



UNIVERSITI PUTRA MALAYSIA

HIGH VELOCITY IMPACT ANALYSIS OF GLASS

EPOXY-LAMINATED PLATES

MOHAMED THARIQ BIN HAMEED SULTAN

FK 2007 32



**HIGH VELOCITY IMPACT ANALYSIS OF GLASS
EPOXY-LAMINATED PLATES**

By

MOHAMED THARIQ BIN HAMEED SULTAN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Master of Science**

June 2007



In the name of Allah, Most Gracious, Most Merciful

Lillahi Taala.....



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment
of the requirement for the degree of Master of Science

**HIGH VELOCITY IMPACT ANALYSIS OF GLASS
EPOXY-LAMINATED PLATES**

By

MOHAMED THARIQ BIN HAMEED SULTAN

June 2007

Chairman: Professor ShahNor bin Basri, PhD

Faculty: Engineering

An experimental investigation on the effect of thickness on fiberglass reinforced epoxy matrix which is subjected to impact loading was conducted. The composite structure consists of Type C-glass/Epoxy 200 g/m² and Type C-glass/Epoxy 600 g/m². The material is used as a composite reinforcement in high performance applications since it provides certain advantages of specific high strength and stiffness as compared to metallic materials.

This study investigates the mechanical properties, damage characterization and impact resistance of both composite structures, subjected to the changes of impact velocity and thickness. For mechanical properties testing, the Universal Testing Machine was used while for the high velocity impact, a compressed gas gun equipped with a velocity measurement system was used.



From the results, it is found that the mechanical properties, damage characterization and impact resistance of Type C-glass/Epoxy 600 g/m² possess better toughness, modulus and penetration compared to Type C-glass/Epoxy 200 g/m². A general trend was observed on the overall ballistic test results which indicated that as the plate specimen thickness continues to increase, the damage at the lower skin decreases and could not be seen. Moreover, it is also found that, as the plate thickness increases, the maximum impact load and impact energy increases relatively.

Impact damage was found to be in the form of perforation, fiber breakage and matrix cracking. Results from this research can be used as a reference in designing structural and body armour applications in developing a better understanding of test methods used to characterize impact behaviour.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS IMPAK KELAJUAN TINGGI TERHADAP KEPINGAN LAPISAN BERGENTIAN KACA

Oleh

MOHAMED THARIQ BIN HAMEED SULTAN

Jun 2007

Pengerusi: Profesor ShahNor bin Basri, PhD

Fakulti: Kejuruteraan

Kajian eksperimen terhadap kesan ketebalan pada plat gentian kaca berhubung dengan hentaman impak telah dijalankan. Plat gentian kaca ini adalah terdiri daripada jenis C 200 g/m² dan 600 g/m². Penggunaan gentian ini sebagai tetulang komposit dalam industri yang melibatkan applikasi tinggi adalah kerana ia memberikan peningkatan dari segi kekuatan spesifik dan ketelusan yang tinggi jika dibandingkan dengan bahan logam.

Kajian ini lebih tertumpu kepada mengkaji sifat mekanikal, sifat kerosakan dan kesan impak bagi kedua-dua jenis gentian kaca komposit berhubung dengan hentaman impak dengan menukarkan kelajuan dan ketebalan. Untuk penghasilan sifat mekanikal, ujian telah dilakukan dengan menggunakan Mesin Pengujian Universal manakala bagi impak kelajuan tinggi, senapang gas termampat dilengkapi dengan sistem pengukuran kelajuan digunakan.

Hasil kajian mendapati bahawa sifat mekanikal, sifat kerosakan dan kesan impak bagi gentian kaca dari jenis 600 g/m^2 menunjukkan kesan yang lebih baik dari segi kekuatan bahan dan impak jika dibandingkan dengan gentian kaca dari jenis 200 g/m^2 . Satu kesimpulan yang boleh dilakukan daripada kajian impak ini adalah semakin tebal sesuatu plat, maka semakin kurangnya kesan kerosakan yang dapat diperhatikan pada bahagian belakang plat tersebut. Malah, semakin tebal plat, maka semakin tinggillah impak beban dan impak tenaga yang diperolehi.

Kerosakan impak yang dapat dikesan adalah dalam bentuk keretakan matriks, delaminasi dan tahap penembusan. Hasil keputusan kajian ini boleh dijadikan sebagai rujukan dan panduan agar sifat kekuatan bahan dan impaknya dapat difahami bagi merekabentuk komposit bergentian ringan bagi kegunaan aplikasi struktur dan bahan kalis peluru.

ACKNOWLEDGEMENTS

Alhamdulillah, all praise to Allah S.W.T, Lord of the Universe, and May peace and blessings be upon His beloved Prophet Muhammad S.A.W, on the household of the prophet, and on his faithful companions. Amin.

First and foremost, the writer would like to thank Allah the Almighty for bestowing him the much-needed patience, perseverance and persistence to successfully accomplish the crucial task of thesis writing, although he had to face many difficulties along the way. The writer would also like to express his respect to his supervisor, Professor Ir. Dr. ShahNor Bin Basri. The writer highly appreciates the effort and contribution made by him. Taking the great opportunity, the writer would also like to extend and express his sincere love and appreciation towards his beloved mother, Sufaidah bt. Mohd Musa, beloved father, Hameed Sultan b. Mohamed Sulaiman, beloved brothers, Mohamed Habibullah b. Hameed Sultan & Mohamed Arif b. Hameed Sultan and beloved wife, Rafidah Barveen Bt Abdul Wahith for their support and sincere doa to Allah, so that his quest for knowledge will be granted by Allah.

Last but not the least; the writer would like to extend his sincere thanks and appreciation to Dr Prasetyo Edi, Dr Mohammad Saleem and all individuals whose names are not mentioned in this acknowledgement who have helped him in one way or another. May Allah's grace and bounty be upon them. Amin.



I certify that an Examination Committee met on 14 June 2007 to conduct the final examination of Mohamed Thariq Bin Hameed Sultan on his Master of Science thesis entitled “High Velocity Impact Analysis of Glass Epoxy-Laminated Plates” 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:

Ahmad Samsuri bin Mokhtar, Ph.D

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ir. Renuganth Varatharajoo, Ph.D

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Rizal bin Zahari, Ph.D

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ishak bin Hj Abdul Azid, Ph.D

Associate Professor
School of Mechanical Engineering
Universiti Sains Malaysia
(External Examiner)

HASANAH MOHD GHAZALI, Ph.D

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 requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

ShahNor Basri, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohammad Saleem, PhD

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Prasetyo Edi, PhD

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD

Professor/ Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9th August 2007



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.

**MOHAMED THARIQ BIN HAMEED
SULTAN**

Date: 21st June 2007

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xix
 CHAPTER	
1	
INTRODUCTION	1
1.1 Introduction	1
1.2 Problem Statement	6
1.3 Aims and Objectives of the Study	8
1.4 Layout of the Thesis	9
1.5 Contribution of Work	10
2	
LITERATURE REVIEW	11
2.1 Introduction	11
2.2 Composites Material and Properties	12
2.2.1 Generic Natural Ceramics and Ceramic Composites	14
2.2.2 Advantages and Disadvantages of Composites	16



2.3	Glass Fiber	18
2.3.1	Formation of fiberglass	19
2.3.2	Properties of Fiberglass	20
2.3.3	Fiber Type Comparison	22
2.4	Impact Mechanics	23
2.4.1	Experimental Techniques	25
2.4.2	Ballistic Limit and Residual Velocity of the Projectile	27
2.4.3	Failure Modes	30
2.4.4	Prediction of Ballistic Limits	31
2.4.5	Ceramic-Composite Armor	34
2.4.6	The Basic Requirements for a High-Speed Gun	36
2.5	Conclusion	38
3	MATERIALS AND METHODOLOGY	39
3.1	Introduction	39
3.2	Material Selection	42
3.3	Composite Specimen Fabrication	44
3.3.1	Sample Preparation Process	45
3.3.2	Material Properties	48
4	TESTING PROCEDURE USING GAS GUN	52
4.1	Introduction	52
4.2	Testing Procedure	52
4.3	Projectile Velocity Measurement Procedure	59
5	EXPERIMENTAL RESULTS	62
5.1	Tensile Test Results	62
5.2	Material Properties of Type C-glass/Epoxy 200 g/m ²	62
5.2.1	Modulus of Elasticity, E ₁₁	64
5.2.2	Modulus of Elasticity, E ₂₂	65
5.2.3	Shear Modulus, G ₁₂	66
5.2.4	Poisson's Ratio, ν_{12}	67

5.3	Material Properties of Type C-glass/Epoxy 600 g/m ²	68
5.3.1	Modulus of Elasticity, E ₁₁	68
5.3.2	Modulus of Elasticity, E ₂₂	70
5.3.3	Shear Modulus, G ₁₂	71
5.3.4	Poisson's Ratio, ν ₁₂	72
5.4	Conclusion of Mechanical Characterization	73
5.5	Impact Test Result	74
5.6	High Velocity Impact Properties	75
5.7	Composites Square Plate of Type C-glass/Epoxy 200 g/m ² and 600 g/m ² at 200 m/s	76
5.7.1	Results for Type C-glass/Epoxy 200 g/m ² at velocity of 200 m/s	77
5.7.2	Results for Type C-glass/Epoxy 600 g/m ² at velocity of 200 m/s	80
5.8	Composites Square Plate of Type C-glass/Epoxy 200 g/m ² and 600 g/m ² at 250 m/s	84
5.8.1	Results for Type C-glass/Epoxy 200 g/m ² at velocity of 250 m/s	84
5.8.2	Results for Type C-glass/Epoxy 600 g/m ² at velocity of 250 m/s	87
5.9	Damage Characteristic Results	91
5.10	Impact Resistance Results	92
6	CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK	95
6.1	Conclusion	95
6.2	Future Recommendations	97
	REFERENCES	98
	APPEDICES	108
	BIODATA OF THE AUTHOR	135
	LIST OF PUBLICATIONS	136



LIST OF TABLES

Table		Page
2.1	Summary of history behind composites	12
2.2	Generic Natural Ceramics	15
2.3	Ceramics Composites	15
2.4	Advantages and Disadvantages of Composites	17
2.5	Composition of glass used for fiber manufacture (all values in wt %)	21
2.6	Fiber Type Comparison	22
3.1	Physical Properties of Matrix	46
3.2	Number of Fiberglass Layers	47
5.1	Geometrical data for C-glass/Epoxy 200 g/m ²	63
5.2	Geometrical data for C-glass/Epoxy 600 g/m ²	69
5.3	Mechanical Properties for C-glass/Epoxy 200g/m ² and 600g/m ²	73
5.4	Type of test being implemented for the two different types of fibreglasses	75
5.5	Observation of damage for test specimen Type C-glass/Epoxy 200 g/m ² at 200 m/s	78
5.6	Observation of damage for test specimen Type C-glass/Epoxy 600 g/m ² at 200 m/s	82
5.7	Observation of damage for test specimen Type C-glass/Epoxy 200 g/m ² at 250 m/s	85
5.8	Observation of damage for test specimen Type C-glass/Epoxy 600 g/m ² at 250 m/s	89
5.9	Composite specimen of high velocity impact results	94

LIST OF FIGURES

Figure		Page
1.1	The above picture is one of the aircraft (C141) involved in a bird strike during flight operation (reproduced from Strange Dangers, 2000)	2
1.2	Orbital debris traveling in outer space at the velocity of 15,240 m/s (reproduced from China National Space Administration, 2003)	3
1.3	Bundles of fiber glass before being woven (reproduced from Elsevier Scientific, 1994)	5
1.4	Fiberglass cloth 200 g/m ² from type C-glass (reproduced from China Foundry Association, 2003)	8
1.5	Single stage gas gun used for this research at Ballistic Lab, Advanced Institute of Technology, Universiti Putra Malaysia	9
2.1	Example of modern composite usage in the aircraft field (reproduced from Avia Pictures, 1988)	14
2.2	Laminate plies tailored to meet specific requirements of composite design (reproduced from G.E. Freger et al. 2004)	16
2.3	Comparison of fiber glass with few other materials in terms of stress vs. strain curves (reproduced from V.N. Kestel'man et al. 2004)	17
2.4	Two types of wool sample with different staple length (reproduced from Department of Agriculture, United States of America)	20
2.5	Residual versus initial kinetic energy of the projectile (reproduced from Lin and Bathnagar, 1991)	28
2.6	Force versus displacement in static tests (reproduced from Zhu et al. 1992)	28

2.7	Schematic view of a projectile traveling in a gun barrel	36
3.1	Flow chart describing the outline plan to carry out the research work	40
3.2	Flow chart describing the composite fabrication process	41
3.3	Type of materials used for this research work	43
3.4	Catch chamber unit where the square plate of test specimen are placed	44
3.5	Sample preparation process	45
3.6	Composite panel produced from mould after 48 hours of curing time and it is later being cut into smaller panels of dimension 100 mm × 100 mm	48
3.7	Sample setup being implemented on the testing machine	49
4.1	A schematic view of the gas gun which consists of five major parts that are the pressure reservoir unit, the firing mechanism unit, the launching unit, the catch chamber and the velocity measurement	53
4.2	Pressure reservoir unit consist of a cylindrical gas tank, pressure regulator, pressure vessel and pressure control valves	54
4.3	Firing mechanism unit that influences the performance of the gun	55
4.4	(a) Loading mechanism where the projectile was placed (b) Propelled mechanism for shooting out purposes	56
4.5	Collar sleeve was designed to close the launching unit once projectile has been place into the launching unit	56
4.6	Projectile made of steel with low hardness to avoid corrosion	57

4.7	Catch chamber unit designed as a protection room during the firing process	57
4.8	Test specimen were placed between the anvil and impact base	58
4.9	Schematic of the velocity measurement set up	59
4.10	A small opening of radius 50 mm was designed in front of anvil's front surface so that projectile can hit the specimen during firing process	60
4.11	The process of launching the projectile is being done by using the Data Measurement Unit	61
5.21	Energy absorbed by the specimen is graphically the area beneath the curve	76
5.22	Impact Load, (N) vs. Time, (μ s) for Type C-glass/Epoxy 200 g/m^2 at velocity 200 m/s	77
5.23	Damage observation of test specimen at velocity 200 m/s for Type C-glass/Epoxy 200 g/m^2	78
5.24	Impact Energy, (J) vs. Time, (μ s) for Type C-glass/Epoxy 200 g/m^2 at velocity 200 m/s	79
5.25	Damage versus impact energy with two types of fiberglass at different thicknesses. (Cantwell et al. 1986)	80
5.26	Impact Load, (N) vs. Time, (μ s) for Type C-glass/Epoxy 600 g/m^2 at velocity 200 m/s	81
5.27	Damage observation of test specimen at velocity 200 m/s for Type C-glass/Epoxy 600 g/m^2	82
5.28	Impact Energy, (J) vs. Time, (μ s) for Type C-glass/Epoxy 600 g/m^2 at velocity 200 m/s	83

5.29	Impact Load, (N) vs. Time, (μs) for Type C-glass/Epoxy 200 g/m^2 at velocity 250 m/s	84
5.30	Damage observation of test specimen at velocity 250 m/s for Type C-glass/Epoxy 200 g/m^2	86
5.31	Impact Energy, (J) vs. Time, (μs) for Type C-glass/Epoxy 200 g/m^2 at velocity 250 m/s	86
5.32	Impact Load, (N) vs. Time, (μs) for Type C-glass/Epoxy 600 g/m^2 at velocity 250 m/s	88
5.33	Damage observation of test specimen at velocity 250 m/s for Type C-glass/Epoxy 600 g/m^2	89
5.34	Impact Energy, (J) vs. Time, (μs) for Type C-glass/Epoxy 600 g/m^2 at velocity 250 m/s	90



LIST OF ABBREVIATIONS

bar	10^5 Pa
E	Modulus of Elasticity
ID	Inside diameter
L	Length
mm	milimeter
v	Velocity of the projectile
ms^{-1}	Meter per second
mgh	Potential energy
$mv^2/2$	Kinetic energy
P_i	Vertical Force
p_i	Internal pressure
p_o	External pressure
r_o	Outside radius
r_i	Inside radius
t	Time in second
U	Deformation
$\text{W/m}^\circ\text{C}$	Thermal conductivity
E_{11}	Young's modulus in longitudinal direction
E_{22}	Young's modulus in transverse direction
G_{12}	In-plane shear modulus
ν_{12}	In-plane Poisson's ratio
ϵ_x, ϵ_y	Axial strain
γ_{12}	Shear strain



τ_{12} Shear stress

σ_x Axial stress

CHAPTER 1

INTRODUCTION

1.1 Introduction

Composites usually refer to fiber reinforced materials that were originally developed for the aerospace, aircraft, modern vehicle and light weight structures in the early 1950's. When composites are used for structural components in the aerospace industry, unexpected impacts may occur. These may be due to damage during flight, bird strike during flight and dropping of tools during maintenance work, as shown in Figure 1.1. The ballistic impact of a bullet that can penetrate the material and bird strikes that take place at high speeds are examples of impact loads that may result in very serious damage. On the other hand, dropped tools and runaway debris that occur at relatively low velocity may also lead to damage.

Furthermore, damage produced by impact may also be serious especially if composites are subjected to compression loading. Many engineering applications and structures which use these composites are subject to impact loads that may compromise the structural integrity of the composites and will lead to failure. Extensive efforts have been taken by researchers to investigate the variation of mechanical properties for the impacted composites.

According to Jacob et al. (2002), a crashworthiness structure is a term that means the ability to absorb impact energy. There are differences between crashworthiness and penetration resistance. Crashworthiness is more concerned towards energy absorption through controlled failure mode that enables the maintenance of a gradual decrease in load profile during absorption. However, penetration resistance is associated with the total absorption without allowing the projectile or fragment penetration to occur during impact (Beaumont et al. 1974).



Figure 1.1: The above picture is one of the aircraft (C141) involved in a bird strike during flight operation (reproduced from *Strange Dangers*, 1992)

The events of impact basically can be divided into four types of velocity ranges. They are low velocity, high velocity, hypervelocity and ballistic impact. Low velocity impact (< 31 m/s) might include situations involving dropped tools whereas high velocity (31 m/s – 240 m/s) might include birds colliding with an aircraft. Situations such as projectile being fired from a gun at speeds exceeding 250 m/s may be classified under ballistic impact events. Finally, orbital debris traveling in outer space at the velocity of 15,240 m/s as shown in Figure 1.2 is considered to be hypervelocity impact events (Stilp and Hohler, 1990).

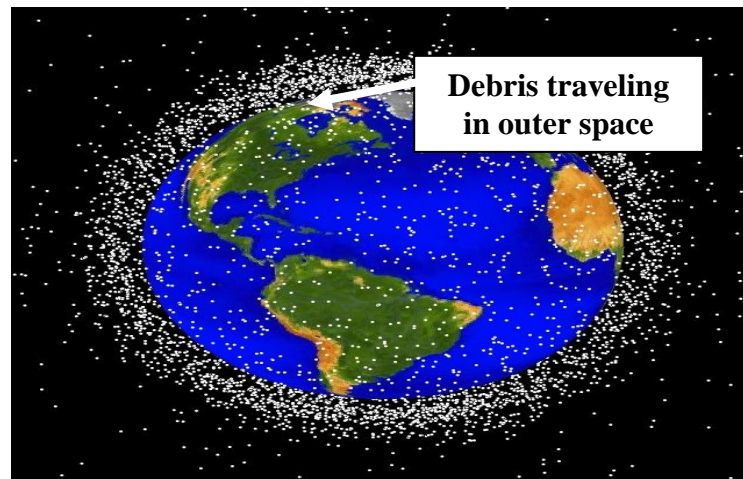


Figure 1.2: Orbital debris traveling in outer space at the velocity of 15,240 m/s (reproduced from China National Space Administration, 2003)

Since the early 1970's, researchers have been looking at new methods to improve impact properties of graphite composites, such as fiber and matrix toughening and interface toughening, through thickness reinforcements and hybridizing (Jacob et al. 2002). Carbon fibers are the stiffest and strongest reinforcing fibers for polymer composites, and are most used after glass fibers. Made of pure carbon in form of graphite, carbon fibers are low density and have a negative coefficient of longitudinal thermal expansion. Carbon fibers however are very expensive and can cause galvanic corrosion when coming into contact with metals. They are generally used together with epoxy for high-strength and stiffness applications such as race cars, automotive, sports equipment and space applications.

For high performance material, carbon or aramid-polyamides fibers such as Kevlar are recommended fibers. They are very strong and highly heat resistant, that they can be used in aircraft applications such as the Euro Fighter 2000 (Robson et al. 1993). Unfortunately, they tend to be expensive. Therefore, for more general applications, the workhorse fiber for composite material is said to be glass (Robson et al. 1993; Gayer and Schuh, 1996).

Glass fiber or fiberglass is a material made from extremely fine fibers of glass. It is used as a reinforcing agent for many polymer products. This composite material, normally known as Fiber Reinforced Polymer (FRP) is more popularly referred to as fiberglass. Glass makers throughout history have experimented with glass fibers, but mass manufacture of fiberglass was only made possible with the advent of finer machine tools. In 1893, Edward Drummond Libbey exhibited a dress at the World's Columbian Exposition, incorporating glass fibers with the diameter and texture of silk fibers. What is commonly known as fiberglass today, however, was invented in 1938 by Russel Games Slayter of Owens-Corning, as a material to be used as an insulator. It is marketed under the trade name of Fiberglass, which has become a generalized trademark.

Glass fibers have many benefits. They are cheap, strong and relatively easy to manufacture. This is the main reason why glass fibers can be introduced as a substitute material compared to carbon fibers. Glass fibers are useful because of their high surface area to weight ratio. However, the increased surface makes them much more susceptible to chemical attack. By trapping air within them, blocks of glass fiber make good thermal insulators with a thermal resistance of 0.04 W/mK. Glass strengths are usually tested and reported for virgin fibers which have just been manufactured. The freshest and thinnest fibers are the strongest, but the fact is that, it is easier for thinner fibers to bend or shape. The more the surface is scratched, the less the resulting tenacity (Volf et al. 1990). Refer to Figure 1.3.