectives of aircraft and automotive manufacturers is related to improvement of the crash behaviour of lightweight structures. The absorbed energy is an important parameter for the development of the vehicle passive security concept. An energy absorption device is a system that converts totally or partially kinetic energy into another form of energy during collision, which is required of an ideal energy absorbing material, is to have the capability of dissipating as much energy as possible per unit weight/ volume. The increasing demand of composite structures in wide range of engineering applications, structures made from composite materials offers important characteristics such as weight reduction, design flexibility and safety improvement. These composite structures provide higher or equivalent crash resistance as compared to their metallic counterparts and therefore find for its using in crashworthiness applications. Polymer composite materials have been introduced in the

automotive industry primarily to reduce the overall weight of the vehicle, which results in energy economy and for better fuel cost. However, the current trend in producing lighter structures puts greater demands on the design of more efficient energy dissipating systems.

The present study is essentially motivated by the increasing use of composite conical structures in crashworthiness applications. This study focuses on experimental and finite element investigation of glass fibre/epoxy and carbon fibre/epoxy composite conical shell were carried-out during the slipping of solid cone or composite cone into composite conical shell under radial and axial loading.

This study has been divided into two main parts: Quasi-static methods and explicit integration methods (dynamic). These parts have been divided also into two sections concerning the problem solution. The first section is the finite element solution, which deals with composite conical shell in order to quantify the study and the second section is an experimental work. These methods used to improve the specific energy absorbed by crushed composite collapsible conical energy absorber devices were undertaken. LUSAS finite element analysis software was used for quasi-static method and ANSYS/LS-DYNA finite element software for dynamic explicit integration method were used to develop the models. Shell elements have been selected for the composite cones with the same wall thickness. Glass and carbon fibres have been used for the fabrication process of the specimens. The cone semi angles used were 4, 8, 12, 16 and 20 degrees.

The cone dimensions were constant for all models as 100 mm height and 76.2 mm of bottom diameter.

Load-displacement curve and deformation histories obtained from quasi-static work include the experimental and finite element results. These results obtained to calculate specific energy absorption and volumetric energy absorption. As well as others parameters, such as crush force efficiency, initial failure indicator, strain efficiency and failure modes. The results show that the cone angle, loading condition, fibre orientation and stacking sequence angle affects the load carrying capacity and energy absorption capacity of conical shell.

On the other hand, the results obtained from finite element analysis for slipping crushed woven roving glass/epoxy composite conical shell by using the explicit integration methods was presented and discussed. The effects of geometrical on energy absorption characteristics and failure modes are investigated as well as the behaviour of structure subjected to dynamic loading. The kinetic energy and energy absorption capability was calculated and failure modes for non-linear dynamic analysis of structures in three dimension was identified. The load-time history curve and deformation history obtained from dynamic work also presented and discussed. The results show that the cone angle, fibre type and loading condition affect the load carrying capacity and energy absorption capacity of composite conical shell.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

UJIKAJI DAN ANALISIS UNSUR TERHINGGA STRUKTUR KONIKAL KOMPOSIT DI BAWAH BEBAN GELINCIRAN

Oleh

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Salah satu daripada objektif pengusaha industri kapal terbang dan otomotif adalah berkaitan dengan pembaikan kelakuan perlanggaren terhadap struktur ringan. Tenaga yang diserap ialah satu parameter penting bagi pembangunan konsep keselamatan pasif kenderaan. Peralatan penyerap tenaga ialah suatu sistem yang menukar tenaga kinetik secara penuh atau sebahagiannya kepada bentuk tenaga yang lain semasa perlanggaran, di mana bagi suatu bahan penyerap tenaga unggul, adalah untuk membebaskan sebanyak tenaga yang boleh bagi setiap berat/isipadunya. Peningkatan permintaan struktur komposit dalam aplikasi kejuruteran yang luas, struktur-struktur yang diperbuat daripada bahan komposit menawarkan ciri-ciri penting seperti pengurangan berat, keanjalan rekabentuk dan pembaikan keselamatan. Struktur-struktur komposit tersebut memberikan rintangan pelanggaran yang lebih tinggi atau yang sama berbanding dengan struktur setara yang diperbuat daripada bahan logam dan oleh itu bahan-bahan

komposit terdapat dalam aplikasi kebolehlanggaran. Bahan-bahan komposit berpolimer telah pun diperkenalkan di dalam industri otomotif terutamanya untuk mengurangkan berat keseluruhan kenderaan, di mana memberikan ekonomi tenaga dan kos petrol yang lebih rendah. Walauagaimanapun, haluan masa kini dalam penghasilan struktur yang lebih ringan lebih memberi penekanan ke atas rekabentuk sistem pembebasan tenaga yang lebih cekap.
Kajian ini pada dasarnya adalah dimotivasikan oleh penggunaan struktur konikal komposit dalam applicasi kebolehlanggaran yang semakin meningkat. Kajian ini menumpukan kepada penyiasatan secara ujikaji dan unsur terhingga ke atas cengkerang komposit konikal di bawah gelinciran kon pejal atau kon komposit ke dalam cengkeram konikal komposit di bawah bebanan jejarian dan paksian.

Kajian ini telah dibahagikan kepada dua bahagian utama: kaedah quasi-statik dan keadah kamiran nyata (dinamik). Bahagian-bahagian ini juga dibahagikan lagi kepada dua seksyen yang berkenaan dengan penyelesaian masalah. Seksyen pertama ialah penyelesaian unsur terhingga, yang menangani cengkerang konikal komposit untuk mengesahkan kuantiti dan seksyen kedua ialah kerja-kerja ujikaji. Perisian analisis unsur terhingga LUSAS telah digunakan bagi kaedah quasi-statik dan ANSYSIS/LS-DYNA untuk kaedah kamiran nyata dinamik telah digunakan untuk membangunkan model-model. Unsur cengkerang telah dipilih bagi kon-kon komposit dengan tebal dinding yang sama. Serabut kaca dan karbon telah digunakan bagi proses penghasilan spesimen-spesimen. Sudut separuh kon yang digunakan adalah 4, 8, 12, 16 dan 20 darjah. Dimensi-dimensi kon adalah malar bagi semua model iaitu ketinggian 100 mm dan diameter tapak 76.2 mm.

Lengkungan beban-sesaran and sejarah deformasi yang diperolehi daripada kerja quasi-statik merangkumi keputusan ujikaji dan analisis unsur terhingga. Keputusan yang diperolehi ini digunakam untuk menghitung penyerapan tenaga spesifik dan penyerapan tenaga volumetrik serta juga parameter-parameter yang lain, seperti kecekapan daya remukan, petunjuk kegagalan awal, kecekapan terikan dan mod-mod kegagalan. Keputusan menunjukkan bahawa sudut kon, keadaan pembebanan, orientasi serabut dan sudut turutan timbunan mempengaruhi kapasiti pembawaan beban dan kapasiti penyerapan tenaga cengkerang konikal.

Keputusan yang diperolehi daripada analisis unsur terhingga bagi gelinciran dentuman anyaman cengkerang konikal komposit kaca/epoksi dengan menggunakan kaedah kamiran nyata telah dibentangkan dan dibincangkan. Kesan secara geometry ke atas ciri-ciri penyerapan tenaga dan mod-mod kegagalan serta juga kelakuan struktur di bawah beban dinamik telah disiasat. Tenaga kinetik dan kapasiti penyerapan tenaga telah dihitungkan dan mod-mod kegagalan bagi analisis dinamik tidak linear bagi struktur dalam tiga dimensi telah dikenalpasti. Lengkungan sejarah beban-masa dan sejarah kecacatan bentuk yang diperolehi daripada kerja dinamik juga dibentang dan dibincangkan. Keputusan menunjukkan bahawa sudat kon, jenis serabut dan keadaan pembebanan mempengaruhi kapasiti pembawaan beban dan kapasiti penyerapan tenaga cengkerang konikal komposit.

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I certify that an Examination Committee has met on 30 November 2006 to conduct the final examination of Hakim S. Sultan Aljibori on his Doctor of Philosophy thesis entitled "Finite Element and Experimental Analysis of Composite Conical Structures Subjected to Slipping Loading" 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 herby declare that the thesis is based on my original work except for quotation 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.

HAKIM S. SULTAN ALJIBORI

Date: 15 DECEMBER 2006

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LIST OF ABBREVIATIONS

FRP	Fibre Reinforced Plastic
H	Total Height of Cone (mm)
Pi	Initial Crush Failure Load (kN)
P_m	Mean Crush Failure Load (kN)
P_{pH}	High peak Crush Failure Loads (kN)
IFI	Initial Failure Indicator
CFE	Crush Force Efficiency
SE	Stoke Efficiency
u	Crushed Distance (mm)
t	Thickness of the Cone Wall (mm)
S	Instantaneous Displacement (mm)
D	Big Diameter of Cone (mm)
d	Small Diameter of Cone (mm)
M	Mass of the Cone (kg)
A	Cross-Sectional Area (m^2)
W_T	The Total Work Done (kJ)
W_p	Work Done at Post Crush Stage
KE	Kinetic Energy
E	Total Energy Absorption (J)
E_s	Specific Energy Absorption (kJ/kg)
E_v	Energy Absorption per Unit Volume (kJ/m^3)

V_{con}	The Volume Occupied Conical Shells Before Crushing
V_m	Volume of Material (m^3)
ρ	Mass Density of Structure (kg/m^3)
V_s	Volume of Structure (m^3)
WRL	Woven Roving Laminate
FWL	Filament Wound Laminate
FEA	Finite Element Analysis
E_x	Young's Modulus in x-direction
E_y	Young's Modulus in y-direction
E_z	Young's Modulus in z-direction
G_{xy}	Shear modulus in xy-direction
G_{yz}	Shear modulus in xy-direction
G_{xz}	Shear modulus in xy-direction
ν_{12}	Poison's Ratio
θ	Fibre Orientation Angle (Degree)
β	Semi-Vertex angle of Cone (Degree
κ	Stiffness Matrix
Δt	Time Step Size (s)
ASTS	Automatic Surface-to-Surface Contact
E_f.	The Energy Lost in Frictional Sliding (J)
V_i	Initial Velocity (m/s)

v_r	residual velocity (m/s)
ΔE_k	Energy Transfer Between The Solid Steel Cone and The Composite Shell (J)