UNIVERSITI PUTRA MALAYSIA

AXIAL AND LATERAL CRUSHING OF ELLIPTICAL COMPOSITE TUBES

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ITMA 2003 4

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By

OMAR M. SALEH ALKOLES

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

June 2003

This work is dedicated

To my family

Parents brother sisters and to my wife sons and daughter

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

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Faculty: Institute of Advanced Technology

Reduce structural weight, design flexibility, and improved structure safety, are the features offered by composite materials. Composite materials provide higher or equivalent crash resistance as compared with their metallic counterparts and therefore find use in applications involving crash. The design of various transport vehicles like automobiles and aircraft for crashworthiness, required collapse behaviour of structural component and energy absorption characteristics

An experimental and computational study of woven roving composite circular and elliptical cross section subjected to quasi-static axial and lateral-loading conditions was carried out in this project. Composite tubes with different ellipticity ratio a/b from 1.00 to 2.00 were investigated under three different loading conditions. The effect of geometry and loading condition on the load carrying capacity, energy

effect of geometry and loading condition on the load carrying capacity, energy absorption capability and their failure mechanism histories are presented and discussed. Finite element models were developed to predict the load carrying capacity, failure mechanism, deformed shapes and stress contours of composite elliptical tubes under different loading conditions.

From the Experimental result, the ellipticity ratio significantly affects the load carrying capacity and the energy absorption capability of the tubes on both three loading conditions. The tubes subjected to axial loading condition showed a stable load deformation curve, higher initial failure load and higher energy absorption capability, compared to the tubes subjected to lateral loading conditions. Experimental result for tubes under axial load show that the tube with ellipticity ratio of a/b=1.00 has the highest initial crush failure load of 42.45 kN, tubes with ellipticity ratio a/b= 1.25, 1.50, 1.75, and 2.00 have the initial failure load of 40.65 kN, 40.45 kN, 36.65 kN, and 36.46 kN respectively.

Under lateral loading condition (LW) the tube with ellipticity ratio a/b=2.00 has the highest initial crush failure load of 1768 N, and has the highest specific energy absorption of 0.70 kJ/kg, the initial crush failure load for the tubes with ellipticity ratio a/b=1.75, 1.50, 1.25, and a/b=1.00 are 1545 N, 1060N, 922 N, and 873 N respectively.

For specimens loaded on lateral side (LN) show that the tube with ellipticity ratio a/b=2.00 has the highest initial crush failure load of 1480 N, and has the highest specific energy absorption of 0.69 kJ/kg, the initial crush failure load for the tubes with ellipticity ratio a/b=1.75, 1.50, 1.25, and a/b=1.00 are 1561 N, 1074 N, 912N, and 873 N respectively.

Finite element simulation predicts the initial failure load and the deformed shapes. The result for tubes under axial load show that tube with ellipticity ratio of a/b=1.00 has the highest initial crush failure load of 49.50 kN, tubes with ellipticity ratio a/b= 1.25, 1.50, 1.75, and 2.00 have the initial failure load of 45.40 kN, 41.30 kN, 36.40 kN, and 32.70 kN respectively.

For lateral loading (LW) the tube with ellipticity ratio a/b=2.00 has the highest initial crush failure load of 2915 N, the initial crush failure load for the tubes with ellipticity ratio a/b=1.75, 1.50, 1.25, and a/b=1.00 are 2657 N, 2232 N, 1805 N, and 1377N respectively.

For Lateral loaded on narrow side (LN) the tube with ellipticity ratio a/b=2.00 **has** the highest initial crush failure load of 2150 N, the tubes with ellipticity ratio a/b=1.75, 1.50, 1.25, and a/b=1.00 have initial crush failure load of 1821 N, 1604 N, 1617 N, and 1377 N respectively.

Finite element model predictions are correlated with the experimental results. Because of the imperfection in the real tubes is not considering in the finite element model, there is different in loads value between experiment and simulation. In general predictions are quite good.

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

HENTAMAN SECARA MENEGAK DAN SISI KE ATAS TIUB KOMPOSIT ELIPS

oleh

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Berat struktur yang berkurangan, fleksibiliti terhadap rekabentuk dan pembaikian keselamatan bagi struktur adalah cirri-siri yang diperkenalkan oleh bahan komposit. Bahan komposit menyediakan rintangan remukan yang tinggi atau setara berbanding dengan bahan logam dan adalah baik bagi kesan hentaman. Rekabentuk kebanyakkan kenderaan dan kapal terbang bagi "crashworthiness" memerlukan sifat remukan oleh komponen struktur dan cirri tenaga penyerapan.

Satu ujikaji dan kajian secara komputer mengenai komposit "woven roving" secara bulatan dan elips yang dikenakan bebanan quai static axial dan lateral telah dijalankandalam projek ini. Tiub komposit dengan nisbah elips a/b yang berbeza dari 1.00 hingga 2.00 telah dikaji dengan tiga jenis bebanan. Kesan geometri dan bebanan tehadap keupayaan beban bawaan,tenaga penyerapan dan mekanisma

kegagalan telah dibincangkan. Elemen tak terhingga telah dibangunkan mengenai keupayaan beban bawaan,tenaga penyerapan, bentuk kegagalan dan kontor tegasan tiub elips dibawah keadaan berbeza .

Daripada keputusan ini, nisbah elips mempengaruhi keupayaan beban bawaan dan tenaga penyerapan pada tiga kondisi bebanan.Tiub dibawah beban axial menunjukkan lengkungan stabil, beban awal yang tinggi dan tenaga penyerapan yang tinggi berbanding dengan tiub dibawah bebanan lateral.

Simulasi elemen tak terhingga menyasarkan kemungkinan beban kegagalan dan bentuk dan disini ia telah menepati ujikaji yang telah dilakukan secara ujikaji. Disebabkan ketidaksempurnaan tuib sebenar berbanding tiub yang telah dibentuk didalam simulasi terdapat nilai yang berbeza. Secara amnya kemungkinan yang dianggarkan adalah baik.

ACKNOWLEDGEMENTS

In the name of Allah, Most Gracious, Most Merciful

الشكر لله سبحانه وتعالى على عظيم فضلة وتوفية لى فى اتمام هذا البحث المتواضع فله الحمد كله والشكر. وكذلك التقدير والمحبة الى ابى وامى الاعزاء لدعائهما لى بالتوفيق والنجاح. و الى زوجتى الفاضله على مابذلتة من جهد وتعب طوال فترة الدراسة.

First by the grace of Allah (sbt), the controller of the whole universe, who has provided me with good health to finish this work in time secondly, I would like to express my sincere gratitude to chairman of the supervisory committee Dr. Elsadig Mahdi for his continuous help and encouragement throughout this work.

I also wish to thank Assoc. Prof. Dr. Abdel-Magid Salem Hamouda and Prof. Ir. Dr. Barkawi Sahari the member of the supervisory committee for their necessary help, guidance and valuable suggestions.

I also wish to express my thanks to my friends in my faculty Institute of Advanced Technology

I am grateful to my country Libya for having offered me scholarship for pursuing the graduate study at university Putra Malaysia. Special thanks go to all the lovely members of my family and relatives with out whose encouragement and overwhelming support this work would not have been possible.

TABLE OF CONTENTS

ABSTRACT	iii
ABSTRAKT	vi
AKNOWLEDGEMENTS	viii
DECLARATION	xi
TABLE OF CONTENTS	xii
LIST OF TABLES	xvi
LIST OF FIGURES	xvii
NOMENCLATURE	xx

CHAPTER

1 INTRODUCTION	1
1.1 Research Objectives	3
1.2 Significance of the Study	4
1.3 Thesis Organization	4
2 LITERATURE REVIEW	
2.1 Composite Materials	5
2.1.1 Glass Fibre	5
2.1.2 Matrix Materials	7
2.1.3 Fabrications Methods of Composite Shells	8
2.1.3.1 Hand Lay-up	8
2.1.3.2 Filament Winding	9
2.1.4 Composite Forms	10
2.1.4.1 Unidirectional Lamina	10
2.1.4.2 Woven Roving Fabrics	10
2.1.4.3 Laminates	11
2.2 Crashworthiness parameters	12
2.2.1 Crush force efficiency (CFE)	12
2.2.2 Stroke efficiency (SE)	12
2.2.3 Definitions of specific energy absorption capability	13
2.3 Previous Work on Crushing Behaviour of Shells	15

2.4 Variables Affecting the Energy absorption Capability 20
2.4.1 Effect of Geometry 20
2.4.2 Effect of Reinforcing Fibre 24
2.4.3 Effect of Fibre Architecture 26
2.5 Discussion 31

3 METHODOLOGY

3.1 Introduction 32
3.2 Experimental Work 33
3.2.1 Design Parameters 34
3.2.2 Materials and Geometry 36
3.2.3 Fabrication Process and Specimens Preparation 38
3.2.4 Loading Condition 40
3.2.5 Test Procedure 40
3.2.5.1 Axial Test (AX) 41
3.2.5.2 Lateral Test (LW) 42
3.2.5.3 Lateral Test (LN) 42
3.3 Finite Element Work 43
3.4 Discussion 44

4 EXPEIMENTAL RESULTS

4.1 Crashworthiness Parameters 45
4.1.1 Initial Failure Indicator 45
4.1.2 Crush Force Efficiency-Stroke Efficiency Relation 46
4.1.3 Energy Absorption Capability 47
4.2 Composite Elliptical Tubes under Axial Crushing Load (AX) 49
4.2.1 Load-Deformation Relation 49
4.2.1.1 Circular Tube with (a/b=1.00) 50
4.2.1.2 Elliptical Tube with (a/b=1.25) 52
4.2.1.3 Elliptical Tube with (a/b=1.50) 52
4.2.1.4 Elliptical Tube with (a/b=1.75) 54
4.2.1.5 Elliptical Tube with (a/b=2.00) 56
4.2.2 Energy-Deformation Relations 57
4.2.3 Failure Modes 58

4.2.3.1 Regular Progressive Failure Mode 60
4.2.3.2 Multi Failure Mode 60
4.2.4 Effect of Ellipticity Ratio on Crushing Behaviour 61
4.2.5 Effect of Ellipticity Ratio on the Load-Carrying Capacity 61
4.2.5.1 Effect of Ellipticity Ratio on the initial failure load 63
4.2.5.2 Effect of Ellipticity Ratio on the Average Crushing Load 63
4.2.6 Effect of Ellipticity Ratio on the Specific Energy 64
4.2.7 Effect of Ellipticity Ratio on Crush Force Efficiency 66
4.2.8 Effect of Ellipticity Ratio on the Stroke Efficiency 66
4.2.9 Summary 67
4.3 Composite Elliptical Tubes Loaded on the Wide Side (LW) 67
4.3.1 Load-Deformation Relations 68
4.3.1.1 Circular Tube With (a/b=1.00) 69
4.3.1.2 Elliptical Tube With (a/b=1.25) 69
4.3.2 Energy-Deformation Relations 75
4.3.3 Failure Modes 76
4.3.4 Effect of Ellipticity Ratio on Crushing Behaviour 82
4.3.4.1 Effect of Ellipticity Ratio on the initial failure load 82
4.3.4.2 Effect of Ellipticity Ratio on the average crushing load 82
4.3.5 Effect of Ellipticity Ratio on the Specific Energy 83
4.3.7 Effect of Ellipticity Ratio on Crush Force Efficiency 84
4.3.8 Effect of Ellipticity Ratio on the Stroke Efficiency 85
4.3.9 Summary 86
4.4 Composite Elliptical Tubes Loaded on the Narrow Side (LN) 86
4.4.1 Load -Deformation Relations 87
4.4.1.1 Elliptical Tube With (a/b=1.25) 88
4.4.1.2 Elliptical Tube With (a/b=1.50) 88
4.4.1.3 Elliptical Tube With (a/b=1.75) 89
4.4.1.4 Elliptical Tube With (a/b=2.00) 89
4.4.2 Energy- Deformation Relations 94
4.4.3 Failure Modes 95
4.4.4 Effect of Ellipticity Ratio on Crushing Behaviour 100
4.4.4.1 Effect of Ellipticity Ratio On the initial failure load 100
4.4.4.2 Effect of Ellipticity Ratio On the average crushing load 101

4.4.5 Effect of Ellipticity Ratio on the Specific Energy 102
4.4.6 Effect of Ellipticity Ratio on Crush Force Efficiency 103
4.4.7 Effect of Ellipticity Ratio on the Stroke Efficiency 103
4.4.8 Summary 104
4.5 Effect of Loading Conditions 104
4.6 Discussion 107

5 FINITE ELEMENT RESULTS

5.1 Finite Element Simulation 109
5.2 Model Development 110
5.3 Material Properties 114
5.4 Circular and Elliptical Tubes under Axial Load (AX) 116
5.4.1 Prediction of Crush Failure Loads 116
5.5 Circular and Elliptical Tubes under Lateral Load on the Wide (LW) 120
5.5.1 Prediction of Crush Failure Loads 120
5.6 Circular and Elliptical Tubes under Lateral Load on the Narrow (LN) 122
5.6.1 Prediction of Crush Failure Loads 122
5.7 Discussion 124

6 OVERALL DISCUSSION

6.1 Effects of Ellipticity Ratio and Loading Condition 125
6.2 Comparison between Experimental and Finite Element Method 126
6.3 Conclusion 127

7 CONCLUSION AND RECOMENDATION

7.1 Elliptical Tubes under Axial Crushing Load (AX) 128
7.2 Elliptical Tubes under Lateral Crushing Load (LW) 129
7.3 Elliptical Tubes under Lateral Crushing Load (LN) 129
7.4 Finite Element Analysis 130
7.5 Suggestion for Further Work 130

REFERENCES 132

VITA 139

LIST OF TABLES

Table		Page
2.1	Specific energy absorption values of materials	30
3.1	Description of the woven roving elliptical composite tubes	37
3.2	Type of material and matrix	38
3.3	Specimen's Identification	40
4.1	Measured crashworthiness parameters of axial loading (AX)	67
4.2	Measured crashworthiness parameters of lateral loading (LW)	86
4.3	Measured crashworthiness parameters of lateral loading (LN)	104
5.1	Typical engineering properties of constituent materials	115
5.2	Comparison between Predicted and experimental critical axial crush load	119
5.3	Comparison between Predicted and experimental critical lateral crush load	122
5.4	Comparison between Predicted and experimental lateral critical crush load	123

LIST OF FIGURES

Figure		Page
2.1	Different fibre architectures	7
2.2	Unidirectional lamina	10
2.3	Glass fibre woven fabric	11
2.4	Unidirectional composite laminate	11
2.5	Typical load-displacement curve of composite tube specimen	14
2.6	Axial collapse of metallic tube	16
2.7	Initial average failure load, specific crushing energy and structural volume	19
3.1	Flow chart describes the methodology used in study	33
3.2	Flow chart describes the experimental work	35
3.3	Composite elliptical tube	37
3.4	Cross-sectional area	37
3.5	Schematic presentation of fabrication process	39
3.6	Elliptical tubes with various ellipticity ratio	39
3.7	Load-displacement curve of three specimens with a/b =1.00	41
3.8	Schematic presentation different loading conditions	42
3.9	Flow chart describes the finite element work	43
4.1	Load-deformation relations of composite elliptical tubes under axial load	50
4.2	Crushing history for axially loaded tube with ellipticity ratio a/b=1.00	51
4.3	Crushing history for axially loaded tube with ellipticity ratio a/b=1.25	53
4.4	Crushing history for axially loaded tube with ellipticity ratio a/b=1.50	54
4.5	Crushing history for axially loaded tube with ellipticity ratio a/b=1.75	55
4.6	Crushing history for axially loaded tube with ellipticity ratio a/b=2.00	57
4.7	Energy-deformation relation of composite elliptical tubes under axial load	58
4.8	Optical micrograph of section through the crush zone for axially crushed tubes	59
4.9	Crush stress-stroke efficiency curves of composite elliptical tubes	62
4.10	Crashworthiness parameters of composite elliptical tubes	63
4.11	Crushing load as a function of the ellipticity ratio a/b	64
4.12	Specific energy absorption-deformation curves of elliptical composite tubes	65

4.13	Crush force efficiency and stroke efficiency as a function of a/b ratio	66
4.14	Crush load- crush stroke for laterally loaded composite tubes on (LW) side	68
4.15	Crushing history for laterally loaded tube on the wide side (LW) a/b=1.00	70
4.16	Crushing history for laterally loaded tube on the wide side (LW) a/b=1.25	71
4.17	Crushing history for laterally loaded tube on the wide side (LW) a/b=1.50	72
4.18	Crushing history for laterally loaded tube on the wide side (LW) a/b=1.75	73
4.19	Crushing history for laterally loaded tube on the wide side (LW) a/b=2.00	74
4.20	Energy -deformation curves for laterally loaded elliptical tubes on (LW) side	75
4.21	Optical micro graph for laterally crushed composite tube on (LW) side a/b 1.00	77
4.22	Optical micro graph for laterally crushed composite tube on (LW) side a/b 1.25	78
4.23	Optical micro graph for laterally crushed composite tube on (LW) side a/b 1.50	79
4.24	Optical micro graph for laterally crushed composite tube on (LW) side a/b 1.75	80
4.25	Optical micro graph for laterally crushed composite tube on (LW) side a/b 2.00	81
4.26	Crashworthiness parameters for laterally loaded elliptical tubes on (LW) side	83
4.27	Specific energy -deformation curves for laterally loaded on (LW) side	84
4.28	Crush force stroke efficiency for laterally loaded elliptical tubes on (LW) side	85
4.29	Crush load-crush stroke curve for laterally loaded elliptical tubes on (LN) side	87
4.30	Crushing history for laterally loaded tube on the narrow (LN) a/b=1.25	90
4.31	Crushing history for laterally loaded tube on the narrow (LN) a/b=1.50	91
4.32	Crushing history for laterally loaded tube on the narrow (LN) a/b=1.75	92
4.33	Crushing history for laterally loaded tube on the narrow (LN) a/b=2.00	93
4.34	Energy -deformation curves for laterally loaded elliptical tubes on (LN)	94
4.35	Optical micro graph for laterally crushed composite tube on (LN) side a/b 1.25	96
4.36	Optical micrograph for laterally crushed composite tube on (LN) side a/b 1. 50	97
4.37	Optical micro graph for laterally crushed composite tube on (LN) side a/b 1.75	98
4.38	Optical micro graph for laterally crushed composite tube on (LN) side a/b 2.00	99
4.39	Crashworthiness parameters for laterally loaded elliptical tubes on (LN)	101
4.40	Specific energy -deformation curves for laterally loaded on (LN)	102
4.41	Crush force efficiency stroke efficiency for laterally loaded on (LN)	103
4.42	Crush force and stroke efficiency curve of elliptical tube with a/b=1.00	105
4.43	Crush force and stroke efficiency curve of elliptical tube with a/b=1.25	105
4.44	Crush force and stroke efficiency curve of elliptical tube with a/b=1.50	106
4.45	Crush force and stroke efficiency curve of elliptical tube with a/b=1.75	106

4.46	Crush force and stroke efficiency curve of elliptical tube a/b=2.00	107
5.1	Flow chart describes the eigen value using finite element analysis	112
5.2	Typical mesh for axially loaded of composite elliptical tube	113
5.3	Typical mesh for laterally loaded of composite elliptical tube on (LW)	113
5.4	Typical mesh for laterally loaded of composite elliptical tube on (LN)	114
5.5	Typical tensile stress-strain curve of composite tubes	115
5.6	Experimental and finite element axially loaded elliptical tube with a/b = 1.00	117
5.7	Experimental and finite element axially loaded elliptical tube with a/b = 1.25	117
5.8	Experimental and finite element axially loaded elliptical tube with a/b = 1.50	118
5.9	Experimental and finite element axially loaded elliptical tube with a/b = 1.75	118
5.10	Experimental and finite element axially loaded elliptical tube with a/b = 2.00	119
5.11	Experimental and finite element laterally loaded on (LW) side with a/b = 1.00	120
5.12	Experimental and finite element laterally loaded on (LW) side with a/b = 1.25	120
5.13	Experimental and finite element laterally loaded on (LW) side with a/b = 1.50	121
5.14	Experimental and finite element laterally loaded on (LW) side with a/b = 1.75	121
5.15	Experimental and finite element laterally loaded on (LW) side with a/b = 2.00	121
5.16	Experimental and finite element for laterally loaded on narrow with a/b = 1.25	122
5.17	Experimental and finite element for laterally loaded on narrow with a/b = 1. 50	123
5.18	Experimental and finite element for laterally loaded on narrow with a/b = 1.75	123
5.19	Experimental and finite element for laterally loaded on narrow with a/b = 2.00	123

NOMENCLATURE

A_1	Cross-section area of the material
A_2	Cross-section area of the structure
h	Height of the tube
t	Thickness of the tube wall
V_i	Initial space volume occupied by the structure
u	The crush distance up to the initiation of material densification
a	Inner major radius
b	Inner minor radius
a/b	Ellipticity ratio
M	Mass of the structure
ρ	Mass density of the structure
P_m	Average crush failure load
P_i	Initial crush failure load
P_{HP}	Highest peak crush failure load
S	Instantaneous deformation
CFE	Crush force efficiency
SE	Stroke efficiency
IFI	Initial failure indicator
Es	Specific energy absorbed per unit area density
E_v	Crushing energy absorbed per unit volume
WRLW	Woven roving laminated wrapped
σ_i	Crush strength at yield
σ_m	Average Crush strength
IEA	Impact energy absorber

CHAPTER 1

INTRODUCTION

The importance of improved safety in automobile and aircraft is evident through increased design requirements. For aerospace application, it is believed that to meet these requirements with increasing the payload efficiency, transport fuselages design started to appear to be constructed from advanced composite materials.

An energy absorber device is designed such that in the event of crash it absorbs impact energy in a controlled manner, such that the net deceleration of the occupants of a car is less than the net deceleration above which irreversible brain damage occurs.

To ensure passenger safety or at least to alleviate severe impact during collision, a highly reliable system is required. Impact energy absorbers (IEA) protect passengers, pedestrians and fragile devices from the effects of sudden impact. This is done by converting the impact energy into many different ranges of deformation energy keeping the peak force exerted on the protected object below the level, which causes damage They must also provide a long deformation path to reduce the deceleration of the protected object. Such IEA will rely solely on a crushable energy absorber to cushion the passenger compartment during impact.

The energy absorption capability of composite devices is significantly influenced by the failure mechanism, which depends on many factors, geometry, constituent material, fabrication process, fibre architecture, and loading conditions.

Crushing behaviour of composite material need to be investigated by performing crushing tests to understand the various variables influences the crushing behaviour and energy absorption capability.

Crushing behaviour and energy absorption of composite structures can be predicted and simulated using numerical methods. In the finite element simulation the cost of experiments is reduced, because of the model parameters can be easily changed whereas it is not achievable experimentally.

From previous work the initial crush failure load was found to have a significant effect on the behaviour of crushing load and failure modes, high initial loads leads to a sharp drop in initial crush load (catastrophic drop) and unstable load-end shortening behaviour. This instability is one of the more critical problems in using fibre composites for crash energy management.

The current research work focuses on the study of the effect of the various variables, which influence the energy absorption capability of composite materials. Most of the experimental work on composite material has been carried out using axisymmetric cylindrical tubes mainly because they are easy to fabricate and their geometry has proven to be one of the most favourable shapes for energy absorption. This geometry is self-stabilising and allows testing of relatively thin-section laminates. The lack of edges along its length reduces the complexity of the boundary conditions and provides consistency throughout the cross section. Moreover, composite cones showed high-energy absorption performance with the advantage of a self-triggering capability.

However, most of the existing data concerns the failure mechanism and energy absorbing characteristics is obtained from the crushing investigations of shell structures with circular, rectangular and square cross-section geometries. In contrast, studies of energy absorption capability as well as the load-carrying capacity of composite elliptical tubes are however still scarce.

1.1 Research Objectives

The main objective of this work is to study the effect of ellipticity ratio on the axial and lateral crushing of composite tube. To investigate experimentally and numerically the effects of loading condition on the crushing behaviour of woven roving glass/epoxy composite elliptical tubes, and the following are the aim of this study

- To investigate the effects of ellipticity ratios and loading conditions on crashworthiness performance
- To study the crushing behaviour of composite elliptical tubes.
- To examine the energy absorption capability of tubes

1.2 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 reduction of fabrication and maintenance costs.
- The efficient use of composite tubes as energy absorber depends on the understanding of their crushing behaviour.
- The generated data from this study can be useful in the design phase of energy absorber elements made from composite materials.

1.3 Thesis Organization

The thesis is divided into seven chapters. Following this Introduction Chapter, Chapter Two introduces the Literature review. The Third Chapter is the methodology, in this Chapter the experimental work and finite element simulation is described and discussed, Chapter Four present and discussed the experimental result. Finite element results presented and discussed in Chapter Five. Chapter Six the Overall discussion is presented. Finally in Chapter Seven, conclusion from the work and the proposal for future studies are listed.