UNIVERSITI PUTRA MALAYSIA

# EXPERIMENTAL AND COMPUTATIONAL CRUSHING BEHAVIOUR OF LAMINATED COMPOSITE SHELLS

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# EXPERIMENTAL AND COMPUTATIONAL CRUSHING BEHAVIOUR OF LAMINATED COMPOSITE SHELLS

By

**ELSADIG MAHDI AHMED SAAD**

**Thesis Submitted in Fulfilment of the Requirement for the Degree of Doctor of Philosophy in the Faculty of Engineering**
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**December 2000**

**To My Exemplary Parents, Sisters and Brothers**

To My Wonderful Brother's and Sister's Sons and Daughters, Especially Shahinaz and Selma, to Whom I am Very Proud.

UPM

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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**December 2000**

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This thesis presents the effect of structural geometry, reinforcement type and hybridisation on the crushing behaviour, energy absorption, failure mechanism and failure mode of cylindrical, conical and compound composite shell. The static crushing behaviour of cylindrical, conical and compound composite shell under uniform axial load has been investigated, experimentally, analytically and numerically. Four types of composites were tested, namely, carbon fibre/epoxy, glass fibre/epoxy, oil palm frond fibre/epoxy and the carbon-glass hybrid. This work also examines the effect of the residual stresses built on the crushing behaviour; energy absorption, failure mechanism and mode of failure of the filament wound laminated circular conical composite shell.

For the circular cylindrical and conical shells, the cones vertex angles tested were 0, 6, 12,and $18^0$. Results for the glass/epoxy circular cylindrical shell show that the stress distribution is constant along the shell generator. On the other hand results for the glass/epoxy circular conical shells with vertex angles of 6, 12 and 18 degrees show that the stress distribution is sensitive along the shell generator. As the vertex angle increases, the average crushing load increases, while the initial failure load decreases.

The compound shells used in this investigation were the cone-cone and cone-cylinder-cone intersection composite shells. For the cone-cone intersection shells, the cone vertex angles were $10^0$, $15^0$, $20^0$ and $25^0$. While for the cone-cylinder-cone, the cone vertex angles are $10^0$ and $15^0$ and the cylindrical part lengths were varied between 0 and 50 mm.

The results showed that the initial failure was dominated by interfacial and shear failure, while the delamination and eventually fibre fracture dominated the failure mechanism after the initial first failure. For the circular cylindrical and conical shells, the proposed analytical solution well predicts the initial failure load for the circular cylindrical and conical laminated composite shells. The failure criteria used to predict the initial failure show an excellent agreement. For the cone-cone intersection composite shell, the results showed that the structures with vertex angles $20^0$ and $25^0$ exhibited good energy absorption capability. For the cone-cylinder-cone, numerical results show that high-localised stress has been concentrated at the junctions between the cylinder and cones. Experimental results showed that structures of cylindrical part length varies between 10 and 20 mm exhibited good energy absorption capability and stands a very high crushing load.

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

# EKSPERIMEN DAN KOMPUTATION PERTEMBUNGAN TINGKAHLAKU BERLAMINA KOMPOSIT RANGKA LUAR

**Oleh**

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Tesis ini memberi penjelasan tentang kesan geometri struktur, jenis perykukah dan hibridisasi lerada kelakuan hentakan dalam, penyerapan tenaga, mekanisma kegagalan dan mod kegagalan kon selinder dan rangka luar sebatian komposit. Kelakuan hentakan statik selinder, kon dan campuran komposit rangka luar dalam bebanan selanjar juga dikaji secara analisis, pengiraan, dan secara percubaan. Terdapat empat jenis komposit yang diuji iaiyu gentian karbon /epoksi, gentian kaca /epoksi, gentian tandan kelapa sawit /epoksi dan karbon gentian kaca /epoksi. Tesis ini juga mengkaji kesan tegasan baki dalam keadaan hentakan, penyerapan tenaga dan mekanisma kegagalan dan mod filamen berlamina rangka luar kon komposit.

Untuk kon dan silinder, sudut puncak kon diuji pada 0, 6, 12, 18 darjah. Kajian dan perkiraan secara pengiraan menunjukkan tegasan baki tertumpu pada hujung kecil kon. Jika tegasan baki merupakan pernasalahan utama maka struktur yang terbaik

adalah rangka luar selinder yang menpunyai sudut 0. Bila sudut puncak meningkat, bebanan tekanan hentakan meningkat manakala kadar bebanan permulaan gagal menurun.

Sebatian rangka luar yang digunakan untuk kajian adalah kon-kon dan kon-kon dan kon-selinder-kon yang terpotong pada komposit rangka luar. Bahagian konikal dalam sebatian terpotong adalah simetri. Untuk rangka luar kon-kon terpotong, sudut puncak adalah 10, 15, 20 dan 25. Bagi kon-silinder-kon, sudutnya adalah 10 dan 15 darjah. Jarak antara silinder adalah diubah diantara 0 dan 50mm.

Mod kegagalan telah dikaji dengan gambar diambil semasa hentakan spesimen dilakukan. Hasilnya kegagalan awal di dominasi oleh antaramuka dan kegagalan tegasan, manakala delaminasi dan kegagalan gentian mendominasi mekanisma kegagalan selepas kegagalan awal. Untuk selinder dan kon rangka luar, seperti yang ditunjukkan oleh kajian analitik mentafsirkan kegagalan awal untuk selinder dan kon berlamina rangka luar komposit. Dengan ini kriteria kegagalan yang digunakan menunjukkan korelasi yang tinggi.

Dari pandangan geometri dan bahan, yang telah dianalisis secara analitik, eksperimen dan pengiraan menunjukkan rangka luar selinder diperbuat daripada karbon/epoksi meramalkan beban berpusat sebagai sebab utama kegagalan awal. Boleh ditunjukkan juga bahawa bila sudut puncak meningkat kadar kegagalan awal menurun. Untuk potongan kon-kon komposit rangka luar, hasil menunjukkan bahawa dengan sudut puncak 20 dan 25 mempamerkan sifat penyerap tenaga yang tinggi. Hasil pengiraan menunjukkan tegasan tetempat banyak ditemui pada pertemuan antara dua kon. Untuk kon-selinder-kon, hasil pengiraan mununjukkan bahawa tegasan tetempat tertumpu pada tempat pertemuan antara selinder dan kon. Hasil Eksperimen juga menunjukan panjang bahagian selinder adalah diantara 10 hingga 20mm mempamerkan suatu keadaan yang boleh menyerap tenaga yang optimum dan dapat menahan bebanan hentakan yang tinggi.

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## NOTATIONS AND ABREVIATIONS

| | |
|---|---|
| $\rho$ | is the mass density of the structure |
| A | is the average cross-section area of the structure |
| M | is the mass of the structure |
| $V_i$, $V_f$ | is the initial and final space volume occupied by the structure respectively. |
| $E_s$ | is the specific crushing energy |
| $H_{z1}$ | is the length of cone |
| $H_{z2}$ | is the length of cylinder |
| $H_z$ | is the total length of the structure. |
| $E_m$ | is the matrix modulus |
| $E_f$ | is the fibre modulus |
| $G_m$ | is the matrix shear modulus |
| $\nu_m$ | is the matrix poison's ratio |
| $\nu_f$ | is the fibre poison's ratio |
| $\xi$ | is the fibre packing geometry factor |
| $E_{11}$ | is the longitudinal modulus |
| $E_{22}$ | is the transverse modulus |
| $G_{12}$ | is the in-plane shear modulus |
| $G_{13}$ | is the transverse shear modulus in 1-3 plane |
| $\nu_{12}$ | is the major poison's ratio |
| $\nu_{21}$ | is the minor poison's ratio |
| $\beta$ | is the semi vertex angle of the cone. |