

**AN EXPERIMENTAL INVESTIGATION OF MULTI-RING UNDER QUASI-
STATIC AND DYNAMIC LOADING**

VINESH A/L UNAKRISHNAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**AN EXPERIMENTAL INVESTIGATION OF MULTI-RING UNDER QUASI-
STATIC AND DYNAMIC LOADING**

VINESH A/L UNAKRISHNAN

**A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering (Structure and Material)**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this project report entitled “An experimental investigation of multi-ring under quasi-static loading and dynamic loading” is the result of my own work except as cited in the references

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials).

Signature ::

Name of Supervisor :

Date :

DEDICATION

To my beloved mother and father

ABSTRACT

Energy absorbers play an important role in reducing the amount of impact subjected to structure to ensure the safety of the human in that structure. Rings are good energy absorbers since it is low in cost and addition of internal rings make it a better energy absorber when subjected to lateral loading. Two types of experiment were conducted which were the tensile test and compression test. Tensile test was conducted to determine the mechanical properties of the mild steel and compression test consisting of quasi-static loading and dynamic loading was conducted onto the ring to determine the energy absorbing capacity. Comparisons were made experimentally between multi ring and single ring under quasi-static loading and dynamic loading and motion recording were done using a camera for the respective experiments. A mild steel multi-ring consisting of four internal rings were fabricated in this project. The energy absorbing capacity was obtained from the area under the graph until the plateau zone. It was proven that multi-ring has a better energy absorbing capacity than single ring when it was quasi-statically loaded and dynamically loaded since there is an addition of constraints.

ABSTRAK

Penyerap tenaga memainkan peranan yang amat penting dalam mengurangkan kesan impak yang dikenakan pada sesuatu struktur untuk memastikan keselamatan manusia di dalam struktur tersebut. Cincin adalah penyerap tenaga yang baik kerana ianya murah dan penambahan cincin secara dalaman dapat meningkatkan kapasiti penyerapan tenaga. Dua jenis eksperimen telah dijalankan iaitu ujian regangan dan mampatan. Ujian regangan telah dijalankan untuk mengetahui ciri-ciri mekanikal bahan yang digunakan dan ujian mampatan dijalankan untuk mengetahui kapasiti penyerapan tenaga cincin. Perbandingan telah dibuat secara eksperimen antara cincin tunggal dan cincin berbilang dimana beban kuasi-statik dan beban dinamik telah dikenakan dan pergerakan impak telah direkodkan menggunakan kamera untuk setiap eksperimen. Cincin berbilang tersebut mempunyai empat cincin dalaman yang diperbuat daripada keluli lembut. Kapasiti penyerapan tenaga telah diperolehi daripada keluasan graf sehingga zon plateau. Ianya telah terbukti bahawa cincin berbilang mempunyai kapasiti penyerapan tenaga yang lebih tinggi daripada cincin tunggal apabila dikenakan beban kuasi-statik dan beban dinamik.

ACKNOWLEDGEMENT

First and foremost I would like to thank God the almighty for providing me the health and wellbeing and also for allowing me to complete this project in a smooth manner. My deepest appreciation to my supervisor, Prof Dr. Md Radzai Bin Said for giving me an opportunity to conduct this final year project under his supervision. His guidance and encouragement was the reason behind the completion of this project. I would like to extend my sincere thanks to him for sharing his expertise in leading me in this project.

My sincere thank you to my family and friends for their continuous support and love on me throughout. I am also grateful to the lab technicians, Mr.Faizal, Mr Wan, and Mr.Faizol for assisting me in the experimental works that were carried out during this project.

CONTENT

CHAPTER	CONTENT	PAGE
	DECLARATION	ii
	APPROVAL	iii
	DEDICATION	iv
	ABSTRACT	v
	ABSTRAK	vi
	ACKNOWLEDGEMENT	vii
	TABLE OF CONTENT	viii
	LIST OF TABLE	xi
	LIST OF FIGURES	xiii
	LIST OF ABBREVIATIONS	xix
	LIST OF SYMBOL	xx
CHAPTER 1	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objective	3
	1.4 Scope of Project	3
CHAPTER 2	LITERATURE REVIEW	4
	2.1 Introduction	4

2.2	Modulus of elasticity	4
2.3	Modulus of rigidity	5
2.4	Yield strength	5
2.5	Ultimate tensile strength	6
2.6	Energy absorber	6
2.7	Quasi-static and dynamic loading	7
2.8	Laterally loaded circular thin-walled structures	8
 CHAPTER 3 METHODOLOGY		19
3.1	Introduction	19
3.2	Proposing design of multi-ring	21
3.3	Tensile testing	22
	3.3.1 Preparation of tensile test specimen	22
	3.3.2 Conducting tensile test	25
3.4	Ring specimen fabrication	26
3.5	Compression test	28
	3.5.1 Quasi-static test	28
	3.5.2 Dynamic test	29
 CHAPTER 4 RESULT AND DISCUSSION		34

4.1	Tensile test	34
4.2	Compression test	38
4.2.1	Quasi-static loading	38
4.2.2	Dynamic loading	55
CHAPTER 5 CONCLUSION AND RECOMMENDATION		79
5.1	Conclusion	79
5.2	Recommendation	80
REFERENCE		81
APPENDIX		84
	A1 Gantt chart of semester 1	85
	A2 Gantt chart of semester 2	86

LIST OF TABLES

TABLE	TITLE	PAGE
1.1	Parameters representative rate-sensitive materials (Lu & Yu, 2003)	9
4.1	Results of mechanical properties for circular mild steel tube	36
4.2	Theoretical and experimental collapse load for single	40
4.3	Energy absorbed by single ring under quasi static loading	42
4.4	Theoretical and experimental collapse load for multi ring under quasi-static loading	47
2.5	Energy absorbed by multi ring under quasi static loading	52
4.6	Experimental data and results for singular ring under dynamic loading	58
4.7	Energy absorbed by single ring under dynamic loading	62
4.8	Chronological order of singular rings samples in terms of amount of potential energy dissipated and in terms of	63

	deformation when subjected to dynamic loading.	
4.9	Experimental data and results for multi-ring under dynamic loading	70
4.10	Energy absorbed by multi ring under dynamic loading	75

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Typical stress-strain graph for ductile material	6
2.2	Elastic, perfectly plastic model (Lu & Yu, 2003)	8
2.3	Rigid, perfectly plastic model (Lu & Yu, 2003)	8
2.4	Experimental arrangements for constrained tubes with friction (Reddy and Reid, 1978)	11
2.5	Experimental arrangements for tubes without friction (Reddy & Reid, 1978)	12
2.6	Geometry of the deforming of the left quadrant in stage one for constrained tube (Reddy & Reid, 1978)	12
2.7	Braced metal tube (single wired) (Reid and Drew, 1983)	13
2.8	Different deformations of single braced tube at angle of 15° (Reid & Drew, 1983)	13
2.9	Comparison between experimental and numerical deformation	14

	under lateral loading (Baroutaji et al., 2015)	
2.10	Geometry of a short circular tube (Baroutaji et al., 2015)	14
2.11	Deformation of internally nested tubes with similar internal tube diameter (Baroutaji et al., 2016)	15
2.12	The mechanics of collapse researched/proposed by de Runtz and Hodge (1963)	16
2.13	The mechanics of collapse researched/proposed by Burton and Craig (1963)	16
2.14	Deforming segment of a quadrant of a ring	17
2.15	Non-dimensional load versus displacement curves from experiments and theories (Reid, 1983)	18
3.1	Flow chart of the project	20
3.2	Geometry of multi-ring structure	22
3.3	ASTM E8 Dimensions that could be used in preparing the tensile test specimen for circular tube with thickness below 20mm	23
3.4	AutoCAD drawing of the tensile test specimen (All dimensions are in mm)	23
3.5	600mm mild steel circular tube used for laser cutting	24
3.6	Laser cutting machine	24

3.7	Tensile test specimen	25
3.8	Instron 8872 Universal Testing Machine	26
3.9	Disc cutter machine	27
3.10	Tube cutter	27
3.11	Welded multi-ring	28
3.12	Quasi-static experimental set up	29
3.13	Olympus i-speed tr camera	31
3.9	Control display unit	32
3.10	Lighting kits	32
3.11	Position of multi-ring (Bottom internal ring perpendicular to the platen)	33
4.1	Tensile test specimens after fracture	35
4.2	Stress-strain graph for tensile test specimen 1	37
4.3	Stress-strain graph for tensile test specimen 2	37
4.4	Stress-strain graph for tensile test specimen 3	38
4.5	Graph of load versus displacement for singular ring 1 under quasi-static loading	41
4.6	Graph of load versus displacement for singular ring 2 under quasi-static loading	41
4.7	Graph of load versus displacement for singular ring 3 under quasi-static loading	42
4.8	Deformations of single ring structure at various displacements	44

	under quasi-static loading	
4.9	Graph of load versus displacement for multi ring 1	49
	under quasi static loading	
4.10	Graph of load versus displacement for multi ring 2	50
	under quasi static loading	
4.11	Graph of load versus displacement for multi ring 3	51
	under quasi static loading	
4.12	Graph of load versus displacement for multi ring 4	51
	under quasi static loading	
4.13	Deformations of multi ring at various displacements	53
	under quasi-static loading	
4.14	Graph of comparison between multi ring and singular ring	54
4.15	Graph of load vs displacement for singular ring 1	59
	under dynamic loading	
4.16	Graph of load vs displacement for singular ring 2	60
	under dynamic loading	
4.17	Graph of load vs displacement for singular ring 3	60
	under dynamic loading	
4.18	Graph of load vs displacement for singular ring 4	61

	under dynamic loading	
4.19	Graph of load vs displacement for singular ring 5	61
	under dynamic loading	
4.20	Graph of load vs displacement for singular ring 6	62
	under dynamic loading	
4.21	Displacement of single ring under dynamic loading	66
4.22	Graph of load versus displacement for multi ring 1	72
	under dynamic loading	
4.23	Graph of load versus displacement for multi ring 2	72
	under dynamic loading	
4.24	Graph of load versus displacement for multi ring 3	73
	under dynamic loading	
4.25	Graph of load versus displacement for multi ring 4	73
	under dynamic loading	
4.26	Graph of load versus displacement for multi ring 5	74
	under dynamic loading	
4.27	Graph of load versus displacement for multi ring 6	74
	under dynamic loading	
4.28	Displacement of multi ring under dynamic loading	77

subjected to quasi-static loading and dynamic loading

LIST OF ABBEREVIATIONS

RSM Response surface method

SEA specific energy absorption

CFE crushing force efficiency

MIG Metal inert gas

LIST OF SYMBOL

E	=	Modulus of elasticity/Energy absorbed
σ	=	Engineering stress
ε	=	Engineering strain
G	=	Modulus of rigidity
F	=	Force/Force indentation stroke
L	=	Initial length
A	=	Area
Δx	=	Transverse displacement
$\dot{\varepsilon}$	=	Strain rate
$\dot{\sigma}$	=	Stress rate
P	=	Flattening force
δ	=	Deflection
P_k	=	Peak crushing force
P_m	=	Mean crushing force
σ_v	=	Standard quasi-static tensile characteristic of a given material

M_0 = Moment per unit length

σ_{od} = Dynamic yield stress

σ_o = Static yield stress

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Energy absorbers has been given much of an attention to researchers around the world because of its ability to protect the occupant or reducing the injury of the occupant placed in a particular structure. Studies regarding crashworthiness have great attention to the behavior of thin-walled structures, which is used as energy absorbers in fields such as aeronautical and automobile (Li et al., 2013). In order to further understand the energy absorption of a structure, understanding of materials engineering, structural mechanics, impact mechanics, and theory of plasticity is important. Usually thin-walled tubes of different geometry and materials are used to absorb kinetic energy through plastic material deformation. There are many ways of destroying thin-walled tubes in order to analyze the energy absorbed such as lateral compression, lateral indentation, axial crushing, tube inversion and tube splitting. (Baroutaji et al., 2016). Axially loaded structures have drawn attention to many researchers since axial crushing has high energy absorbing capacity. However, its disadvantage is that it has very large fluctuations of the collapse load about a mean load and unstable deformation mode. This project focuses on the effects of lateral loading on short circular tube. Energy absorbing capacity of laterally loaded structures are higher compared to laterally indented structures because bending

collapse mode generated from lateral loading results in a smooth force-deflection response. Besides, it does not undergo any unstable deformation mode (Baroutaji et al., 2015). A research study has found out that circular tube structures under lateral quasi-static loading using response surface method (RSM) and showed that specific energy could be increased by increasing the thickness and reducing the diameter of the tubes (AlaviNia and Chahardoli, 2016). On the other hand, a study conducted shows that an elliptical ring has greater energy absorbing capacity compared to circular ring because of its higher displacement stroke (Morris et al., 2007). The effects multi-ring structure subjected to laterally quasi-static loading and laterally dynamic loading will be studied throughout this project.

1.2 PROBLEM STATEMENT

Energy absorption plays a vital role in engineering structures and fields such as in the automobile and aeronautical industries. These impact energy absorption devices are highly responsible in ensuring the safety and life of human beings. Besides, impact energy absorption devices are used to avoid high impact loads on commercial goods packages. In the current world, it is important for a designer to design an impact energy absorbing device which could limit loads and deceleration on the structure and occupants. Circular rings are used as thin-walled energy absorbers since it is low in cost compared to solid tubular energy absorbers and is widely used in crash barriers. Multi-circular rings increases the energy absorption capacity when impact is exerted on a structure compared to a single ring.