UNIVERSITI PUTRA MALAYSIA

CRUSHING BEHAVIOR OF HEXAGONAL COMPOSITE TUBES

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By

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

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DEDICATION

This work is dedicated

To my family

Parents brothers sister and to my wife and daughter

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in partial fulfillment of the partial requirements for the degree of Master of Science

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Faculty: Engineering

An experimental and finite element analysis was carried out to investigate effect of hexagonal composite tube dimension on failure mode and energy absorption capability. Throughout this investigation, the hexagonal tube with different aspect ratio of length to thickness (L/t) varying from 30 to 100 and different hexagonal angles varying from 35° to 60° in 5° increments were investigated under the axial load condition. All the hexagonal tubes tested were fabricated from fabric plain weave /epoxy.

The effect of hexagonal geometry on the load carrying capacity and energy absorption capability was presented. A finite element model to predict the load carrying capacity, deformation mesh, stress contours at pre-crush stage of hexagonal tube under an axial load condition were developed.

Experimental results show that the hexagonal geometry (length to side diminutions) increases the load carrying capacity by 32.0, 13.8, 2.1and 18.7٪ respectively for hexagonal side angle of 35˚, 45˚, 50˚, and 55˚ respectively, the load carrying capacity is reduce by 49.6 and 29.6٪ for hexagonal side angles of 40˚and 60˚repectively. The energy absorption also increases by 1.42 and 1.5 ٪ for hexagonal side angles of 35˚ and 60˚respectivelyand energy absorption is reduced by 48.6, 11.6, 20.0and 46,7٪ respectively for hexagonal side angle of 40˚, 45˚, 50˚ and 55˚ respectively. Finite element model predictions are correlated with experimental results. The variation between the experimental and finite element is in the range of 5.9٪ to 9.8٪ .The effect of geometry of fabric plain weave/epoxy (Ring Chain System With Hexagonal Shape) on crushing behavior, energy absorption capability, crush failure loads and failure modes were also investigated.

Failure modes were examined using several photographs taken during the crushing stages for each experiment. The main failures modes that occured during the experiment are local buckling, catastrophic and matrix failure modes.

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

KELAKUAN PENGHANCURAN BAGI TIUB KOMPOSIT HEKSAGON

Oleh

MUNIR FARAJ M. ALKABIR

Mac 2004

Pengerusi: Profesor Madya Abdel Magid Salem Hamouda, Ph.D.

Fakulti : Kejuruteraan

Satu eksperimen dan analisis unsur terhingga telah dijalankan bagi mengkaji kesan dimensi tiub komposit heksagon ke atas ragam kegagalan dan keupayaan penyerapan tenaga. Sepanjang kajian ini, tiub heksagon dengan nisbah bidang yang berbeza bagi panjang lawan ketebalan (L/t) berubah daripada 30 kepada 100 dan sudut-sudut heksagon yang berbeza berubah daripada 35° kepada 60° pada tokokan 5° telah dikaji di bawah keadaan beban paksian.

Kesemua tiub heksagon yang diuji telah dibikin daripada jalinan biasa fabrik/epoksi. Kesan geometri heksagon ke atas keupayaan membawa beban dan keupayaan penyerapan tenaga telah dipersembahkan. Satu model unsur terhingga bagi meramal keupayaan membawa beban, jejaring ubah bentuk dan kontor-kontor tegasan pada tahap pra-hancur bagi tiub heksagon di bawah keadaan beban paksian telah dibangunkan.

Keputusan-keputusan eksperimen menunjukkan bahawa geometri heksagon (panjang lawan pengecilan sisi) menambah keupayan membawa beban sebanyak 32.0, 13.8, 2.1

dan 18.7 bagi sudut sisi heksagon 35°, 45°, 50° dan 55°. Keupayaan membawa beban telah dikurangkan sebanyak 49.6 dan 29.6 bagi sudut-sudut sisi heksagon 40o dan 60o. Penyerapan tenaga juga bertambah sebanyak 1.4 dan 1.5 bagi sudut-sudut sisi heksagon 35° dan 60° dan penyerapan tenaga telah dikurangkan sebanyak 48.6, 11.6, 20.0 dan 46.7 bagi sudut sisi heksagon 40 °, 45 °, 50 ° dan 55 °. Peramalan-peramalan model unsur terhingga telah dikorelasi dengan keputusan-keputusan eksperimen. Variasi antara eksperimen dan unsur terhingga ialah dalam julat 5.9 ke 9.8. Kesan goemetri bagi jalinan biasa fabrik/epoksi (sistem rantai cincin dalam bentuk heksagon) ke atas kelakuan penghancuran, keupayaan menyerap tenaga, beban-beban kegagalan hancur dan ragam-ragam kegagalan telah juga dikaji.

Ragam-ragam kegagalan telah diperiksa menggunakan beberapa gambarfoto yang diambil semasa tahap-tahap penghancuran bagi setiap eksperimen. Ragam-ragam kegagalan yang utama yang berlaku semasa eksperimen adalah lengkokan setempat, ragam kegagalan bencana dan ragam kegagalan matriks.

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A	Cross sectional are of hexagonal tube
A,b,c,t	Dimension of hexagonal tube
CFE	Crush force efficiency
E_S	Specific energy absorption
IFI	Initial failure indicator
L/t	Aspect ration of hexagonal tube
M	Weight of the specimens
S_E	Stroke efficiency
β	Hexagonal angle
(H. Δ L/t. Δ β)	hexagonal tube with different aspect ratio (L/t) different angles varying
P_{cr}	Critical crushing load
P_i	Initial crushing load
P_m	Mean – crushing load

CHAPTER 1

INTRODUCTION

1.1. General Introduction

Materials have such an influence on our lives that the historical period of humankind have been dominated, and named, after materials over the last thirty years, composite materials, plastics, and ceramics have been the dominant emerging materials. The volume and number of applications of composite material has grown steadily, penetrating and conquering new markets (relentlessly).

Composite materials are formed by a combination of two or more materials to achieve properties (physical, chemical, ect) that are superior to those of its constituent. The main components of composite material, or composites, are fiber and matrix. Fiber provides most of the stiffness and strength, and the matrix binds the fiber together thus providing load transfer between fiber and between the composite and the external loads and supports. The matrix is the principal phase in which other constituents (e.g., reinforcement, or fillers) are embedded or surrounding the reinforcement is material used to reinforce, strengthen or give dimensional stability.

The reasons for choosing composites in automotive applications include lower weight and greater durability (improved corrosion resistance, fatigue life, wear and impact resistance). Applications include drive shafts, fan blades, tires, brake shoes, clutch plates, gaskets, hoses, belts, and engine parts hybrid composite drive shaft for trucks manufactured by pultrusion where carbon and glass fiber composite are pultuded over aluminum cylinder to create a drive shaft that is significantly lighter and less expensive.

The use of advanced composites in structures such as bridges and buildings has lagged behind applications in other areas. One major reason for this is that weight is not an important consideration in static structures. However, as the benefits of reduced. An interesting example is the use of maintenance and erection costs combine with architectural enhancements are recognized, the application of composite in these structures will follow. Composites are also in use in lightweight overhead walkways, as well as lighting and communications poles [1].

Composite tube is common structural components that can be used for a wide variety of applications. Some of these applications include oil pipelines, trusses for space vehicles and chassis of automobiles. Composite materials offer the stiffness of conventional metal at a lower weight. With this viewpoint, the automotive industry is currently exploring to adapting more fiber reinforced polymer matrix composites into automobile bodies. The amount of energy that vehicle absorbs during a collision is a matter of concern to ensure safer and more reliable vehicles. If composite can be economically manufactured and be made to offer equivalent energy absorption under impact as metals at a fraction of the weight, the savings to both automakers and consumers would be substantial.

Investigations of crushing energy absorption are important and are expected from the point of view of safety design of passenger vehicles. In order to reduce the damage to occupants in a collision, it necessary to understand the crushing behavior and to enhance the energy absorbing capability of tubular structures [2]. In passenger vehicles the ability to absorb impact energy and be survivable for the occupant is called the "crashworthiness" of the structure. This absorption of energy is through controlled failure mechanisms and modes that enable the maintenance of a gradual decay in the load profile [3].

Usually the experimental analysis is more common, but finite element also is getting a great attention for its quick results. The effect of the number of layers, type of the fiber, type of the matrix and fiber orientation angles were the common features which are usually evaluated for each structure by developing the load-displacement and energy absorption relation. Several researches were carried out on composite materials and structures to evaluate their properties, strength, and behavior structures including cylinders plats, and cones, which were tested experimentally and theoretically.

Throughout this investigation, the investigation of energy absorption capability in hexagonal composite tube is carried out experimentally and numerically under an axial crashing load by using the finite element method. Also, the experimental validation has been done in the crushing behavior of composite hexagonally ring system under lateral cashing load. The effects of mandrel geometry on crashworthiness performance of fabric plain weave /epoxy hexagonal tubes and ring chain system and their effects on energy absorption capabilities have been observed.

1.2 Research Objectives

The main objectives of this work are:

- To study the effects of geometry of hexagonal composite tube and ring chain systems with hexagonal shape on crushing behavior.
- To investigate the energy absorption capability of hexagonal composite tubes and ring chain system with hexagonal shape

1.3 Significance of the Study

- Composite materials are rapidly becoming potential substitutes for metal due to their higher strength and stiffness-to-weight ratio, improved corrosion resistance, styling enhancement and the reeducation of fabrication maintenance costs.
- The efficient use of hexagonal composite tubes as energy absorber depends on the understanding of their crushing behavior.

- The generated data from this study can be useful in design phase of energy absorber element made from composite material.

1.4 Thesis Layout

This thesis is divided into seven chapters. Following this introduction Chapter, chapter two presents a review of literature related to matrix and reinforcement, advantages and Classification of composite material. Crushing behavior and energy absorption characteristics of composite structures are also discussed. The methodology used in this study is explained in chapter three. Chapter four presents the experimental results. Finite element results are presented and discussed in chapter five. Finally in chapter six, conclusion from the work and the proposal for future studies are listed

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, literatures related to composite materials are reviewed. Attention is directed towards, fabrication methods, energy absorption capability in composite material, crushing modes and mechanisms and crashworthiness parameters in composite materials are discussed in details.

2.2 Composite Materials

The general definition of composite material is very closely related to the dictionary definition of the word composite, meaning made up of different parts or materials. Composite materials are constructed from two or more materials, commonly referred to as constituents, and have characteristics derived from the individual constituents. Depending on the manner in which the constituents are put together the resulting composite material may have the combined characteristics of the constituents, this according to Gurdal, and Hajela [4].