UNIVERSITI PUTRA MALAYSIA

HIGH VELOCITY IMPACT ANALYSIS OF GLASS EPOXY-LAMINATED PLATES

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

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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

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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/m^2 and Type C-glass/Epoxy 600 g/m^2. 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/m^2 posses better toughness, modulus and penetration compared to Type C-glass/Epoxy 200 g/m^2. 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/m^2 dan 600 g/m^2. Penggunaan gentian ini sebagai tetulang komposit dalam industri yang melibatkan applikasi tinggi adalah kerana ia memberikan peningkatan dari segi kekuatan specifik 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 Pengujiaan 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 kuranglah kesan kerosakan yang dapat diperhatian pada bahagian belakang plat tersebut. Malah, semakin tebal plat, maka semakin tinggilah 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.

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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:

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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

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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
$W/m^{o}C$	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).

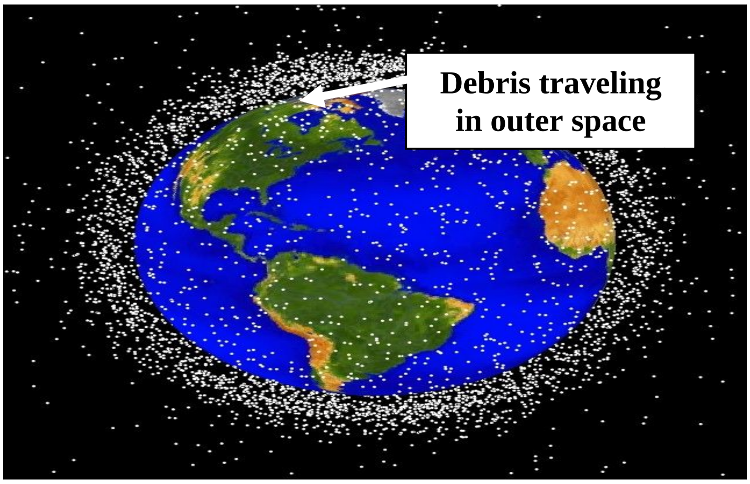

Figure 1.2: **Orbital debris traveling in outer space at the velocity of 15,240 m/s (reproduced from China National Space Administration, 2003)**

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.