UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL ASSESSMENT OF ENERGY ABSORPTION CAPABILITY AND CRUSHING BEHAVIOUR OF HYBRID COMPOSITE SQUARE TUBE SUBJECTED TO OBLIQUE LOADINGS

LIM KENG TEEK

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By

LIM KENG TEEK

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

November 2014

DEDICATIONS

SPECIALLY DEDICATED TO:

My Dad

And

My Mom

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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Chair : Rizal Bin Zahari, PhD
Faculty : Engineering

Hybrid composite materials had been widely used as energy absorber devices during crushing or accident mainly in automobile as well as aircraft in this era. They had been effectively applied in the various industries for its light weight, high resistance to chemical and temperature and part integration purposes from military to public service levels. Previous studies have shown that axially crushing of tube yielded very good energy absorption capability. However, lack attentions have been given to the analysis of the oblique compressive tests of Kevlar/glass hybrid square tubes as well as pure Kevlar or fiberglass square tube. This research were focused on the 200g/m^2 and 600g/m^2 woven roving C-glass square tube, pure Kevlar-29 and hybrid of the 200g/m^2 C-glass and Kevlar-29 square tubes subjected to quasi-static oblique loads. The main objective of the investigation was to study the effect of oblique loadings to the crushing behavior and energy absorption characteristics of the pure and hybrid square tubes. Comparison of the performance among the different materials on the crushing tubes were also been carried out. The crushing patterns of the tubes were investigated at loading angles of 0^o, 5^o, 10^o, 15^o and 20^o with respect to the longitudinal direction of the tube. Square tubes were fabricated by using a square steel bar and by the mean of hand lay-up process. The oblique load was realized by applying a load via the inclined compression plate to the specimens. When the structures are subjected to the axial and oblique quasi-static loading, the deformation modes, such as progressive collapse, axisymmetric collapse, bending and buckling of the tubes were identified. Results showed that the energy absorption effectiveness factors of axial loading tube structures were significantly higher than those subjected to higher angles of oblique loadings. The hybrid composite Kevlar/Glass tube had the highest energy absorption capability compared to pure C-glass and pure Kevlar composite tubes.

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

PENILAIAN EKSPERIMEN TERHADAP KEUPAYAAN PENYERAPAN TENAGA DAN TINGKAH LAKU PENGHANCURAN KOMPOSIT HIBRID YANG TERTAKLUK KEPADA MUATAN SERONG

Oleh

LIM KENG TEEK

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Bahan hibrid komposit telah banyak digunakan sebagai alat penyerap tenaga dalam bidang automobil dan pesawat pada era ini. Bahan-bahan tersebut telah digunakan secara berkesan dalam pelbagai industri dari tahap tentera kepada tahap perkhidmatan awam disebabkan cara-caranya yang ringan, rintangan yang tinggi terhadap bahan-bahan kimia dan suhu dan juga tujuan seperti integrasi bahagian. Kajian yang terdahulu telah menunjukkan bahawa penghancuran berpaksi tiub akan menghasilkan daya keupayaan penyerapan tenaga yang sangat baik. Walau bagaimanapun, kurang perhatian telah diberikan kepada analisis mampatan serong kepada tiub hibrid Kevlar/kaca, Kevlar tulen dan gentian kaca tiub persegi. Kajian ini ditumpukan kepada 200g/m^2 dan 600g/m^2 tenunan yang keliling C-kaca tiub persegi, Kevlar-29 tulen dan hibrid 200g/m^2 C-kaca dan Kevlar-29 tiub persegi tertakluk kepada beban serong kuasi-statik. Salah satu objektif utama penyiasatan ini adalah untuk mengkaji kesan beban serong kepada tingkah laku penghancuran dan ciri-ciri penyerapan tenaga daripada tiub persegi yang tulen and hybrid. Perbandingan prestasi antara bahan-bahan yang berbeza pada tiub juga telah dijalankan. Corak penghancuran tiub telah disiasat dengan muatan sudut 0^o, 5^o, 10^o, 15 ° dan 20^o berhubung dengan arah longitud tiub. Tiub persegi telah direka dengan menggunakan bar keluli persegi dan dengan cara berlapis. Beban serong telah direalisasikan dengan menggunakan beban melalui mampatan plat condong kepada spesimen. Apabila struktur tertakluk kepada beban paksi dan beban serong kuasi-statik, kaedah ubah bentuk, seperti keruntuhan progresif, paksi simetri, mod ubah bentuk tidak bersimetri, lenturan dan rebah tiub telah dikenal pasti. Hasil kajian menunjukkan bahawa faktor keberkesanan penyerapan tenaga pada paksi struktur tiub muatan adalah jauh lebih tinggi berbanding dengan yang tertakluk kepada sudut beban serong. Selain itu, komposit hibrid menunjukkan ciri-ciri penyerapan tenaga yang lebih berkesan dibandingkan dengan tiub komposit jenis tulen.

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This thesis was 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 were as follows:

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Date: 23 January 2015

Declaration by Graduate Student

I hereby confirm that:

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Committee: ____________________

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF NOMENCLATURES

F	Axial crushing force
V	Transverse crushing force
F_m	Mean load
E_a	Absorbed energy
E_t	Total energy absorbed
E_s	Specific energy absorption (SEA)
M, m	Mass
S	Displacement
δ_f	Permanent axial displacement
L	Length of the tube
T	Tube wall thickness
Tg	Glass transition temperature
σ	Normal stress
τ	Shear stress
θ	Angle of inclination
A_0	Area of the section perpendicular to the axis of the member
A_θ	Area of the section at the inclined angle to the axis of the member
F_f	Friction force
μ	Coefficient of friction force

CHAPTER 1

INTRODUCTION

This research focused on the fabrication and testing of the composite tube subjected to oblique loadings. The composite materials are tested by using the machine Instron 3382 100kN at Mechanical Lab of Engineering, UPM. The crushing behavior and energy absorption of composite materials are recorded and computerized.

1.1 Background

Safety of transportation vehicles, especially aircraft and car is getting high attention. Over the past decades, effort in understanding the crashworthiness of sea, land and air vehicles is already actively in progress. Development in the safety systems in vehicles have already led to high standards. In the early 1960, the safety regulations had opened the new demanding area of engineering analysis in all sector of transportation. The latest generation of light aircrafts is a lot faster, thus the energy generated in any impact is potentially greater. Therefore, the thin-walled structure of the aircraft is designed to sustain abnormal loadings during various kind of accident.

It is a vital necessity for the development of energy absorbing structures and materials to absorb the impact force and prevent it from transferring to the occupants. Composite has come to play it roles in the material development for the transportation due to its low cost, high strength property, flexibility in fabrication and others properties if compare to conventional metal like steel. The energy absorption potential of structures made from various materials has to be investigated and evaluated. The Federal Aviation Agency (FAA) in the United State has performed series of full scale aircraft crash tests analytically and experimentally on fuselage and complete transport aircraft. The effort has been spent in conducting experimental tests to establish good design criteria and material selections. This will provide knowledge to engineer with the ability to design vehicle structures that maximize the energy absorption during deformation of the structures, hence protecting and improving occupant survivability.

1.2 Crashworthiness of Composite Materials

The aircraft crashworthiness has been improving with time and attention is mainly directed towards reducing the impact of crash that in turn minimizing occupant injury severity. Different types of materials have been used to serve the purpose. Among them are metals, polymers and composite materials. In the automobile and aerospace industry, the primary fiber reinforcements are carbon or graphite fibers, high strength glass fibers, ceramic fibers and Kevlar. Composite materials are very popular materials used in constructing aircraft replacing metals due to their very good mechanical properties. Composite materials are fabricated in many different geometry and shape, for example, tail, fin, wings and fuselage to serve the respective function. Some are function as protective shell to the occupant and energy absorption device during crush. Composite materials can be engineered to achieve high specific strength and stiffness. Addition advantages like their lightweight and design flexibility have offered the materials good potential to be used in the aerospace and automotive industries.

In general, a crashworthy vehicle or aircraft must meet the integrity and impact energy management requirements. For example, in case of a catastrophic disaster, the passenger compartments are required to sustain the crushing loads without excessive deformation which will compromised the safety of the occupants. Other the other hand, the other structural parts for examples as shown in Figure 1.1 (aircraft) and Figure 1.2 (automotive) are required to absorb the impact load and kinetic energy of the transport while keeping the deceleration level below the human tolerable limit. Figure 1.3 showed the M16 ultra-light helicopter which also has the strut components that act as energy absorber during crushing.

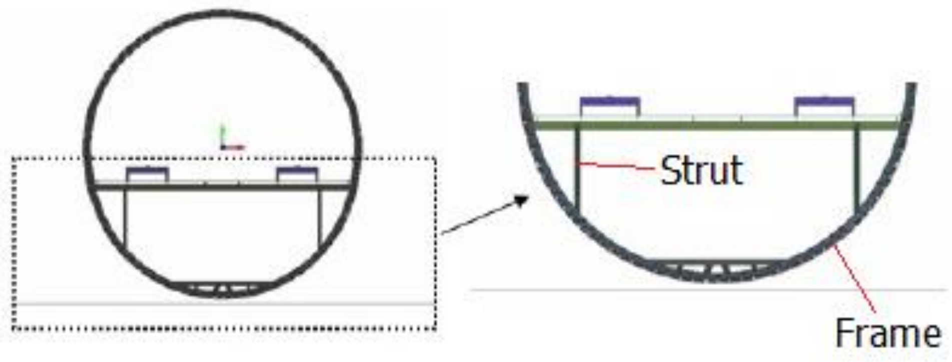

Figure 1.1: Strut and frame structure of aircraft as energy absorber and support [1].

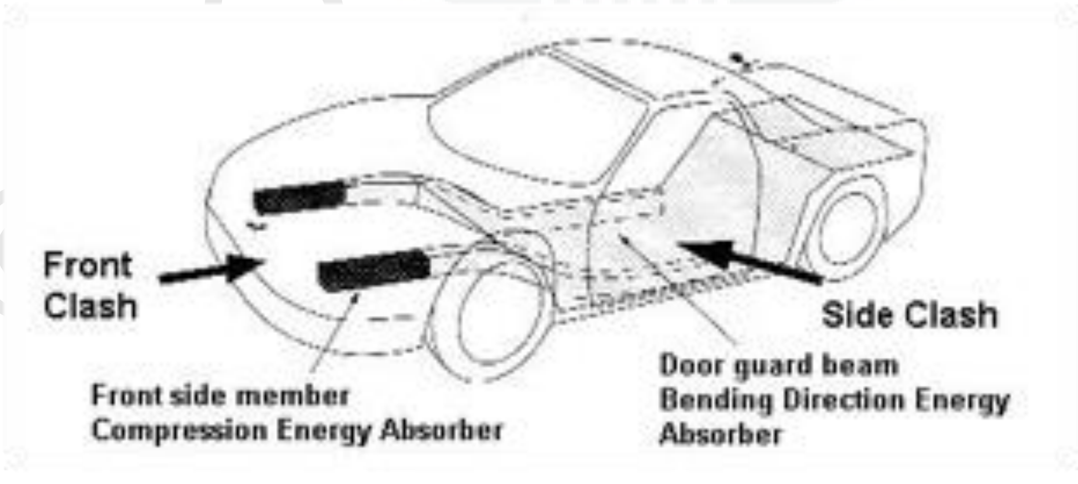

Figure 1.2: Application of carbon fiber reinforced plastic as shock absorber for automobile [2].

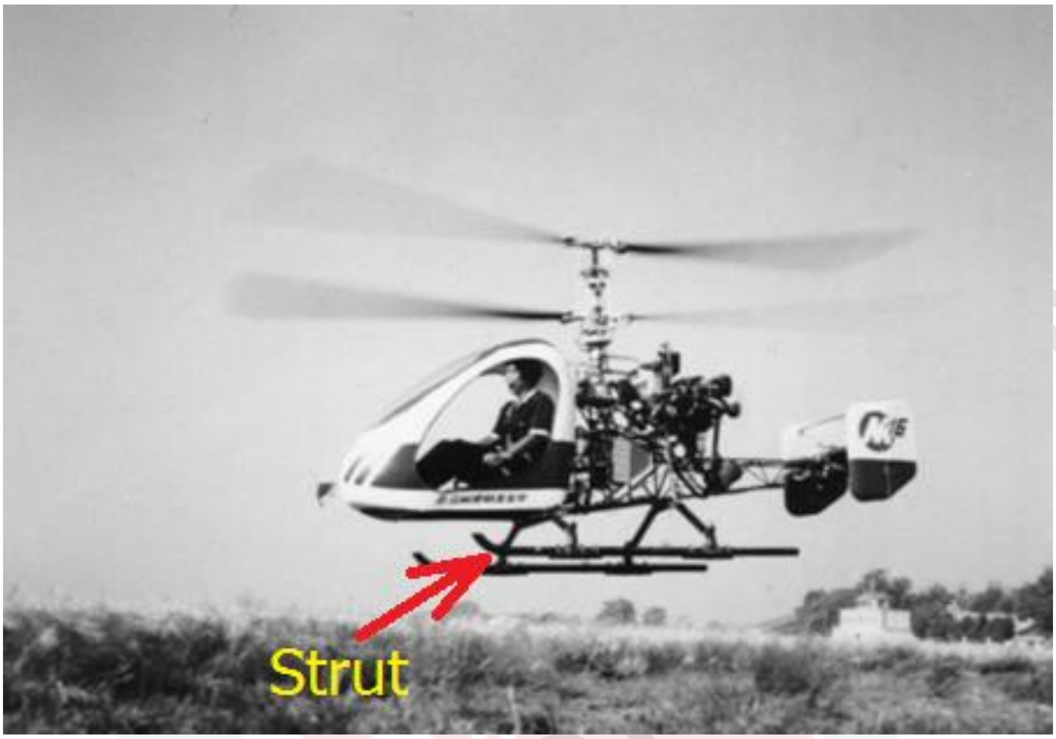

Figure 1.3: M16 ultra-light helicopter [3].

1.3 Problem Statements

The historical study of crushing behavior of hybrid composite tube has been discussed previously in the background of study in this thesis. If the composite is fabricated in hybrid which contained two type of different material, it will have better strength compare to the pure type. In the oblique loading on the composite square as well as the fiberglass-Kevlar hybrid composite tube, axially crush tube will have better energy absorption capability because by introducing angle, the material will subject to other forces like bending and shearing which will weaken the structural component of the tubes to absorb energy.

There is lack of experimental assessment on the crushing behavior and energy absorption of the hybrid composite square tube of fiberglass and Kevlar. These hybrids composite can play a very important role in the crashworthiness of transportations as these materials are more economical and have high strength to weight ratio if compare to metal like stainless steel and aluminum. Therefore, further studies are needed to analyze in detail the failure behavior of the structures of the materials due to oblique crushing forces. This is because crushing may occur at all directions in our life, not just axial impact and for better cost management.

1.4 Research Objectives :

1.4.1 To determine the effectiveness of pure and hybrid composite in the energy absorption capability subjected to axial and oblique loads by using the means of experimental tests.

1.4.2 To compare the performance of the composite and hybrid composite tubes in terms of the effect of different crush angle, energy absorbed capability and crashworthiness.

1.5 Thesis Flow Chart

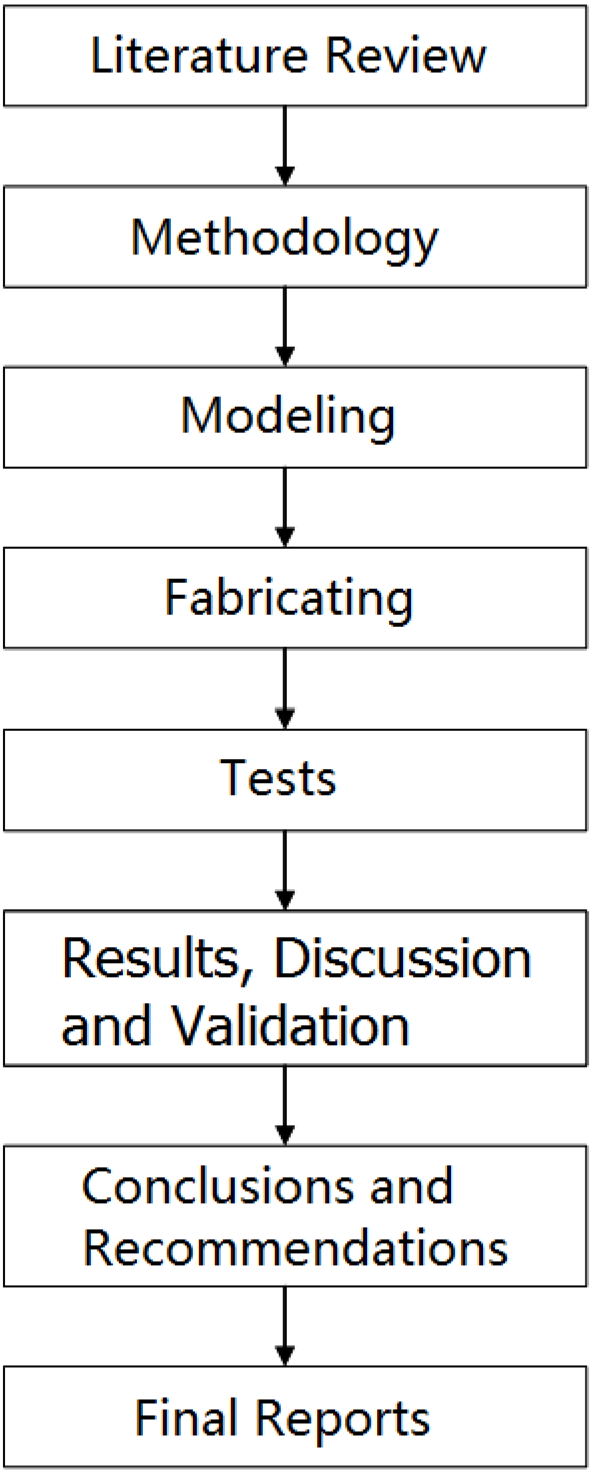

Figure 1.4: Thesis flow chart.

1.6 Thesis Layout

This thesis consists of 5 chapters. Chapter 1 is the introduction of crashworthiness related to the research work. Chapter 2 is about the review of previous studies where the fundamental theory related to the topic of research were learnt and recalled. The methodology will be showing the process of fabrication of the samples and setting up of experimental instruments which will be reported in Chapter 3. In the third chapter, the steps of carrying out the experimental test will be explained as well. The next chapter which is Chapter 4, it will be the results and discussions. All the related results, graphs and figures will be studied and discussed in detailed and presented in the chapter regarding the title of research. Chapter 5 reports about the fulfillment of the objectives of the research. In addition, the conclusions and recommendations for future investigated are also written in the last chapter, Chapter 6.

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