UNIVERSITI PUTRA MALAYSIA

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By

ELFETORI FARAJ ABDEWI

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

July 2007

DEDICATION

To my exemplary parents

Who taught, care, …and support me since the first seconds of my life,

To my honored wife Rugaya who really the great support behind this success,

To my wonderful children, Fatima-azzahra, Abdulrahman, and Muhammad

Whom I am very proud.

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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July 2007

Chairman: **Professor Shamsuddin Sulaiman, PhD**

Faculty: **Engineering**

This research is devoted to investigate the effect of structural geometry on the crushing behaviour, energy absorption, failure mechanism, and failure mode of radially corrugated composite shells. A multi-discipline literature review on the use of composite materials in the field of crashworthiness was carried out. Based on the literature review findings, new composite structure (Radially Corrugated Composite Tube RCCT) was proposed to be fabricated and investigated experimentally.

An extensive experimental program has been performed through four main phases. First phase involves fabrication and testing of three different sizes of cylindrical composite shells. Three sizes of Cylindrical Composite Tubes (CCT) were first tested mainly in order to set the basis for comparison when testing subsequent radially corrugated tubes. Moreover, to find out the effect of tubes' diameter to thickness ratio (*d/t*) on energy absorption capability. Second phase deals with comparison between three geometrical different shells: Cylindrical Composite Tube (CCT), Radially Corrugated Composite Tube (RCCT), and Combined Radially

Corrugated Composite Tube (CRCT). Results found at this phase shows that RCCT fit to proceed for further investigation. The comparison between tested models at each phase has been carried out based on the criteria of maximum energy absorption. The third phase involves examining the corrugation profile. Three different profiles have been examined (Sinusoidal Profile Corrugated Tube (SPCT), Triangular Profile Corrugated Composite Tube (TRCT), and Trapezoidal Profile Corrugated Composite Tube (TZCT)). Results found show that radially corrugated tube with sinusoidal profile gives the best result in terms of energy absorption capability. Finally, further investigations have been carried out on the tube with sinusoidal profile in order to test the effect of corrugation density. At this phase, in addition to the 16-corrugation that have been tested, three more models with same dimensions and different corrugation densities had also been tested. 18-corrugation, 20-corrugation, and 22-corrugation (RCCT-18, RCCT-20, and RCCT-22) have been investigated. Here, it is wise to mention that all corrugations have the same shape and dimensions. Moreover, 22 corrugations were found the maximum number of corrugations that can be fabricated in the tube circumference. In other words it was impossible to fabricate a tube with more than 22-corrugations at that certain diameter, since all tested composite tubes have the same length and diameter at all testing phases. Results show that corrugation density has an influence on the performance of composite shells as an energy absorber. It has been found that as corrugation density increases, total energy absorption increases.

All models were subjected to two kinds of load: axial as well as lateral quasi-static compressive load. Transfer from one phase to another was carried out based on the results of axial load. All models were tested under same condition. For axial tests,

RCCT exhibits excellent results compared to other models through out all research phases. However, for lateral tests, there is a little influence of the geometry on the tested parameters. Failure modes were examined for each specimen using digitally recorded photographs taken during the crushing of the specimens and employing optical microscope.

Linear buckling finite element was conducted for all models using commercially available Finite Element Software (LUSAS). Numerical results presented via includes predicted critical load, deformation mesh, and stress contours. Experimental and numerical results were presented for all models at different load cases. Results obtained show good agreement between experimental and numerical study. Among all models, radially corrugated composite tube with sinusoidal profile and 22-corrugation density model (RCCT-22) exhibit the best result with respect to the tested parameters.

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

CIRI PENYERAPAN TENAGA SECARA RADIAL KELOMPANG KOMPOSIT BERALUN DIBAWAH KEADAAN BEBANAN QUASI-STATIK BERBEZA

Oleh

ELFETORI FARAJ ABDEWI

Julai 2007

Pengerusi: **Profesor Shamsuddin Sulaiman, PhD**

Fakulti: **Kejuruteraan**

Penyelidikan ini berkaitan kajian kesan struktur geometri keatas kelakuan penghancuran, penyerapan tenaga, mekanisma kegagalan dan mod kegagalan tiub komposit beralun selari. Sorotan kajian multi-disiplin penggunaan bahan komposit dalam bidang *crashworthiness* telah dijalankan. Berdasarkan penemuan sorotan kajian, struktur komposit baru (Komposit beralun selari RCCT) telah dicadangkan untuk di buat dan dikaji secara eksperimen.

Program eksperimen ekstensif telah dilakukan melalui empat fasa utama. Fasa pertama termasuk pembentukan dan ujian ke atas kelompang komposit selinder dengan tiga saiz yang berbeza. Tiga saiz Tiub Komoposit Selinder (CCT) telah diuji dengan dua sebab utama: Pertama, untuk mendapatkan dimensi optimum pembantukan dan ujian tiub beralun selari, dan menjadi tajuk utma penyelidikan ini. Kedua, menjadi asas perbandingan bila menguji tiub beralun selari berikutnya. Fasa kedua berkaitan dengan perbandingan tiga kelompang geomatri berbeza: Tiub Komposit Selinder (CCT), Tiub Komposit beralun Selari (RCCT), dan Gabungan

Tiub Komposit beralun Selari (CRCT). Penemuan keputusanfasa ini menunjukan RCCT sesuai untuk penyelidikan seterusnya. Fasa tiga melibatkan pemeriksaan profil alunan. Tiga profil berbeza telah diperiksa. Tiub Beralun Profil Sinusoid (RCCT), Tiub Komposit Beralun Profil Segi tiga (TRCT) dan Tiub Komposit Beralun Profil Trapezoid (TZCT). Keputusan menunjukkan tiub beralun selari dengan profil sinusoid memberikan keputusan terbaik berkaitan keupayaan penyerapan tenaga. Akhirnya penyelidikan seterusnya telah dilakukan keatas tiub profil sinusoidal untuk melihat kesan ketumpatan alunan. Pada fasa ini, selain daripada 16-alunan yang telah diuji, tiga model lagi dengan dimensi sama dan ketumpatan alunan berbeza juga telah diuji. 18-alunan, 20-alunan dan 22-alunan (RCCT-18, RCCT-20 dan RCCT-22) telah di kaji. Adalah diingat bahawa kesemua alunan mempunyai dimensi dan bentuk yang sama. Lebih dari itu, 22 alunan telah ditemui menjadi maksimum alunan yang boleh dihasilkan dengan ukurlilit tiub. Dengan lain perkataan, adalah mustahil untuk membentuk tiub dengan lebih daripada 22-alunan kerana kesemua tiub komposit telah diuji dengan panjang dan diameter sama pada semua fasa ujian. Keputusan menunjukan bahawa ketumpatan alunan mempengaruhi prestasi tiub komposit sebagai penyerap tenaga. Penemuan juga menunjukkan peningkatan ketumpatan alunan akan menambah jumlah tenaga yang diserap.

Kesemua model tertakluk kepada dua bentuk bebanan: bebanan paksi dan bebanan mampatan kuasi-statik sisi. Pindahan dari satu fasa ke satu fasa telah dijalankan berdasarkan keputusan bebanan paksi. Kesemua model telah diuji dibawah keadaan yang sama. Untuk ujian paksi, RCCT berkelakuan keputusan cemerlang berbanding model-model lain dalam semua fasa. Sungguhpun begitu, untuk ujian sisi, terdapat

sedikit pengaruh geometri keatas parameter ujian. Mod kegagalan telah diperiksa pada setiap spesimen menggunakan rakaman foto digit yang diambil semasa menghancurkan spesimen dan juga menggunakan mikroskop optik.

Sebagai tambahan, kajian linear unsure terhingga telah dijalankan menggunakan perisian Unsur Terhingga (LUSAS). Keputusan berangka dibentangkan termasuk beban genting teramal, jaringan ubah bentuk dan kontur tegasan. Keputusan eksperimen dan berangka dibentangkan untuk semua model pada bebenan berbeza. Keputusan diperolehi menunjukkan persetujuan yang baik antara eksperimen dan kajian berangka. Daripada kesemua model, model tiub komposit beralun selari dengan profil sinusoid dan ketumpatan 22-alunan (RCCT-22) memberikan keputusan baik berdasarkan parameter ujian.

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I certify that an Examination Committee has met on 30th of July 2007 to conduct the final examination of Elfetori Faraj Abdewi on his Doctor of Philosophy thesis entitled "Energy absorption characteristics of radially corrugated composite shells under different quasi-static loading conditions" 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 of Doctor of Philosophy.

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 15 November 2007

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ELFETORI FARAJ ABDEWI

Date: 29 August 2007

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