



**UNIVERSITI PUTRA MALAYSIA**

***NUMERICAL SIMULATION AND EXPERIMENTAL STUDIES ON THE  
BALLISTIC IMPACT CHARACTERISTICS OF CERAMIC/ARAMID  
HYBRID COMPOSITE***

**AYAD ABED RAMADHAN**

**FK 2012 11**

**NUMERICAL SIMULATION AND EXPERIMENTAL STUDIES ON THE  
BALLISTIC IMPACT CHARACTERISTICS OF CERAMIC/ARAMID  
HYBRID COMPOSITE**

**By**

**AYAD ABED RAMADHAN**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

**June 2012**

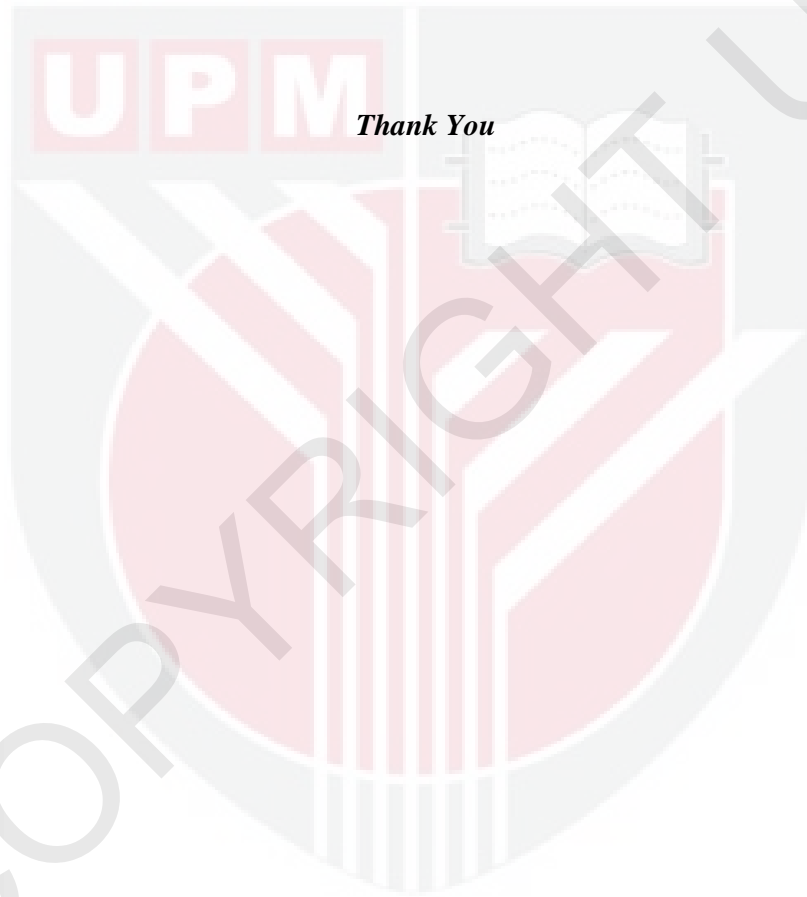
*Dedicated to*

*My dearest Family (Father and Mother)*

*For their extraordinary love and their endless care*

*My Brothers and Sisters for their supporting, encouragement, and prayer*

*My wife for her patience*



*Thank You*

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

**NUMERICAL SIMULATION AND EXPERIMENTAL STUDIES ON THE BALLISTIC IMPACT CHARACTERISTICS OF CERAMIC/ARAMID HYBRID COMPOSITE**

By

**AYAD ABED RAMADHAN**

**June 2012**

**Chair: Associate Professor Abd Rahim Abu Talib, PhD**

**Faculty: Engineering**

Enhancement of the influence of epoxy resin by adding 10% Alumina powder ( $\text{Al}_2\text{O}_3$ ) in the mixture to obtain good mechanical properties of tensile and compression strength has been investigated in this research. The effect of fiber orientation ( $0^\circ/90^\circ$  and  $+45^\circ/-45^\circ$ ) on the composites (kevlar-29/epoxy and kevlar-29/epoxy- $\text{Al}_2\text{O}_3$ ) and different (45, 50, 55 and 60 %) volume fractions ( $v_f$ ) on the behavior of tensile and compression strength have been studied experimentally in comparison with each other. In addition, the tensile strength testing of Kevlar-29/epoxy- $\text{Al}_2\text{O}_3$ , glass/epoxy- $\text{Al}_2\text{O}_3$  and carbon/epoxy- $\text{Al}_2\text{O}_3$  composites using 50% volume fraction was studied and compared the results obtained of these composites of fiber-epoxy without  $\text{Al}_2\text{O}_3$ .

An application of this research was the study of the fabrication of a novel Hybrid (Ceramic/Aramid) composite based on fiber/metal laminates FML (Kevlar-29/epoxy- $\text{Al}_2\text{O}_3/\text{Al}$  6061-T6) that may be comparable to the ARALL-2 (Aramid- Aluminum alloy composite) or GLARE (Glass-Al alloy) composites used in aerospace applications. High velocity impact loading with a range of velocities (160-400 m/s) has been experimentally and numerically investigated.

The energy absorption on the ballistic impact characteristics of Hybrid composites has been investigated in this work. The results obtained show that the energy absorption is higher for Kevlar-29/Epoxy backed with 6061-T6 Al alloy with 7.3% at front Al alloy and (5 -6%) reduction in the density and quantity (for 20 mm thickness laminated plates) of Kevlar respectively.

The predictions of the energy absorption simulation model using ANSYS AUTODYN 3D v.12.1 are compared with the experimental work. Good agreement is generally obtained with error of 8.7% where it has been shown that these novel sandwich structures exhibit excellent energy absorbing characteristics under high velocity impact loading conditions. Hence the FML presented in this work may be considered as a suitable composite for some aircraft structures.

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

**SIMULASI BERANGKA DAN KAJIAN EKSPERIMEN BERKENAAN  
TENTANG SIFAT IMPAK BALISTIK KOMPOSIT HIBRID  
SERAMIK/ARAMID**

Oleh

**AYAD ABED RAMADHAN**

**Jun 2012**

**Pengerusi: Profesor Madya Abd Rahim Abu Talib, PhD**

**Fakulti : Kejuruteraan**

Peningkatan pengaruh resin epoksi dengan menambahkan 10% serbuk Alumina ( $Al_2O_3$ ) dalam campuran itu memperoleh sifat-sifat mekanikal iaitu ketegangan dan kekuatan mampatan telah disiasat dalam penyelidikan ini. Kesan orientasi serat ( $0^\circ/90^\circ$  and  $+45^\circ/45^\circ$ ) di komposit (Kevlar-29 / epoksi dan Kevlar-29 / epoksi  $Al_2O_3$ ) dan berbeza (45, 50, 55 dan 60%) pecahan-pecahan jumlah ( $v_f$ ) di tingkah laku tegang dan kekuatan mampatan telah dikaji secara eksperimen dalam perbandingan dengan satu sama lain. Sebagai tambahan, kekuatan tegangan menguji Kevlar-29 / epoksi  $Al_2O_3$ , kaca / epoksi  $Al_2O_3$  dan karbon/komposit epoksi  $Al_2O_3$  menggunakan 50% pecahan isipadu telah dikaji dan compared keputusan-keputusan memperolehi epoksi serat komposit ini xy tanpa  $Al_2O_3$ .

Satu permohonan penyelidikan ini ada kajian rekaan satu Hybrid novel (Ceramic / Aramid) rencam berdasarkan serat / logam melapisi FML (Kevlar-29 / epoksi  $Al_2O_3$ /

Al 6061-T6) yang mungkin setanding kepada ARALL-2 (Aloi Aluminium Aramid komposit) atau GLARE (Kaca Al aloi) komposit menggunakan dalam aplikasi-aplikasi aeroangkasa. Pemuatan kesan halaju tinggi dengan satu julat halaju-halaju (160-400 m/s) secara eksperimen dan dari segi bilangan disiasat.

Penyerapan tenaga di ciri-ciri kesan balistik komposit Hybrid telah disiasat dalam tugas ini. Keputusan-keputusan memperolehi pertunjukan yang penyerapan tenaga berada lebih tinggi untuk Kevlar-29 / Epoxy menyokong dengan 6061-T6 Al aloi dengan 7.3% di hadapan Al aloi dan (5-6%) pengurangan dalam ketumpatan dan kuantiti (untuk 20 mm ketebalan bersalut plat-plat) Kevlar masing-masing.

Ramalan-ramalan model simulasi penyerapan tenaga menggunakan ANSYS AUTODYN 3D v.12.1 dibandingkan dengan kerja eksperimen. Perjanjian baik amnya mendapat dengan ralat 8.7% di mana ia telah ditunjukkan bahawa struktur-struktur sandwich novel ini mempamerkan tenaga cemerlang mengasyikkan ciri-ciri di bawah keadaan-keadaan pemuatan kesan halaju tinggi. Oleh itu FML menyampaikan dalam tugas ini boleh dipertimbangkan sebagai satu gabungan sesuai untuk beberapa struktur-struktur pesawat.

## ACKNOWLEDGEMENTS

In the name of Allah, the most Beneficent, the most Merciful Praise is to Allah who gave me the power, the strength, the motivation, help and the patience to complete this study after so many hurdles and obstacles; and blessings and peace be upon our prophet Muhammad (S.A.W).

I would like to express my heartiest thanks to my supervisor, Associate Professor Dr. ABD RAHIM ABU TALIB, for his support, patience, advice and devotion of time, throughout my research. I learnt from him on how to arrange my research and how to innovate my ideas to achieve my goal with highest accuracy and shorter time. I have the honor to work under his supervision. I am forever indebted to him for his excellent guidance. I would like to extend my thanks to my co-supervisor, Dr. Rizal Zahari, for him support, him direct and indirect encouragement. He has added to my personality as a human, as much as a researcher. I would also like to thank my co-supervisor, Dr. Azmin S. Mohd Rafie, for his guidance. He taught me how to be a researcher with his wonderful personality. I have asked Allah to keep them safe, and support them with good health and the power to help the students with the knowledge and their scientific abilities. My gratitude also goes to department of aerospace engineering for their encouragement and motivations. And special thanks to all colleagues especially to Ayad alwaise, Amer Kakahy, Suhil Najim, Hussien alwaise, and Arshad Mohamed. Finally, I would like to thank my family for their unconditional care until I have reached to this point, as without their continuous support and precious prayers I could not have been able to finish my research. I know their blessings will always be with me in all my endeavors and I dedicate this success to them. Thanks to my beloved family and wife.



I certify that a Thesis Examination Committee has met on **19<sup>th</sup> June 2012** to conduct the final examination of **AYAD ABED RAMADHAN HAMD** on his thesis entitled "**Numerical Simulation and Experimental Studies on the Ballistic Impact Characteristics of Ceramic/Aramid Hybrid Composite**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Surjatin Wiriadidjaja, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Harijono Djojodihardjo, PhD**

Professor. IR. DR.  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Faizal Mustapha, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Wesley James Cantwell, PhD**

Professor  
School of Engineering  
University of Liverpool  
U. K.  
(External Examiner)

---

**SEOW HENG FONG, PhD**  
Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

**Date:**

This Thesis was submitted to the senate of University Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of **Doctor of Philosophy**. The members of the Supervisory Committee were as follows:

**Abd Rahim Abu Talib, PhD**

Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Chairman)

**Rizal Zahari , PhD**

Senior Lecturer  
Faculty of Engineering  
University Putra Malaysia  
(Member)

**Azmin Shakrine Mohd Rafie, PhD**

Senior Lecturer  
Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Member)

---

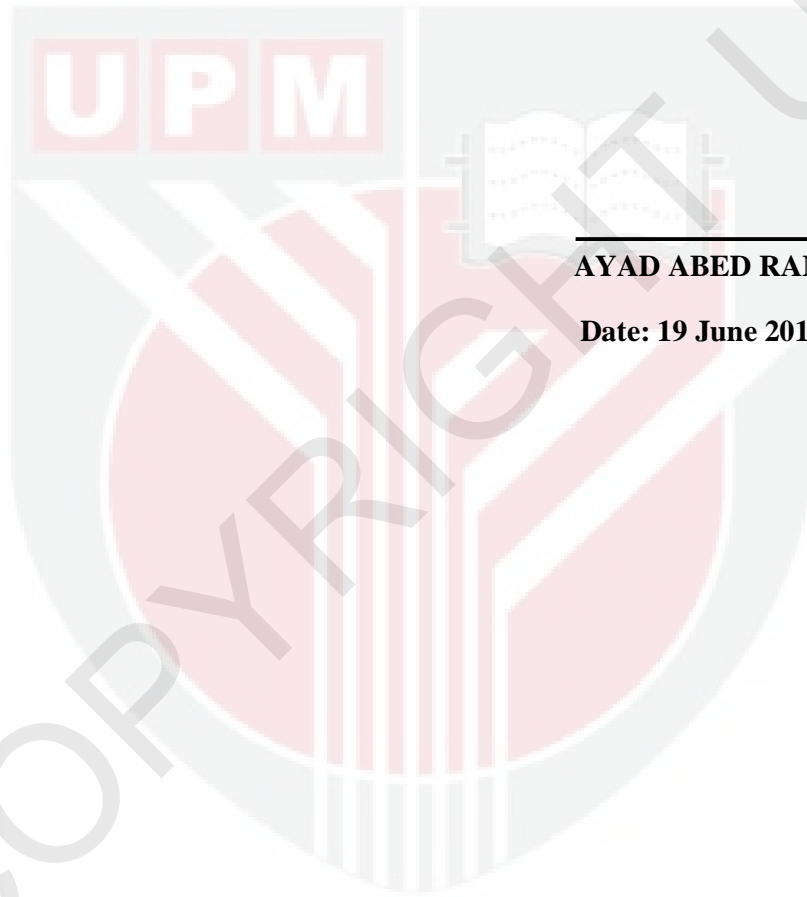
**BUJANG BIN KIM HUAT, PhD**

Professor and Dean  
School of Graduate studies  
University Putra Malaysia

Date:

## 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 other institution



---

**AYAD ABED RAMADHAN**

**Date: 19 June 2012**

## TABLE OF CONTENTS

	Page
<b>DEDICATION</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>ABSTRAK</b>	<b>v</b>
<b>ACKNOWLEDGEMENTS</b>	<b>vii</b>
<b>APPROVAL</b>	<b>viii</b>
<b>DECLARATION</b>	<b>x</b>
<b>LIST OF TABLES</b>	<b>xiv</b>
<b>LIST OF FIGURES</b>	<b>xvi</b>
<b>LIST OF NOMENCLATURE</b>	<b>xxv</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xxiv</b>
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	
1.1 Background	1
1.2 Wing of Aircraft Structure and Composite	3
1.3 Composite Material	5
1.4 Types of Composites	6
1.4.1 Ceramic Materials	7
1.4.2 Hybrid Materials	10
1.4.3 Metal Matrix Composites	10
1.4.4 FML Materials	11
1.5 Discussion	12
1.6 Problem Statement	13
1.7 Objectives	15
1.8 Scope of Work	18
1.9 Thesis Layout	20
<b>2 LITERATURE REVIEW</b>	
2.1 Overview	21
2.2 Mechanical Properties of Composites	22
2.2.1 Fiber Reinforced Composite	23
2.2.2 Ceramic Materials	24
2.2.3 Hybrid Materials	26
2.2.4 Ceramic to Alloys Materials	26
2.2.5 Fiber Metal Laminate (FML)	28

2.3	Background of Impact	37
2.3.1	Charpy and Izod Test	41
2.3.2	Drop Weight and Low Velocity Impact	46
2.3.3	High Velocity Impact	50
2.3.3.1	Ceramic Composite Armour under Ballistic Response	52
2.3.3.2	Kevlar-49/Ceramic under Ballistic Limit	53
2.3.3.3	Ceramic/Metal Composites and the Armours	53
2.3.3.4	Response the GLARE and ARALL Composite for Impact Loading	55
2.3.4	Hyper Velocity Impact	57
2.4	The Parameters Effect on the Ballistic Limit and Energy Absorption	59
2.4.1	Thickness of Composite Structure	63
2.4.2	Shape of Projectile	64
2.4.3	Types of Polymer Matrix Composites	67
2.4.4	Volume Fraction ( $v_f$ )	67
2.4.5	Fiber Orientation of Laminated Plates	68
2.4.6	Influence of Stacking Sequence of Multi Materials	70
2.4.7	Adhesive Layer Thickness of the Efficiency of the Composite	75
2.5	Prediction the Ballistic Limit	75
2.6	Numerical Solution of the Ballistic Limit	78
2.7	Review of Development Target Geometry	86
2.8	The Materials Used in Upper Wing Skin	88
2.9	The Structural Damage and the Bird Strike	89
2.10	Bird Impact on Composite Plates with and without preload	91
2.11	Summary	93
2.12	Contribution	95
<b>3</b>	<b>METHODOLOGY FOR EXPERIMENTAL STUDIES</b>	
3.1	Overview	97
3.2	FML Overview	99
3.3	Experimental Procedures	103
3.3.1	Materials used , Properties and Fabricating the Specimens	105

3.3.1.1	Fabrication of Test Specimens	105
3.3.1.2	Tensile and Compression Tests of the Composite	109
3.3.2	The Gas Gun Device and Impact Test	115
3.3.3	Velocity Measuring by using High Speed Camera and Calibration	122
3.3.4	Calculation of Energy Absorption	124
3.4	Discussion	126
<b>4</b>	<b>METHODOLOGY FOR NUMERICAL SIMULATION</b>	
4.1	Introduction	127
4.2	Analytical Work of Composite Materials	131
4.2.1	Poisson's ratio in Principal Coordinate System	135
4.2.2	Shear modulus in principal coordinate system	136
4.2.3	Determination of Modulus of Elasticity	137
4.2.4	Coefficient of thermal expansion in principal coordinate system	141
4.3	Modelling and Simulation	144
4.3.1	Description of the Numerical Model	148
4.3.2	Material Modelling and Properties	148
4.3.3	Finite Element mesh and AUTODYN simulation	149
4.4	Principles of formulations	153
4.5	Discussion	154
<b>5</b>	<b>RESULTS AND DISCUSSIONS</b>	
5.1	Overview	156
5.2	Mechanical properties of Resin (Epoxy and Epoxy- $Al_2O_3$ ) Composite	160
5.3	Mechanical Properties with different Parameters	163
5.4	High Velocity Impact of Kevlar/epoxy and Kevlar/epoxy- $Al_2O_3$	171
5.5	Mechanical Properties of FML (7075 and 6061-T6 Al alloy)	181
5.6	High Velocity Impact on The FML	187
5.7	The Summary of High Velocity Impact	218
5.8	The Cost Reduction	221
<b>6</b>	<b>CONCLUSIONS</b>	
6.1	Overview	223

6.2 Conclusions	224
6.3 Recommendations for Future Research	228
6.4 The Advantages	229
6.5 The Limitations in the Research	229
<b>REFERENCES</b>	225
<b>APPENDICES</b>	240
<b>BIODATA OF STUDENT</b>	256

