Faculty of Mechanical Engineering

CIRCULAR COMPOSITE TUBES UNDER QUASI-STATIC AXIAL LOADING

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DECLARATION

I declare that this thesis entitled “Circular Composite Tubes Under Quasi-Static Axial Loading” is the result of my own research except as cited in the references.

Signature	:	....
Name	:	....
Date	:	....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering (with Honours).

Signature :……………………………………………

Supervisor's Name :……………………………………………

Date :..……………………………………….. .....

ABSTRACT

Composite structures are extensively used in the aerospace and automotive industry, where high amounts of force are involved. Manufacturers are currently venturing into green and ecologically friendly materials such as plant-based fibres and synthetic-plant fibre hybrids to improve crashworthiness of composites. However, these composites still exhibit poor energy absorption characteristics compared to conventional load bearing materials such as metal and have to be improved by altering parameters during the fabrication process. This experiment aims to determine the effects of parameters, specifically triggering mechanism and fibre lay-up sequence on the energy absorption capability of fibre reinforced composites. In this study cross-ply of unidirectional glass (G), banana (B), and glass-banana hybrid fibre reinforced composite tubes were investigated. The composites were fabricated with different fibre lay-up sequence, and each fibre sequence features three different triggering mechanism. Composite specimens were fabricated using the bladder assisted moulding method which utilised a circular tube with 1000 mm in length and 57.30 mm outer diameter. Specimens are 100 mm in length and have an outer diameter of 57.30 mm. Triggering mechanisms tested are flat-end, 45° chamfer and the 4-petal tulip. The specimens are fabricated with GGG lay-up, BBB lay-up, and two hybrid GBG and BGB lay-up configurations. A quasi-static axial crushing test was performed at 10 mm/min with a 150 kN capacity universal testing machine Instron 5585. From the test, it was found that triggered specimens experienced better crushing performance, with the tulip trigger achieving higher values of mean load, specific energy absorption and crush force efficiency compared to the flat-ended and 45° chamfered specimens. In terms of fibre lay-up sequence, hybridisation between banana and glass fibres (GBG and BGB sequence) exhibited better values of parameters tested and displayed stable and progressive crushing during the test.

ABSTRAK

Projek ini melibatkan keupayaan komposit untuk menyerap daya. Struktur-struktur komposit banyak digunakan dalam industri automotif dan aero-angkasa, di mana struktur-struktur tersebut akan didedahkan kepada nilai daya yang tinggi. Pada zaman ini, teknologi bahan mesra alam sedang diberi fokus, terutamanya dalam kajian serat tumbuhan, serat sintetik dan serat hibrid sintetik-tumbuhan. Namun demikian, komposit-komposit tersebut tidak mengemukakan keupayaan menyerap daya sebaik dengan bahan-bahan menyerap daya konvensional seperti besi dan logam, dan parameter-parameter perlu diubah dalam proses fabrikasi komposit. Tujuan kajian ini adalah untuk meneliti kesan-kesan mengubah mekanisma pencetusan daya dan susunan kain serat ke atas keupayaan komposit untuk menyerap daya. Kajian ini melibatkan tiub komposit hibrid yang dibuat daripada tenunan serat semula-jadi pisang (G), serat sintetik kaca dan hibrid antara serat pisang-kaca. Proses fabrikasi komposit menggunakan proses 'bladder assisted moulding' dengan acuan yang mempunyai panjan 1000 mm dan diameter luaran 57.30 mm. Spesimen yang dihasilkan mempunyai panjang 100 mm dan diameter luaran 57.30 mm. Mekanisma pencetusan daya yang dikaji adalah spesimen rata, pemotongan serong 45°, dan tulip dengan 4 kelopak. Susunan kain serat yang dikaji adalah susunan GGG, BBB, dan susunan hibrid GBG dan BGB. Satu ujian hentaman kuasi statik dengan kelajuan 10 mm/min dan sel beban 150 kN telah dijalankan ke atas spesimen mneggunakan mesin penguji sejagat Instron 5585. Data yang diperolehi menunjukkan bahawa mekanisma pencetudan daya tulip mencapai nilai daya purata, penyerapan daya spesifik dan kecekapan tenaga yang tinggi berbanding dengan mekanisma pencetusan daya yang lain. Dari segi susunan kain serat, data menunjukkan bahawa komposit susunan hibrid (susunan GBG dan BGB) mencapai nilai-nilai yang tinggi dalam parameter yang diuji dan menampilkan ciri-ciri hentaman yang stabil dan progresif.

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LIST OF SYMBOLS/ABBREVIATIONS

SEA	-	Specific Energy Absorption
CFE	-	Crush Force Efficiency
FRC	-	Fibre Reinforced Composite
G	-	Glass Fibre
B	-	Banana Fibre
RTM	-	Resin Transfer Moulding
P_{max}	-	Maximum Load
P_{mean}	-	Mean Load
SMA	-	Shape Memory Alloy
Ɵ	-	Orientation Angle
D/t	-	Diameter to Thickness ratio
CNTs/PSF	-	Carbon Nanotubes/Polysulfone
NT	-	Non-triggered specimens
CT	-	Chamfer-triggered specimens
TT	-	Tulip-triggered specimens

CHAPTER 1

INTRODUCTION

1.1 Background

Crashworthiness is an aspect of kinetic energy absorption that is widely studied and researched, especially in the aerospace and automotive industry. Crashworthiness is the ability of the structure to absorb kinetic energy in a crash situation to protect the components or inhabitants in the structure. It involves the distribution of forces in the event of a crash as long and as widespread as possible to avoid the impact force on a person. Moreover, some studies emphasize the importance of the occupant or component compartments to retain its structural integrity during a crash (Jackson, Dutton, Gunnion, & Kelly, 2011; Ramakrishna & Hull, 1993; Sigalas, Kumosa, & Hull, 1991).

The crashworthiness of a structure can be determined analytically by calculating its specific energy absorption (SEA). It is the energy absorbed per unit mass of crushed material. A structure is said to have good SEA if it fulfils certain criteria, like low total weight, high specific stiffness, and high specific strength (Luo, Yan, Meng, & Jin, 2016). For decades, the automotive and aerospace industry has primarily used metal in building structures and compartments to absorb impact energy. However, recent studies have shown that composite materials with polymers and fibres display improved mechanical properties compared to metal, with a fraction of its weight and cost. In terms of crashworthiness, fibre-polymer composites prove to have more efficient energy dissipation around its structure. This is shown by the SEA values determined by quasi-static axial loading tests (Hosseini & Shariati, 2018).

In the pursuit of green and sustainable technology, researches have focused on the application of natural fibres, and also the hybridisation of natural and synthetic fibres. Natural fibres such as banana fibre are by-products from banana fruit plantations, where the stalk necessary for fibre production can be obtained for free after the fruit is harvested. This process not only reduces the manufacturing cost, but also reduces waste generated from banana plantations (Padam et al., 2014).

Apart from the type of material used, trigger mechanisms applied on the structure have also shown to effect the energy absorption of the structure involved (Siromani et al., 2014). Trigger mechanisms have two types, internal and external triggers. These triggers mainly effect the way the loading is distributed within the structure, with trigger spots absorbing varied amounts of energy (Sivagurunathan et al., 2018) Examples of triggers include chamfered trigger, tulip trigger, plug trigger and crush cap trigger. Studies on trigger mechanisms in composite structures show that it significantly improves the SEA of the structures while reducing overall weight (Eshkoor et al., 2013).

1.2 Problem Statement

As the automotive and aerospace industry expands, the attention on building material is shifting from metals to composite polymers. This is because metals not only cost more, but they also add to the overall weight of the structure. Metals also present the problem of unsuitable mechanical properties. Moreover, the use of metals causes the build-up of rust, which will affect the performance of the structure or mechanism involved.

Alternative materials that behave better under loading are being focused on. One such alternative is using composite structures reinforced with fibres.

Extensive research has been conducted on plant fibres mainly due to the inexhaustible supply of plant-based materials. Plant fibres such as kenaf, hemp, and jute are used in numerous studies to test its mechanical properties as a suitable replacement for metal (Alia, Cantwell, Langdon, Yuen, & Nurick, 2014). Synthetic fibres are also in demand, as glass fibre is highly sought after for concrete and composite reinforcement. Specifically, fibres are used to produce fibre reinforced composites (FRC) as metal substitutes for structures and mechanisms. However, these composites exhibit poor energy absorption levels and undergo catastrophic failure when placed under quasi-static axial loading (Jackson et al., 2011). Many factors can affect the failure modes and specific energy absorption (SEA) values obtained by the composites, such as fibre to weight ratio, type of fibre used, fibre orientation, moulding pressure and trigger mechanisms. Studies are required to improve the FRC energy absorption capability.

1.3 Objectives

The objectives of the current research are:

a) To study the crushing behaviour of the fibre reinforced composites with different triggering mechanisms by applying a quasi-static axial crushing test.

b) To study the effects of varying fibre-lay-up on the crushing behaviour of the fibre reinforced composites.

1.4 Scope of Project

The research is divided to two parts. The first part comprises of the fabrication process of the fibre reinforced composites, and the second part focuses on the quasi-static axial crush testing of the FRC components.

For the fabrication of the composites, bladder assisted moulding method is used. Glass fibre (G) and banana fibre (B) will be used to fabricate the composite tubes. Initially, specimens will be fabricated with different fibre lay-up sequences. Internal trigger mechanisms such as chamfered triggers and tulip triggers will then be fabricated. The second phase of the research is the testing phase, where the composite tubes produced will undergo a quasi-static axial loading crush test.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will focus on the concept of crashworthiness and energy absorption, as well as the factors that influence these values in related literature works. Some of those factors are triggering mechanisms, fibre stacking and geometrical parameters. Before the application of composite materials, metal tubes were heavily and extensively researched to determine their crashworthiness and energy absorbing capabilities in high impact situations. However, metals proved to be heavy and expensive to acquire, as well as laborious in terms of fabrication and machining. Years of research prove that fibre reinforced composite structures were cheaper, easier to fabricate and much more efficient in terms of its crashworthiness and energy absorbing abilities.

2.2 Energy Absorption Classification

Energy absorption represents the rate of which energy can be dissipated in a specimen in the event of a crush. A high value of energy absorption indicates that a specimen is very efficient in uniformly propagating energy when exposed to loading. However, this parameter does not indicate the specimen's efficiency in terms of vibration dampening, buckling resistance, and other mechanical properties (Stamenovic et.al., 2011).

In a quasi-static crushing test, peak load (P_{max}) is denoted as the first maximum value or initial peak of load value in the load vs deformation graph. This value represents the highest value of load the specimen achieves before entering plastic deformation or post-crushing zone.

Mean load (P_{mean}) is the average load sustained by the specimen while the crushing process is in the post-crushing zone. It is determined by the total accumulated load in the post-crushing zone divided by the distance of crushing in the same region, expressed in Eq (2.1):

$$P_{mean} = \frac{\int_0^{l_{max}} P(l)dl}{l_{max}} \quad (2.1)$$

where l_{max} is the maximum crushing distance of specimen before compaction zone and $P(l)$ is the area under the graph of load vs deformation.

Energy absorption can also be quantified in the form of specific energy absorption (SEA), which is the amount of absorbed energy per unit mass of crushed material and evaluated as in Eq. (2.2)

$$SEA = \frac{\int_0^{l_{max}} P(l)dl}{m} \quad (2.2)$$

where m is the mass of crushed specimen.

Crush force efficiency (CFE) compares the performance of specimen as a ration of the mean load to the peak load. Values closer or higher than unity are favourable, thus indicating a stable and progressive crushing process (Palanivelu et al., 2011). CFE is described in Eq (2.3) as:

$$CFE = \frac{P_{mean}}{P_{max}} \tag{2.3}$$

The ranking of parameters by decreasing priority in determining energy absorbing characteristics are specific energy absorption, mean load, peak load and lastly crush force efficiency. SEA is regarded as priority as it is normalised with the weight of specimen, giving an accurate measure of absorbed force per kilogram of specimen.

To test the static loading capacity of a specimen, it must undergo a quasi-static crushing test. This test involves the specimen placed in between two steel platens of a hydraulic press. The upper platen is then lowered typically at a low cross head speed, between 1mm/s and 20mm/s depending on the material crushed. Quasi static crushing/loading tests are commonly used to observe the behaviour of a sample in terms of axial compression. The crushing behaviour, coupled with the SEA value obtained, determines the failure mode as well as the suitability of the sample in handling that load (Sivagurunathan et al., 2018)

From the crushing test. A graph of load vs deformation/displacement will be obtained, as seen in Figure 2.1. The region after peak load is regarded as the post-crushing zone and is where most energy absorption parameters are observed. This region extends to the beginning of compaction zone as seen in Figure 2.1. By using the load vs displacement graph, Figure 2.2 shows the common failure modes experienced by composites (Kaneko et al., 2017). Development of peaks in the post-crushing region indicate progressive folding happening to the composite. A relatively stable load value after achieving peak load is a sign of progressive crushing in the composite specimen.

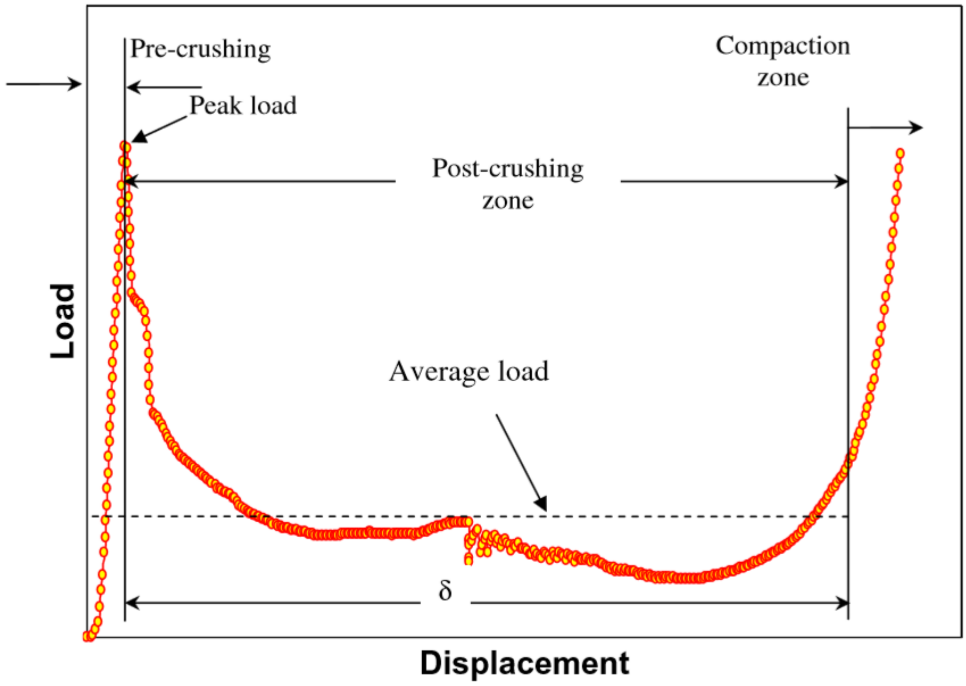

Figure 2.1: A typical load vs displacement graph of a quasi-static crushing test (Ataollahi et al., 2012)

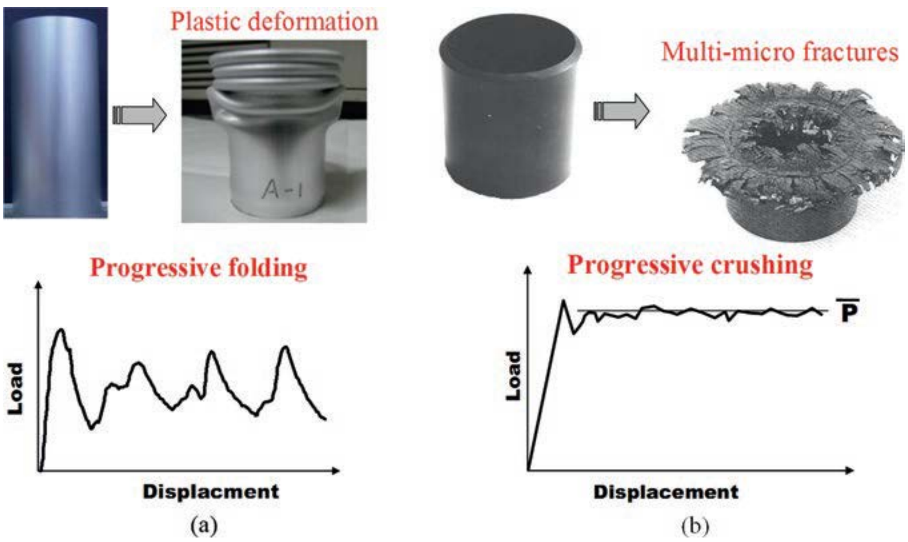

Figure 2.2: Examples of load vs displacement graph in a (a) progressive folding and (b) progressive crushing situation (Kaneko et al., 2017)

2.3 Fabrication Method

The application of composites has existed for over 500 years, dating back to time when Egyptians used mud and straw as composite construction blocks for added durability and strength. In the current age, there are many more advanced processes to fabricate composites, especially involving fibres as reinforcement. These new methods push the mechanical properties of composites to the maximum, where their mechanical properties can now rival that of metal.

2.3.1 Hand Lay-Up

One of the earlier methods that is still being used today is hand lay-up. This technique involves manual stacking of the fibre layers, while coating each stacked layer with the binding matrix. Once every layer is placed on the shaped mould, a roller is used to press the layer, as seen in Figure 2.3. This not only removes any trapped air bubbles between layers, but also ensures that the coating of binding matrix is even and uniform throughout the surface. Hand lay-up method is cheap, easy, and versatile in terms of shaping and forming the desired product. However, it requires large amounts of labour hours, especially for detailed or large-scale products (S. Y. Kim, Shim, Sturtevant, Kim, & Song, 2014).