UNIVERSITI PUTRA MALAYSIA

MECHANICAL AND BALLISTIC RESISTANCE PROPERTIES OF A COCONUT SHELL POWDER EPOXY COMPOSITE (COEX) SUBJECTED TO IMPACT LOADS

RISBY MOHD SOHAIMI

MECHANICAL AND BALLISTIC RESISTANCE PROPERTIES OF A COCONUT SHELL POWDER EPOXY COMPOSITE (COEX) SUBJECTED TO IMPACT LOADS

RISBY MOHD SOHAIMI

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

March 2009

DEDICATION

First and foremost, I submit in humility and utmost gratitude to "**Allah Subhana Wa Taala**" for having giving me this opportunity and inspire me in fulfilling this thesis. Islam is a religion that strongly encourages its followers to gain and search for knowledge (as stated by **Allah S.W.T** in Surah Al -'Alaq, verses 1-5):

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ ٱقْرَأْ بِٱسْمِ رَبِّكَ ٱلَّذِى خَلَقَ ۝١ خَلَقَ ٱلْإِنسَٰنَ مِنْ عَلَقٍ ۝٢ ٱقْرَأْ وَرَبُّكَ ٱلْأَكْرَمُ ۝٣ ٱلَّذِى عَلَّمَ بِٱلْقَلَمِ ۝٤ عَلَّمَ ٱلْإِنسَٰنَ مَا لَمْ يَعْلَمْ ۝٥

"In the Name of Allah, The Most Gracious, Most Merciful. Read (O Muhammad) in the name of your Lord Who created, He created man from a clot; Read, and your Lord is Most Honorable, - Who taught (to write) with the pen, Taught man what he knew not."

Secondly, i would not be truly thankful also if i did not express gratitude towards my mum, Hafshah and my dad Mohd Sohaimi, who always taught me to chase the dreams: when I caught it, learn to live with it. I would like to fully thank them for the necessary contributions made especially during my current studies. My deepest gratitude and love goes to my beautiful wife, Siti Noor Adnalizawati, my sons, Danish Muqri, Harraz Zihni, Muhammad Faris Irfan and my daughter Nur Batrisyia. They are my inspirations and guiding light in everything I do. Many personal sacrifices they had endured for me in order to accomplish these works are greatly appreciated. They have been there through it all, the good and the bad and i am eternally thankful to Allah S.W.T for bequeathing me this family in my care.

Abstract of Thesis Presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

MECHANICAL AND BALLISTIC RESISTANCE PROPERTIES OF A COCONUT SHELL POWDER EPOXY COMPOSITE (COEX) SUBJECTED TO IMPACT LOADS

By

RISBY MOHD SOHAIMI

March 2009

Chairman: Associate Professor Wong Shaw Voon, PhD

Faculty: Engineering

An armor design study has been carried out to determine the feasibility of utilizing a coconut shell powder (CSP) reinforced composite as one of the protective component in hard body armor application. Few experimental approaches have been carried out to determine the physical and mechanical properties of coconut shell powder-epoxy composite (COEX). The COEX composite panel bonded with Twaron CT716 fabric as its spall liner (or COMBAT) was also subjected to ballistic tests at several impacting velocity in order to determine the COEX armor ballistic resistance capabilities at certain threat levels.

The physical properties of CSP-A (coarse grade) with low aspect ratio of 0.71, bulk density of 0.424 g/cm^3 and broad particle size distribution were important factors in

the its selection as the best powder type for COEX specimen fabrication. This was due to its potential influences (based from the properties) of increasing the particle-matrix interfacial bonding in the COEX composite system. CSP-B (fine grade) and CSP-C (super fine grade) although possessing higher bulk density which can lead to better compaction, were not chosen due to its higher moisture content and aspect ratio. where these properties is expected to give a weak interfacial bonding for the composite system. These statements was proven in the mechanical testing (tensile, flexural, compression and hardness), where COEX-A (with CSP content of 50%) imparts the highest value in all mechanical properties. It had been found that the tensile, compressive and flexural strength of COEX-A was measured at 17.44 MPa, 100.05 MPa and 194.8 MPa respectively when compared to the other COEX configurations. The Rockwell hardness value for COEX-A was also found to be the highest compared to COEX-B and COEX-C. All these mechanical properties play a significant influence in the ballistic resistance capabilities of the COEX materials

Statistical models were developed using 2 level of Full Factorial Design method to predict the armor's impact resistance and blunt trauma depth using several parameters which are critical to the fabrication and ballistic testing of the COMBAT armor panel. The models were verified and showed good agreement with the actual laboratory test data. Finally, the for actual ballistic armor test of the COMBAT armor panels were tested according to NIJ Standard 0101.08 with 9 mm Full Metal jacket and 7.52 mm M-16 bullets. It was observed that the imprint patterns on the COEX materials could be identified according to the effectiveness in impact energy dissipation. COMBAT test panels were found to withstand impact equivalent to NIJ Level IIIA using a 9 mm FMJ ammunition but perforated at NIJ Level III of 7.62

mm FMJ bullet impacts. Test results showed that COEX panel do possess shock absorbance characteristics and can be utilized as an armor component in the hard body armor system. Dependency on the numbers of Twaron fabric layers as ballistic reinforcements had been reduced up to 3 times with 170 % improvement on energy absorption capabilities when using COEX composite as the frontal component of the armor.

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

SIFAT-SIFAT MEKANIKAL DAN RINTANGAN BALISTIK KOMPOSIT SERBUK TEMPURUNG KELAPA-EPOKSI (COEX) APABILA DIKENAKAN BEBANAN IMPAK

Oleh

RISBY MOHD SOHAIMI

Mac 2009

Pengerusi : Profesor Madya Wong Shaw Voon ,Ph.D.

Fakulti : Kejuruteraan

Kajian ini telah dijalankan untuk menentukan keupayaan penggunaan komposit serbuk tempurung kelapa (CSP) yang akan digunakan sebagai salah satu daripada komponen dalam aplikasi perisai pelindungan keras. Suatu pendekatan secara ujikaji telah dipilih untuk menentukan keupayaan ringtangan dan respon balistik komposit serbuk kelapa (COEX) yang dilapisi dengan fabrik Twaron CT716 (atau COMBAT) pada tahap ancaman yang spesifik apabila dikenakan hentaman berkelajuan tinggi.

Sifat-sifat fizikal CSP-A (gred kasar) dengan nisbah aspek yang rendah iaitu 0.71; ketumpatan pukal sebanyak 0.424 g/cm^3 dan saiz taburan partikel yang luas adalah factor penting dalam pemilihan CSP-A sebagai serbuk yang terbaik dalam proses pembuatan COEX disebabkan oleh ia memepunyai potensi untuk meningkat ikatan

partikel-matrik dalam system komposit tersebut. CSP-B (gred halus) and CSP-C (gred super halus), walaupun mempunyai ketumpatan pukal yang tinggi dimana akan memberikan kemampatan yang tinggi, tidak terpilih disebabkan oleh kandungan air dan nilai nisbah aspek yang juga tinggi. Ini akan menyebabkan ikatan antara muka yang lemah dalam sistem komposit. Ini telah terbukti dalam ujikaji mekanikal (tegangan, mampatan, lenturan dan kekerasan), dimana COEX-A (dengan kandungan CSP sebanyak 50%) menunjukkan sifat mekanikal yang paling baik. Daripada keputusan ujikaji-ujikaji yang telah dijalankan, didapati bahawa kekuatan tegangan, mampatan dan lenturan bagi COEX-A adalah 11.44 MPa, 100.05 MPa dan 194.8 MPa. Kekerasan Rockwell skala R yang diukur pada COEX-A adalah juga yang terbaik diantara konfigurasi COEX yang lain. Kesemua sifat-sifat mekanikal ini memainkan peranan penting dalam keupayaan rintangan balistik bahan COEX tersebut.

Model statistik telah dibangunkan untuk menganggarkan rintangan impak dan trauma tumpul perisai pelindung tersebut dengan menggunakan beberapa parameter yang dianggap kritikal kepada fabrikasi dan ujikaji balistik panel COEX/Twaron tersebut. Panel COEX/Twaron didapati boleh menahan impak yang menggunakan peluru 9 mm pada tahap NIJ IIIA tetapi tembus dengan impak peluru M-16 7.62mm pada tahap NIJ III . Hasil ujian menunjukkan bahawa panel COEX/Twaron juga mempunyai sifat-sifat penyerap kejutan dan boleh digunakan sebagai komponen dalam sistem baju kalis peluru. Pengantungan terhadap bilangan lapisan fabrik Twaron sebagai tetulang balistik telah berjaya dikurangkan tiga kali ganda dengan penambahbaikan keupayaan tenaga penyerapan sebanyak 170 peratus dengan menggunakan komposite COEX sebagai komponen hadapan untuk perisai.

ACKNOWLEDGMENTS

A research work of this nature is generally a teamwork effort which requires assistance, cooperation and support from various parties to achieve its objectives. My profound thanks go to my chairman, Associate Professor Dr. Wong Shaw Voon for his assistance and guidance throughout the course of this study.

I would like to record my appreciation for the valuable comments and guidance given by co-supervisor Professor Dr. Abdel Magid Hamouda for his patience and expertise in guiding me to accomplish what I have started in UPM. His vast experience, friendship and wisdom have made major impact on the progress of this research work. I thank also Dr. Elsadig Mahdi, for his constructive arguments and innovative ideas towards the progress of this study.

Special thanks and gratitude to Mr. Khairul Azmi Md Rezali and Mr. Amjad Hanesh, for their help and assistance in the development of this research work. Mr. Khairul Azmi have contributed much in the fabrication stage which I am very indebted for his diligent and workmanship whereas Mr. Amjad Hanesh have helped me to develop the BANG-SYSTEMS and enriched me with his knowledge and ideas.

I wish to thank all the faculty of engineering staffs and technicians who participate in my work from the Mechanical and Aerospace Engineering department for their kind assistance during the design and laboratory works .Many thanks to all the ITMA staffs and researchers without exclusion who I enjoyed very much for their assistance during the course of my study.

I certify that an Examination Committee met on 27th March 2008 to conduct the final examination of Risby bin Mohd Sohaimi on his Doctor of Philosophy thesis entitled "Mechanical and Ballistic Resistance Properties of a Coconut Shell Powder Epoxy Composite (COEX) Subjected to Impact Loads" 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:

Sapuan Salit, Phd
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Berkawi Shaari, Phd
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ahmad Samsuri, Phd
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Radzali Othman, Phd
Professor
School of Material and Mineral Engineering
Universiti Sains Malaysia
(External Examiner)

_____

BUJANG KIM HUAT, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date

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

Wong Shaw Voon, Ph.D.
Fakulti Kejuruteraan Mekanikal
Universiti Putra Malaysia
(Chairman)

Abdel Magid Saleem Hammuda, Ph.D.
Professor
Fakulti Kejuruteraan Mekanikal
Universiti Putra Malaysia
(Member)

Elsadig Mahdi, Ph.D.
Fakulti Kejuruteraan Aeroangkasa
Universiti Putra Malaysia
(Member)

_____
HASANAH MOHD GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date : 17th July 2009

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.

_____

RISBY BIN MOHD SOHAIMI

Date: 27th March 2009

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS