



UNIVERSITI PUTRA MALAYSIA

**CRUSHING BEHAVIOUR OF WOVEN ROVING
GLASS FIBRE/EPOXY LAMINATED COMPOSITE
RECTANGULAR TUBES SUBJECTED TO 'QUASI-STATIC
COMPRESSIVE LOAD**

FAYIZ Y. M. ABU KHADRA

ITMA 2002 1

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LAMINATED COMPOSITE RECTANGULAR TUBES SUBJECTED TO
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By

FAYIZ Y. M. ABU KHADRA

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfillment of the Requirement for the Degree of Master of Science**

November 2002



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

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November 2002

Chairman: Associate Professor Abdel Magid Salem Hamouda, Ph.D.

Faculty: Institute of Advanced Technology

The automotive industry is exploring to adapting more fibre reinforced composite materials due to their stiffness to weight ratio. The amount of energy that a vehicle absorbs during a collision is a matter of concern to ensure safer and more reliable vehicle. The efficient use of composite material in the field of crashworthiness depends on the understanding of how a composite member absorbs and dissipates energy during the event of an impact.

An experimental and finite element investigation of the woven roving glass fibre/epoxy laminated composite rectangular tubes subjected to compressive loading were carried out under compressive loading. Through out this investigation, rectangular tubes with different cross-sectional aspect ratio varying (a/b) from 1 to 2 with 0.25 increment were investigated under axial and lateral loading conditions applied independently. The effects of increasing the cross-sectional aspect ratio on the load carrying capacity and the energy absorption capability were also presented and discussed. Finite element models to predict the load carrying capacity, failure



mechanism and stress contours at pre-crush stage of the rectangular tubes under axial and lateral loading conditions have been developed.

Experimental results show that the cross-sectional aspect ratio significantly affects the load carrying capacity and the energy absorption capability of the tubes. The axially loaded rectangular tubes have better load carrying capacity and energy absorption capability compared to the laterally loaded rectangular tubes. The buckling failure mode has been identified for the rectangular tubes under the different loading conditions.

The developed finite element models approximately predict the initial failure load and the deformed shapes. The discrepancy between the finite element prediction and the experimental results is due to the assumption made in the finite element models and not considering the imperfection of the real tubes in the finite element models. From the experimental and finite element results 'knockdown' factors have been proposed to be used in the design phase of energy absorption elements to predict the initial failure load.

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

**PENYIASATAN KEATAS RECTANGULAR KAPAS/EPOKSI YANG
DIBAWAH BEBAN MAMPTAN PAKSI**

Oleh

FAYIZ Y. M. ABU KHADRA

November 2002

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

Fakulti: Institut Teknologi Maju

Disebakan oleh nisbah stiffness teradap berat, industri automotif kini mencari dan mengadaptasikan kegunaan bahan komposit bergentian. Jumlah tenaga yang diserap ketika perlanggaran adalah perkara yang dititikberatkan bagi menentukan tahap keselamatan di dalam bidang ini bergantung kepada pemahaman bagaimana member komposit tersebut menyerap dan menyelerakan tenaga impak.

Pada penyiasatan ini, didapati rectangular tubes dengan nisban aspek keratan rentas meliputi dari julat 1 hingga 2 dengan 0.25 increment telah diselidiki dibawah bebanan axial dan lateral. Kesan daripada kenaikan nisbah aspek keratan rentas tersebut ialah pada kapasiti beban bawaan dan keupayaan penyerapan tenaga. Model elemen tidak terhingga digunakan untuk menganggar kapasiti beban bawaan. Mekanisma kegagalan dan kontour stress didapati pada keadaan remukan rectangular tubes model.

Elemen tidak terHINGGA yang telah di bentuk secara tepat telah menggunakan initial failure load dan kecacatan bentuk. Ketidak seragaman diantara elemen tidak terHINGGA dan keputsan ujikaji adalah disebarakan dan andaian yang dibuat adalah pada model elemen tidak terHINGGA dan tidak mengambil kira ketidak sempurnaan of the real tubes dalam model tersebut.

Daripada keputusan dan permodelan ini 'knockdown' faktor telah dicadangkan untuk kegunaan fasa rekabentuk keupayaan penyerapan elemen untuk menganggar kegagalan beban permulaan.

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I certify that an Examination Committee met on 12th November 2002 to conduct the final examination of Fayiz Y. M. Abu Khadra on his Master of Science thesis entitled “Crushing Behaviour of Woven Roving Glass Fibre/Epoxy Laminated Composite Rectangular Tubes Subjected to Quasi-static Compressive Load” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Megat Mohamad Hamdan Megat Ahmad, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abdel Magid Salem Hamouda, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Barkawi Bin Sahari, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Elsadig Mahdi Ahmed, Ph.D.

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)



SHAMSHER MOHAMAD RAMADILI, Ph.D,
Professor / Deputy Dean,
School of Graduate Studies,
Universiti Putra Malaysia

Date **31** DEC 2002

This thesis submitted to the senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirements for the degree of Master of Science. The members of the Supervisory Committee are as follows:

Abdel Magid Salem Hamouda, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Barkawi Bin Sahari, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Elsadig Mahdi Ahmed, Ph.D.

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)



AINI IDERS, Ph.D.

Professor / Dean
School of Graduate studies,
Universiti Putra Malaysia

Date: **13** FEB 2003

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



Fayiz Y. M. Abu Khadra

Date: 27/12/2002

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xv
LIST OF FIGURE	xvi
NOMENCLATURE	xxi
CHAPTER	
1 INTRODUCTION	1
1.1 Research Objectives	3
1.2 Significance of the Study	4
2 LITERATURE REVIEW	5
2.1 Composite Materials	5
2.1.1 Glass Fiber	5
2.1.2 Matrix Materials	7
2.1.3 Fabrications Methods of Composite Shells	8
2.3.3.1 Hand Lay-up	9
2.1.3.2 Filament Winding	9
2.2 Mechanics of Composite Materials	10
2.2.1 Isotropic Linear Elastic Materials	10
2.2.2 Anisotropic Materials	12
2.2.3 Transformation of Axes	14
2.2.4 Transformed Reduced Stiffness	16
2.2.5 Classical Lamination Theory	17
2.2.6 Laminate Stiffness: The ABD Matrix	18
2.3 Energy Absorption in Composite Materials	22
2.3.1 Crashworthiness Parameters	24
2.3.1.1 Load-Carrying Capacity	25
2.3.1.2 Energy Absorption Capability	26
2.3.2 Crushing Behaviour of Composite Materials and Failure Modes	27
2.3.3 Variables Affecting the Energy Absorption Capability	33
2.3.3.1 Structural Geometry	33
2.3.3.2 Microstructural Variables	38
2.3.3.3 Loading Conditions	41
2.4 Discussion	42
2.5 Summary	43
3 METHODOLOGY	44
3.1 Experimental work	46
3.2.1 Geometry	48



3.2.2	Materials	49
3.2.3	Fabrication Process	50
3.2.4	Loading Conditions	52
3.2.5	Test Procedure	53
3.3	Finite Element work	54
3.4	Discussion	55
4	EXPERIMENTAL WORK	56
4.1	Axially Loaded Composite Rectangular Tubes	56
4.1.1	Load-Displacement Relations	57
4.1.2	Energy-Displacement Relations	58
4.1.3	Crushing History and Failure Modes	60
4.1.4	Effect of the a/b Ratio on the Load Carrying Capacity of the Tubes	62
4.1.4.1	Effect of the a/b Ratio on the Initial Crushing load	62
4.1.4.2	Effect of the a/b ratio on the Average Crushing load	63
4.1.5	Effect of the a/b Ratio on the Energy absorption Capability of the Tubes	64
4.1.5.1	Effect of the a/b Ratio on the Energy Absorbed in the Pre-crush Stage	64
4.1.5.2	Effect of Cross-sectional Aspect Ratio on the Total Energy Absorbed	65
4.1.5.3	Effect of Cross-sectional Aspect Ratio on the Specific Energy	66
4.1.5.4	Effect of Cross-sectional Aspect Ratio on Crush Force Efficiency	66
4.1.5.4	Effect of Cross-sectional Aspect Ratio on the Stroke Efficiency	67
4.1.6	Summary	69
4.1.7	Conclusions	69
4.2	Laterally loaded Rectangular Tubes on the 'A' Side	70
4.2.1	Load-Displacement Relations	70
4.2.2	Energy-Displacement Relations	72
4.2.3	Crushing History and Failure Modes	73
4.2.4	Effect of the a/b Ratio on the Load Carrying Capacity of the Tubes	79
4.2.4.1	Effect of the a/b ratio on the Initial crushing load	79
4.2.4.2	Effect of the a/b ratio on the Average crushing load	80
4.2.5	Effect of the a/b Ratio on the Energy Absorption Capability of the Tubes	80
4.2.5.1	Effect of the a/b Ratio on the Total Energy Absorbed	80
4.2.5.2	Effect of the a/b Ratio on the Energy Absorbed in the Pre-crush Region	80
4.2.5.3	Effect of the a/b Ratio on the Specific Energy	82
4.2.5.4	Effect of the a/b Ratio on the Crush Force Efficiency	82

4.2.6	Summary	85
4.2.7	Conclusions	85
4.3	Laterally loaded Rectangular Tubes on the 'B' Side	86
4.3.1	Load-Displacement Relations	86
4.3.2	Energy-Displacement Relations	88
4.3.3	Crushing History and Failure Modes	89
4.3.4	Effect of the Cross-sectional Aspect Ratio on the load Carrying Capacity of the tubes	92
4.3.4.1	Effect of the cross-sectional Aspect Ratio on the Initial Crushing load	92
4.3.4.2	Effect of the a/b ratio on the Average Crushing Load	93
4.3.5	Effect of the Cross-sectional Aspect Ratio a/b on the Energy Absorption Capability	94
4.3.5.1	Effect of the a/b ratio on the Total Energy Absorbed	94
4.3.5.2	Effect of the a/b Ratio on the Specific Energy	94
4.3.5.3	Effect of the a/b Ratio on the Crush Force Efficiency	96
4.3.6	Summary	96
4.3.7	Conclusions	97
5	FINITE ELEMENT WORK	98
5.1	Modelling Composite Materials Using the ANSYS Finite Element Software	98
5.2	Axially loaded Rectangular Tubes	101
5.2.1	Finite Element Model	101
5.2.2	Finite Element Results and Comparison with the Experimental Results	102
5.3	Rectangular tubes under Lateral load on the 'A' side	106
5.3.1	Finite Element Model	106
5.3.2	Finite Element Results and Comparison with the Experimental Results	107
5.4	Rectangular tubes under Lateral load on the 'B' side	110
5.4.1	Finite Element Model	110
5.4.2	Finite Element Results and Comparison with the Experimental Results	111
5.5	Conclusions	114
6	OVERALL DISCUSSION	115
6.1	Experimental Work	115
6.2	Finite Element Results	117
6.3	Conclusion	119
7	CONCLUSIONS AND FUTURE WORKS	120
7.1	Quasi-static Axial Crushing of the Rectangular Tubes	120
7.2	Quasi-static Lateral Crushing on the 'A' Side	121
7.3	Quasi-static Lateral Crushing on the 'B' Side	122
7.4	Effect of the Loading Conditions	122
7.5	Finite Element Analysis	123

7.6	Suggestions for Further Work	124
	REFERENCES	126
	BIODATA OF THE AUTHOR	130



LIST OF TABLES

Table		Page
3.1	Description of the Woven Roving Rectangular Tubes	49
3.2	Specimens Identifications	52
4.1	Crashworthiness parameters for axially loaded tubes	69
4.2	Crashworthiness Parameters for laterally loaded rectangular tubes on the 'A' side	85
4.3	Crashworthiness parameters for laterally loaded tubes on the 'B' side	98
5.1	Results of the FEM eigenvalue analysis for axially loaded tubes	103
5.2	Results of the FEM eigenvalue analysis for laterally loaded tubes on the 'A' side	108
5.3	Results of the FEM eigenvalue analysis for laterally loaded tubes on the 'B' side	112



LIST OF FIGURES

Figure		Page
2.1	Different fibre architectures	7
2.2	An orthotropic material	12
2.3	Rotation of axes	15
2.4	Definition of force resultants N_x , N_y , and N_{xy}	19
2.5	Definition of moment resultants M_x , M_y , and M_{xy}	20
2.6	Laminate nomenclature	21
2.7	Flow chart describe steps for a stress analysis for a composite laminate	23
2.8	Schematic presentation of the load-displacement curve for a composite material under axial crush condition	24
2.9	Various failures at different scales	29
2.10	Transverse shearing crushing mode	30
2.11	Lamina Bending crushing mode	31
2.12	Local buckling crushing mode	32
2.13	Various variables that influence Energy absorption capability of composite materials	34
3.1	Flow chart describes the methodology used in the study	45
3.2	Flow chart describes the experimental work	47
3.3	Cross-sectional Area	48
3.4	Flow chart describes the fabrication process of the specimens	51
3.5	Schematic presentation of the fabrication process	51
3.5	Rectangular tubes with various cross-sectional aspect ratios	52
3.6	Schematic presentation of the Loading Conditions	53
3.7	Flow chart describes the Finite Element work	54

4.1	Load-displacement relations for axially loaded rectangular tubes with various cross-sectional aspect ratios a/b	58
4.2	Energy-displacement relations for axially loaded rectangular tubes with various cross-sectional aspect ratios a/b	59
4.3	Typical crushing history for axially loaded tube with the cross-sectional aspect ratio $a/b=1.0$	60
4.4	Axially crushed rectangular tubes with various cross-sectional aspect ratios	61
4.5	Initial crushing load as a function of the cross-sectional aspect ratio a/b axially loaded tubes	63
4.6	Average crushing load as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	64
4.7	Energy absorbed in the pre-crush region as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	65
4.8	Total energy absorption as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	66
4.9	Specific energy as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	67
4.10	Crush force efficiency as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	68
4.11	Stroke efficiency as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	68
4.12	Load-displacement curves for laterally loaded rectangular tubes on the 'A' side with various cross-sectional aspect ratios	71
4.13	Energy-displacement curves for laterally loaded rectangular tubes on the 'A' side with various cross-sectional aspect ratios	72
4.14	Crushing history for laterally loaded tube on the 'A' side with the cross-sectional aspect ratio $a/b = 1.0$	74
4.15	Crushing history for laterally loaded tube on the 'A' side with the cross-sectional aspect ratio $a/b = 1.25$	75
4.16	Crushing history for laterally loaded tube on the 'A' side with the cross-sectional aspect ratio $a/b = 1.50$	76



4.17	Crushing history for laterally loaded tube on the 'A' side with the cross-sectional aspect ratio $a/b = 1.75$	77
4.18	Crushing history for laterally loaded tube on the 'A' side with the cross-sectional aspect ratio $a/b = 2.00$	78
4.19	Initial crushing load as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'A' side	81
4.20	Average crushing load as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'A' side	81
4.21	Total energy as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'A' side	83
4.22	Energy Absorbed in the pre-crush region as a function of the a/b ratio for laterally loaded tubes on the 'A' side	83
4.23	Specific energy as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'A' side	84
4.24	Crush force efficiency as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'A' side	84
4.25	Load-displacement curves for laterally loaded rectangular tubes on the 'B' side with various cross-sectional aspect ratios a/b	87
4.26	Energy-displacement curves for laterally loaded rectangular tubes on the 'B' side with various cross-sectional aspect ratios a/b	89
4.27	Crushing history for laterally loaded tube on the 'B' side with the cross-sectional aspect ratio $a/b = 1.25$	90
4.28	Crushing history for laterally loaded tube on the 'B' side with the cross-sectional aspect ratio $a/b = 1.50$	90
4.29	Crushing history for laterally loaded tube on the 'B' side with the cross-sectional aspect ratio $a/b = 1.75$	91
4.30	Crushing history for laterally loaded tube on the 'B' side with the cross-sectional aspect ratio $a/b = 2.0$	91
4.31	Initial crushing load as a function of the a/b ratio for laterally loaded tubes on the 'B' side	92
4.32	Average crushing load as a function of the a/b ratio for laterally loaded tubes on the 'B' side	93
4.33	Total energy as a function of the a/b ratio for laterally loaded tubes on the 'B' side	95

4.34	Specific energy as a function of the a/b ratio laterally loaded tubes on the 'B' side	95
4.35	Crush force efficiency as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'B' side	96
5.1	Shell 91 element	99
5.2	Flow chart describes the eigenvalue analysis using the ANSYS finite element program	100
5.3	Typical mesh for rectangular Tube with the cross-sectional aspect ratio $a/b=1.00$.	101
5.4	$[0]_4$ Laminate	102
5.5	Experimental deformed shape and buckling mode with stress contour for axially loaded rectangular composite tube with $a/b=1.0$	104
5.6	Experimental deformed shape and buckling mode with stress contour for axially loaded rectangular composite tube with $a/b=1.25$	104
5.7	Experimental deformed shape and buckling mode with stress contour for axially loaded rectangular composite tube with $a/b=1.50$	104
5.8	Experimental deformed shape and buckling mode with stress contour for axially loaded rectangular composite tubes with $a/b=1.75$	105
5.9	Experimental deformed shape and buckling mode with stress contour for axially loaded rectangular composite tube with $a/b=2.0$	105
5.10	Experimental and FEM initial crushing load as a function of the cross-sectional aspect ratio a/b for axially loaded tubes	106
5.11	Typical mesh generation of laterally loaded rectangular tube with the aspect ratio $a/b=1.0$	107
5.12	Experimental and the finite element initial crushing load as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'A' side.	108
5.13	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'A' side with $a/b=1.0$	109



5.14	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'A' side with $a/b=1.25$	109
5.15	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'A' side with $a/b=1.50$	109
5.16	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'A' side with $a/b=1.75$	110
5.17	Experimental deformed shape and Buckling mode with stress contour for laterally loaded rectangular on the 'A' side with $a/b=2.0$	110
5.18	Experimental and the finite element initial crushing load as a function of the cross-sectional aspect ratio a/b for laterally loaded tubes on the 'B' side.	111
5.19	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'B' side with $a/b=1.25$	112
5.20	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'B' side with $a/b=1.50$	113
5.21	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'B' side with $a/b=1.75$	113
5.22	Experimental deformed shape and buckling mode with stress contour for laterally loaded rectangular on the 'B' side with $a/b=2.0$	114



NOMENCLATURE

A	Cross-sectional area
a/b	Cross-sectional aspect ratio
E	Young's Modulus
E ₁	Longitudinal Young's Modulus (direction-1)
E ₂	Transverse Young's Modulus (direction-2)
E ₃	Transverse Young's Modulus (direction-3)
G ₁₂	In-plane Shear Modulus(in the 1-2 Planes)
M	mass
L	length
P ₁	Initial crushing load
\bar{P}	Average crushing load
Q _{ij}	Reduced stiffnesses (i,j=1,2,6)
\bar{Q}_{ij}	Transformed reduced stiffnesses (i,j=1,2,6)
S _{ij}	Reduced compliances (i,j=1,2,6)
\bar{S}_{ij}	Transformed reduced compliances (i,j=1,2,6)
N _x	Stress resultant in x-direction
N _y	Stress resultant in y-direction
N _{xy}	Shear force
M _x	Moment resultant in x-direction
M _y	Moment resultant in y-direction
M _{xy}	Moment resultant in xy-plane
A _{ij}	Elements of the A Matrix
B _{ij}	Elements of the B Matrix
D _{ij}	Elements of the D matrix
E	Total energy absorbed
E _s	Specific energy absorbed
CEF	Crush force efficiency
SE	Stroke efficiency
AX	Axial loading condtions
LTA	Lateral loading condition on the 'A' side
LTB	Lateral loading condition on the 'B' side
t	Thickness of the tube
V _f	Volume fraction of fibre
W _f	Weight of fibre
W _m	Weight of matrix
ρ	Density
ρ _f	Density of fibre
ρ _m	Density of matrix
V	Volume



CHAPTER 1

INTRODUCTION

Structural crashworthiness is now an essential requirement in the design of automobiles, rail cars and aerospace application. The structural crashworthiness covers the energy absorbing capability of crushing structural part as well as the demand to provide a protective shell around the occupants i.e. post crash structural integrity.

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.

Composite materials are found to have an energy absorption capability, structural weight reduction, and improved vehicle safety by higher or at least equivalent crash resistance compared to metallic structure. Therefore, the increasing use of composite material in aerospace and in automobile industries has resulted in many economical and technical advantages. The efficient use of energy absorbing devices made from composite material depends on the full understanding of the crushing behaviour of tubular structures. The only possible way to fully understand the crushing behaviour is in performing crushing tests to understand how the various variables influence the crushing behaviour. In a later stage the generated data can be very useful in deriving

mathematical models which can describe the crushing behaviour and predict the energy absorbed from a tubular structure, because the development and validation of reliable analytical and simulation tools for the crashworthiness studies is an important means of reducing development cost and tests for certifications to meet safety and crashworthiness requirements.

The current research work focuses in studying the effect of the various variables, which influence the energy absorption capability of composite materials. Much 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. Also composite cones show high-energy absorption performance with the advantage of a self-triggering capability.

Limited work is available on the flat plates. A test fixture for crushing flat plate specimens is needed. The plate is stabilised by steel rod that provide a simply-supported boundary condition on the sides of the specimens. Some researchers suggest by testing flat plate the complexity of the geometry reduced and the response may be more easily studied. Furthermore, the manufacturing cost of flat specimens is less than that of tube specimens. Using such specimens, the influence of the various variables on failure modes and the energy absorption performance can be studied.

Tubes of square and rectangular cross-sections tubes made of metal are frequently used as energy absorbing structural elements, the S-rail of an automobile is an example. Studies on the crushing behaviour of these tubes have been frequently conducted, although the use of square and rectangular tubes made of composite materials as an energy absorbing structural element can result in many technical and economical advantages. Studies on the performance of square and rectangular tubes made of composite material under compressive load are very scarce. Therefore, the main aim of the present work is to explore the response of square and rectangular tubes to axial and lateral compressive load. In this project the load-displacement response, the specific energy absorption capability, and failure mode of rectangular tubes will be investigated when the cross-sectional aspect ratio increases from 1 to 2 in 0.25 increment.

1.1 Research Objectives

The aims of this study can be summarised as follows:

- To study the performance of the woven roving glass/epoxy composite material under quasi-static compressive load.
- To explore the behavior of the rectangular tubes under quasi-static compressive load.
- To investigate the effect of the cross-sectional aspect ratio on the crushing behaviour of the tubes under quasi-static compressive load.
- To study the effect of loading conditions on the crushing behaviour of the rectangular tubes.

1.2 Significance of the Study

This study is important because of the following:

- Tubes of square and rectangular cross-sections made of metal are frequently used as energy absorber elements, the use of composite tubes instead of metal tubes can result in much technical and economical advantage.
- 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.

The remainder of this thesis is organised as follows: Chapter 2 reviews the literature of the fibre reinforced composite materials and studies on their use as energy absorption structural element. The methodology used in this study is explained in chapter 3. In chapter 4, the experimental results will be presented and discussed. In chapter 5 finite element results will be presented and discussed. Overall discussion is presented in chapter 6. Finally, the conclusion from the work and the proposal for future studies are listed in chapter 7.