CRASHWORTHINESS PERFORMANCE OF KENAF/GLASS FIBRE-REINFORCED EPOXY HYBRID COMPOSITE FILAMENT WINDING TUBE

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By

MOHD SUPIAN BIN ABU BAKAR

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

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DEDICATION

From Al-Quran, the greatest source of knowledge

Bring me sheets of iron" - until, when he had levelled [them] between the two mountain walls, he said, "Blow [with bellows]," until when he had made it [like] fire, he said, "Bring me, that I may pour over it molten copper." (Al-Kahf: Verse 96)

&

To my beloved late father and mother for their invaluable sacrifices, encouragements and support throughout my life

&

To my beloved wife for her love, patience and understanding &
to my beloved daughter

&

To my awesome seven siblings and my family in law.

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

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July 2020

Chairman : Professor Mohd Sapuan bin Salit, PhD
Faculty : Engineering

The composite material in energy absorption tube application have gained a tremendous function as sacrificial structure device in automotive, motorsport, train and aerospace applications. Due to various capabilities of composite material in reinforcement structure applications, many researchers have explored to tailor the composite material structure with various parameters to withstand and increases the strength and crashworthiness capability under static and impact load conditions. Composite structure from synthetic material such as carbon fibre-reinforce polymer (CFRP), glass fibre-reinforce polymer (GFRP) and Kevlar has used in many high-performance application as a reinforcement due to light-weight and strong properties, besides, these synthetic materials was not easily degrading and it cause many issues related to waste and environmental, moreover, the operation cost to produce was high.

Therefore, this present study was upholding the natural and synthetic fibres as a constituent material in a high-performance hybrid application such as energy absorption tube to reduce the synthetic materials waste. Furthermore, this present study of filament-wound natural/synthetic hybrid composite tube has presented the automated filament winding technique to merging efficiently two distinct fibres into single fibre-band with various parameters related. Besides, this present study has shown the abilities of natural/synthetic hybrid composite tube to withstand the compression load and impact load efficiently compare to single synthetic material.

The two aspect parameters in filament-wound kenaf/glass hybrid composite tube in quasi-static compression load and intermediate-velocity impact load experiments have exposed the first parameters of winding orientation in the hybrid composite tube has identified that the high winding orientation was contributed high energy absorption characteristics and stable collapse behaviour performance. Meanwhile, the second

parameter of intraply stacking sequence parameter in hybrid composite tube significantly increase 28% of initial peak load and 68% of the energy absorbed compared to the glass fibre-reinforced epoxy tube during compression and impact load experiments. Therefore, from the experimental results, obviously showed that natural fibre as a constituent in hybrid synthetic components has plentiful of potential as a hybrid reinforcement material in structural application device.

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

PRESTASI KEBOLEHANCURAN BELITAN FILAMEN KENAF/GLASS FIBRE-REINFORCED EPOXY HIBRID KOMPOSIT TIUB

Oleh

MOHD SUPIAN BIN ABU BAKAR

Julai 2020

Pengerusi : Profesor Mohd Sapuan bin Salit, PhD
Fakulti : Kejuruteraan

Bahan komposit dalam aplikasi tabung penyerapan tenaga telah memperoleh fungsi yang luar biasa sebagai alat struktur kebolehancuran dalam aplikasi automotif, sukan permotoran, kereta api dan aeroangkasa. Oleh kerana pelbagai keupayaan bahan komposit dalam aplikasi struktur tetulang, banyak penyelidik telah meneroka untuk menyesuaikan struktur bahan komposit dengan pelbagai parameter untuk menahan dan meningkatkan kekuatan dan kemampuan menghadapi kemalangan dalam keadaan beban statik dan hentaman. Struktur komposit dari bahan sintetik seperti polimer penguat serat karbon (CFRP), polimer penguat gentian kaca (GFRP) dan Kevlar telah digunakan dalam banyak aplikasi berprestasi tinggi sebagai struktur penguat kerana sifatnya yang ringan dan kuat, selain itu, bahan sintetik ini tidak mudah merosakkan dan menyebabkan banyak masalah berkaitan dengan sampah dan alam sekitar, tambahan lagi, kos operasi untuk menghasilkan adalah tinggi.

Oleh itu, fokus kajian ini adalah mengetengahkan gentian semula jadi dan sintetik sebagai bahan asas dalam aplikasi hibrid berprestasi tinggi seperti tiub penyerapan tenaga untuk mengurangkan sisa bahan sintetik. Selanjutnya, kajian ini mengenai tiub filamen semula jadi / sintetik komposit hibrid telah memperlihatkan teknik penggulungan filamen automatik untuk menggabungkan dua gentian yang berbeza menjadi satu jalur tunggal dengan pelbagai parameter yang berkaitan. Di samping itu, kajian ini telah menunjukkan kebolehan tiub komposit hibrid semula jadi / sintetik untuk menahan beban mampatan dan beban hentaman dengan berkesan berbanding dengan bahan sintetik tunggal.

Untuk parameter yang kedua aspek dalam tiub komposit hibrid kenaf / kaca dalam beban mampatan kuasi-statik dan eksperimen beban impak halaju-sederhana telah mendedahkan parameter pertama bagi orientasi belitan dalam tiub komposit hibrid telah dikenal pasti bahawa orientasi belitan tinggi dapat menyumbangkan ciri penyerapan

tenaga tinggi dan prestasi tingkah laku keruntuhan yang stabil. Sementara itu, parameter kedua bagi urutan susunan intraply dalam tiub komposit hibrid secara signifikan telah meningkatkan 28% beban puncak awal dan 68% tenaga diserap berbanding dengan tiub epoksi bertetulang gentian kaca semasa eksperimen beban mampatan dan hentaman. Oleh itu, dari hasil eksperimen, jelas menunjukkan bahawa serat semula jadi sebagai penyusun dalam komponen sintetik hibrid mempunyai banyak potensi sebagai bahan penguat hibrid dalam alat aplikasi struktur.

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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 Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CFE	Crush Force Efficiency
CFRP	Carbon Fibre Reinforced Composites
EA	Energy Absorbed
FRP	Fibre-Reinforced Polymer
GMT	Glass Mat Thermoplastic
GFRP	Glass Fibre-Reinforced Polymer
HTS	Hybrid Tube Specimen
IVI	Intermediate-velocity impact
M	Mass / weight
N	Number of ply
NF	Natural fibres
NTS	Non-Hybrid Tube Specimen
NFRP	Natural Fibre-Reinforced Polymer
P	Force
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
PET	Polyester
Pmax	Peak load
Pmean	Mean load
PMC	Polymer Matrix Composite
RFI	Resin Film Infusion
RTM	Resin Transfer Molding
SEA	Specific Energy Absorption
SEM	Scanning Electron Microscope
UD	Uni-Directional
UTM	Universal Testing Machine
VARTM	Vacuum-Assisted Resin Transfer Molding
ℓ	Tube length
ΔL	Displacement
θ°	Winding orientation
t	Tube thickness

CHAPTER 1

INTRODUCTION

1.1 Background of study

The energy absorption tube or thin-walled tube has practically used in many transportation industries as reinforced structures or safety device structures. In aviation industry the tubular tube was known and applied as webbed/gridder fuselage structures (Figure 1.1), landing gears tube and steering columns in (Heimbs et al., 2010). Meanwhile, other application is widely used as body structures in train and crash box fitted at front section of vehicle body in Figure 1.2 (Marzbanrad & Ebrahimi, 2011). The evolution of energy absorption tube design also has extended into various shape and cross-section profile to function better as safety devices. The concept and basic principle of energy absorption tube was to absorb and dissipate the energy from sudden impact, head to head collision and other compression loads.

The study of hybrid composite energy absorption tube bring out abundantly of a new finding and have a numerous synergistic enhancement property in the field of nature composite study where it has advantage on being at economical to manufacture, eco-friendly, harmless to health, lightweight, high stiffness and specific strength provide a possible alternative to the synthetic fibre. Therefore, a various technique of fabricating the hybrid composite structures are existing in various scale. The principle and method of fabricating the energy absorption tubes from distinct composite materials could be affected by various results of structure deformation and crashworthiness performance. Furthermore, the combination of several different types of fibres into a single matrix has led to more advantageous stability between the inherent advantages and disadvantages, which the advantages of one type of fibre could complement with what is lacking in the other.

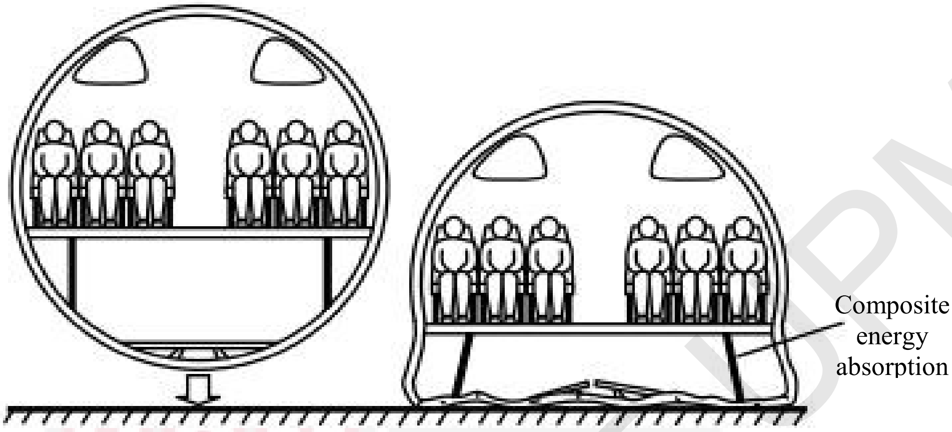

Figure 1.1 : Energy absorption structure in aircraft fuselage (Heimbs et al., 2010)

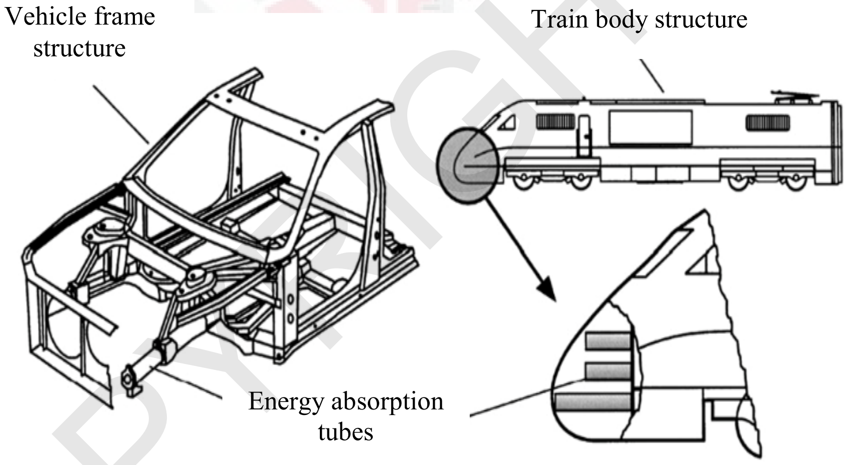

Figure 1.2 : Cylindrical shells automobile/train safety component
(Marzbanrad & Ebrahimi, 2011)

Otherwise, there has been great interest on natural material to reduce the use of synthetic material in engineering applications which offer advantages such as bio-renewable and eco-friendly factors. Thus, the previous hybridization technique in composite energy absorption tube studies, has indicated the potential in natural fibre materials could be explored to achieve better understanding the characteristics into dissipation energy capacity. The results of experimental from the hybridization technique by Albahash and Ansari (Albahash & Ansari, 2017), have showed the potential of natural jute fibre as great element in hybrid energy absorption composite tube to enhanced the energy absorption capabilities, thus, from the results has revealed that the hybrid material from natural/synthetic composite tube has provided better results in crashworthiness behaviour compared to single fibre material of synthetic or nature fibre material.

Besides, the further influence in previous composite studies have revealed the advantage of hybridization technique in energy absorption tube application has allow the engineer to tailor the energy absorption tube with various technique which the output performance could complement into specific requirements, therefore, the studies by Özkan Özbeket et al. (Özbek et al., 2019) have discovered the intraply fibre hybridisation and winding angles of basalt and filament wound glass fibre-reinforced tubes have resulted a significant improvement in energy absorption capability compare to synthetic glass fibre tube. Otherwise, in other studies of natural fibres as hybrid component by Mahdi et al. (E Mahdi et al., 2003), have depicted the significant enhancements in mechanical properties and energy absorption value with damage tolerance were distinguished.

The hybrid composite tube consist of continuous kenaf fibre yarn as a reinforcement fibre has indicate as extremely valuable natural fibre with robust mechanical properties, moreover, kenaf yarn was excellent in previous fabrication technique such extruded or hand-lay technique and also can be optimize with the filament winding process, which has compared with glass fibre composite tube. From the study by Safri et al. (Safri et al., 2017), has showed that hybrid natural/synthetic which consist kenaf fibre as hybrid reinforcement material was displayed an excellent impact property. Therefore, also has selected as hybrid natural/synthetic due to previous studies which has displayed an excellent impact property. Meanwhile, the study by Meon et al. (Meon et al., 2012) has indicated that potential in kenaf reinforced fibre with thermosets and thermoplastics polymer has improved significantly the tensile properties of the structure.

To understanding the load effect on failure mode or damage characteristics while exploiting the resistance of structural materials, the energy absorption composite tube applications should consider structural integrity with crashworthiness performance under both static and dynamic conditions. Therefore, the advantages of filament winding technique in this present study, have offered a stable combination of distinct fibres placement and consistency of fibre/matrix distribution to resist compression or impact loads in progressive collapse mode behaviour. Moreover, kenaf/glass hybrid composite tubes have demonstrated a different crashworthiness characteristic over a synthetic glass fibre composite tube under both of quasi-static compression load and intermediate-velocity impact load experiments. Therefore, this present study also has investigated the effect of winding orientation and intraply stacking sequence parameters with variation of mass fibre fraction to strengthen and enhance the crashworthiness performance and perform a stable collapse behaviour of hybrid kenaf/glass energy absorption under quasi-static compression load and impact load condition.

1.2 Problem Statements

A composite material in many tubular structural studies has proved the excellent performance in improving the crashworthiness performance and easy to customize in various technique of fabrications. Therefore, fibre-reinforced polymers receive considerable attention in various structural applications which these materials have great features in high tensile strength, chemical resistance, dimensional stability as well as excellent insulation properties. Apart from this, varieties of composite materials have been attributed as energy-absorbing devices, therefore, the optimization of hybridization technique in energy absorption tube application has displayed the advantage of utilization of various composite hybrid materials from synthetic, metal or natural components and elevate their high specific strength and high specific stiffness but also in their capacity to dissipate impact energy.

The hybrid material component from natural fibres more likely used as a substitution for existing bulky synthetic materials have inspired an interest in various engineering applications where the goal is to preserve the environment and reduce the dependency on synthetic material. Utilising natural fibres such as kenaf, jute, hemp and wood pulp as a reinforcement in composite energy absorption tubes is an alternative answer to negative environmental effects due to disposal process of synthetic fibre which are not easily degrade. Therefore, natural fibres have other great of interest, they are abundantly available around the world, especially in tropical Asian countries. Moreover, the hybridization of natural fibre with stronger and more corrosion-resistant synthetic fibre will generally enhance the stiffness, strength and moisture-resistant behaviour and would contribute into decreases the consumption of synthetic material into high performance structure applications. Hence, a balance between the environmental impact and performance aspect can be achieved.

From the previous studies, the hybrid energy absorption tube has tailored with most existing technique of manual hand lay-up and pultrusion, where it was found was very difficult to merging various type of fibre material especially natural and synthetic fibres. Therefore, the concept of hybridisation of natural and synthetic materials with filament winding technique has provides flexibility to tailor various material properties according to specific requirements, which is one of the major advantages of the hybridisation concept in composite structures. Hybridization technique uses the filament winding process provide the advantage in merging of different-continuous fibre composites into a single hybrid fibre composite band of a tubular structure. The fabrication process of cylindrical composite structures with filament winding technique provide persistent quality in geometrical accuracy, high fibre volume fractions and load stresses compared to other fabrication processes (Aleksendrić & Carlone, 2015; Martins et al., 2014; Quanjin et al., 2018; Ramesh, 2016; Savage, 2010). The filament winding technique structures could be tailored or customised with the prominent effect on the winding orientation parameters to improve the collapsing behaviour and other improvements that influenced the energy absorption capability (Gramoll & Ramaprasad, 1995; Hu et al., 2016; Morozov, 2006; Ricciardi et al., 2019; Rousseau wt al., 1999). Besides, in previous technique in combination of natural and synthetic materials as energy absorption tube have limitation in parameter to improve crashworthiness performance and collapse behaviour. Therefore, filament winding has great benefit to tailored various material properties into specific requirements of application.

1.3 Research Objectives

The specific objectives of this study are stated as follows;

a) To investigate the crashworthiness characteristic and failures mode behaviour of hybrid and glass composite energy absorption tube with the effect of winding orientation parameter under quasi-static (QS) experiments.
b) To investigate the crashworthiness characteristic and failures mode behaviour of hybrid and glass composite energy absorption tube with the effect of winding orientation parameter under intermediate-velocity impact (IVI) experiments.
c) To investigate the crashworthiness characteristic and failures mode behaviour of hybrid and glass composite energy absorption tube with the effect of stacking sequence parameter under quasi-static (QS) experiments
d) To investigate the crashworthiness characteristic and failures mode behaviour of hybrid and glass composite energy absorption tube with the effect of stacking sequence parameter under intermediate-velocity impact (IVI) experiments.

1.4 Significance of study

There are many processes / techniques that can apply to manufacture the hybrid composite energy absorption tube, particularly hand lay-up technique. Filament winding is a manufacturing process mostly suited to optimization of various fibres merge and formed into single tubular structure. The effect of hybridization in filament winding technique of combination of natural and synthetic fibre in multilayer of intraply fibre-band in fabrication will be the achievement of new hybrid composite energy absorption tube study within crashworthiness characteristic and failure mode behaviour under quasi-static and intermediate-velocity impact tests. Therefore, the significant of this study has elaborate as per detail below.

a) Hybridization technique in filament winding process has merged two constituent composite fibre with equal mixture of fibres and matrix. Therefore, the final shape of hybrid composite tube is stable and smooth.
b) Continuous rotating mandrel in the filament winding process will allowed the hybrid composite tube fabricate with multi-fibre combination which is useful for high strength or high stiffness tubular shaft or other similar application.
c) The variation in crashworthiness performance and collapse behaviour could be customised within various parameters in filament winding technique.
d) The fabrication process of hybrid composite tube in the filament winding technique was apply the fibre/resin equal composition and controlled by winding speed and fibre tension, therefore fibre/resin composition are stable for entire process, thus, the quality product could transform a better result in experiment.
e) The successful development of natural fibre materials in hybrid composition material would provide opportunities to utilization of other natural fibre hybridization with filament winding technique.

Furthermore, the fabrication of hybrid composite tube through filament winding technique, the synthetic Glass Fibre-Reinforced Polymer (GFRP) composite tube will also fabricate through similar technique, moreover the experiments result data will differentiate with glass tube in crashworthiness characteristics and failure mode behaviour.

1.5 Scopes and limitations of research

This research study has focused on two stage of practical work out. First stage of this research study is to fabricate the hybrid energy absorption tube with two distinct fibres merged into single fibre-band through automated filament winding process. Through the process, two main parameters have been customized as parameter toward characteristic of hybrid kenaf/glass as composite energy absorption tube, which it will undergo quasi-static compression and intermediate-velocity impact load. Kenaf fibre, glass fibre and incorporated with epoxy resin has been chosen as a main material due to common material of regular consumption in composite application. The hybrid kenaf/glass materials through filament winding process fabrication has been characteristic with various winding orientation and various intraply stacking sequence parameter.

Second stage of this study was experimental stage, where the two parameter of kenaf/glass hybrid composite tubes has provided by the fabrication filament winding technique. During this stage, the crashworthiness performance and collapse behaviour of hybrid kenaf/glass composite tube were characterized the peak load (Pmax), mean load (Pmean), crush force efficiency (CFE), specific energy absorption (SEA) and energy absorb (EA) were carried out under quasi-static compression load and intermediate-velocity impact load. Additionally, the results experiment for all parameters of hybrid composite tube will be compare with the same parameter of synthetic glass fibre composite tube to evaluate through comparison on the primary characteristics against the synthetic composite fibre material.

1.6 Thesis outlined

This thesis is structured into five main chapters which accordance with the thesis format of Universiti Putra Malaysia. Thesis has been divided into sub-section to relevant areas associated with the topics in this research. Therefore, five mains chapter in this thesis was presented as below description;

Chapter 1: The problems that initiate this research and the research objectives were clearly highlighted in this chapter. The significance of this work and the scope of study were also elaborated within the chapter.

Chapter 2: This chapter presents a comprehensive literature review on the areas related to the topic of this thesis. In addition, the research gaps obtained from the review were also clarified within the chapter.

Chapter 3: This chapter presents the methodology used in this study for the preparation of materials, testing procedure, and data collection.

Chapter 4: This chapter presents the result and discussion of crashworthiness and failure mode behaviour of hybrid and glass composite tubes. Moreover, from the results, all the characteristic will specific focus through the specific objective highlighted.

Chapter 5: And final chapter, a discussion of the overall conclusion and recommendation for future works are presented.

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