



**Faculty of Mechanical and Manufacturing Engineering  
Technology**

**INVESTIGATION OF THE BUCKLING BEHAVIOUR OF  
AXIALLY COMPRESSED CONE WITH DIMPLE  
IMPERFECTION**

**Norinni Binti Abu Bakar**

**Bachelor of Mechanical Engineering Technology (Maintenance) with honour**

**2019**

**INVESTIGATION OF THE BUCKLING BEHAVIOUR OF  
AXIALLY COMPRESSED CONE WITH DIMPLE  
IMPERFECTION**

**NORINNI BINTI ABU BAKAR**

**A thesis submitted  
in fulfillment of the requirements for the degree of Bachelor of Mechanical  
Engineering Technology (Maintenance) with honour**

**Faculty of Mechanical and Manufacturing Engineering Technology**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

**2**

## BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

**TAJUK: INVESTIGATION OF THE BUCKLING BEHAVIOUR OF AXIALLY COMPRESSED CONE WITH DIMPLE IMPERFECTION**

**SESI PENGAJIAN: 2019/20 Semester 2**

Saya **NORINNI BINTI ABU BAKAR**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **\*\*Sila tandakan (✓)**

- SULIT** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
- TERHAD** (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
- TIDAK TERHAD**

Disahkan oleh:

\_\_\_\_\_  
NORINNI BINTI ABU BAKAR

\_\_\_\_\_  
DR OLAWALE IFAYEFUNMI

Cop Rasmi:

Alamat Tetap:

KM 1593 JALAN ALOR 1,

\_\_\_\_\_  
TAMAN ALOR

\_\_\_\_\_  
ALOR GAJAH 78000 MELAKA

**\*\* Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.**

## DECLARATION

I hereby, declared this report entitled STUDY OF THE BUCKLING BEHAVIOUR OF AXIALLY COMPRESSED CONE WITH DIMPLE IMPERFECTION is the results of my own research except as cited in references.

Signature : .....

Author : NORINNI BINTI ABU BAKAR

Date :

## **APPROVAL**

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance) with honour. The member of the supervisory is as follow:

Signature : .....

Supervisor : DR OLAWALE IFAYEFUNMI

## **ABSTRACT**

This study focuses on investigating of the buckling behaviour of mild steel truncated cones under the effect of axial loading. This study will be conduct experimentally using INSTRON 50kN Universal Testing Machine. There are total of 14 sample with various number of dimple imperfection. The effect of dimple imperfection as well as the variation of number of dimple on the load carrying capacity of cones will be investigate. Finally, a comparison between the collapse load of perfect and imperfect conical shells has been conducted. All the objectives has been successfully achieved.

## **ABSTRAK**

Kajian ini menumpukan kepada penyiasatan kelakuan gelendong kon keluli lembut yang dipotong di bawah kesan beban paksi. Kajian ini dijalankan secara eksperimen menggunakan INSTRON 50kN Universal Testing Machine. Terdapat sejumlah 14 sampel dengan bilangan pelbagai lekuk ketidaksempurnaan. Kesan ketidaksempurnaan lekuk dan perubahan beberapa lekuk kepada beban membawa kapasiti kon akan diselidiki. Akhir sekali, perbandingan di antara beban keruntuhan cangkerang konikal sempurna dan tidak sempurna akan dilakukan.

## ACKNOWLEDGEMENTS

I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them. I am highly indebted to my supervisor, Dr Olawale Ifayefunmi for his guidance and constant supervision as well as for providing necessary information regarding the project and also for his support in completing the project. I would like to express my gratitude towards my parents, Zainullah Din bin Mahbob and Bakhmina Qadar Khan for their kind co-operation and encouragement which help me in completion of this project. I would like to express my special gratitude and thanks to assistant engineers, Mr. Basri bin Bidin, Mr Mohd Syafiq bin Ismail, Mr. Mohd Fauzi bin Suleiman and Mr. Azizul Ikhwan bin Mohd for giving me such attention and time.



# TABLE OF CONTENTS

<b>TABLE OF CONTENTS</b>	<b>PAGE</b>
<b>DECLARATION</b>	i
<b>APPROVAL</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	iv
<b>ACKNOWLEDGEMENTS</b>	v
<b>TABLE OF CONTENTS</b>	vi
<b>LIST OF TABLES</b>	ix
<b>LIST OF FIGURES</b>	x
<b>LIST OF APPENDICES</b>	xii
<b>LIST OF SYMBOLS</b>	xiii
<b>LIST OF ABBREVIATIONS</b>	xiv
<b>CHAPTER 1: INTRODUCTION</b>	1
1.1 Background	1
1.2 Statement of the Purpose	2
1.3 Problem Statement	2
1.4 Scope	3
<b>CHAPTER 2: LITERATURE REVIEW</b>	4
2.1 Introduction	4
2.1.1 Application of Conical Shells in Industries	4
2.2 Buckling Behaviour	5
2.2.1 Buckling Behaviour of Conical Shells	5
2.2.2 Buckling of Axially Compressed Conical Shells	6
2.3 Type of Imperfections	8
2.3.1 Initial Geometric Imperfections	8
2.3.2 Loading Imperfections	10
2.3.3 Uneven Length Imperfections	10
2.3.4 Dimple Imperfection	10
2.4 Review of Literature Study	11

<b>CHAPTER 3: METHODOLOGY</b>	13
3.1 Research Design	13
3.2 Conceptual Design	14
3.2.1 Sketching and CAD Design	15
3.3 Material Selection	16
3.3.1 Advantages of Mild Steel in Engineering Applications	18
3.4 Fabrication Process	18
3.4.1 Cutting Process	19
3.4.2 Rust Proof	22
3.4.3 Specimens Gridding	23
3.4.4 Thickness Measurement Process	24
3.4.5 Shaping Process	26
3.4.6 Welding Process	28
3.4.7 Conical Shell Measurements	29
3.4.8 Materials Testing	31
3.4.8.1 Tensile Testing	32
3.4.8.2 Three Point Bending	33
3.4.9 Experimental Axial Compression Test	34
 <b>CHAPTER 4: RESULT</b>	 36
4.1 Introduction	36
4.2 Pre – Test Measurement	36
4.2.1 Thickness Measurement of Specimens	36
4.2.2 Diameter of Mild Steel Conical Shell	39
4.2.3 Measurement of height of specimen	40
4.3 Dimple Measurement	45
4.4 Experimental Procedures	47
4.5 Experimental Result	48

<b>CHAPTER 5: CONCLUSION AND FUTURE WORK</b>	56
5.1 Conclusion	56
5.2 Future Work	57
<b>REFERENCES</b>	58
<b>APPENDICES</b>	65

## LISTS OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Comparison between studies	12
3.1	Properties of Mild Steel	17
3.2	Composition of Mild Steel	17
4.1	Specimen Thickness	34
4.2	Specimen Thickness	35
4.3	Vertical height of specimens	37
4.4	Slant height of specimens	37
4.5	Dimple location, amplitude and actual amplitude	38
4.6	Experimental results	40

## LIST OF FIGURES

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Geometry of perfect cone	6
2.2	Geometry of analysed cone (a) subjected to: (b) axial compression	7
2.3	Photograph of collapsed cone subjected to axial compression	8
2.4	Locations of dimple on cone slant	11
3.1	Working Process Flow Chart	13
3.2	Conceptual design of a perfect truncated cone	14
3.3	Dimension of a perfect truncated cone	16
3.4	Mild steel plate with 0.5mm thickness	16
3.5	Overall fabrication process of a conical shell specimen	19
3.6	Arrangement of Specimen in LaserJet Cutting Machine	20
3.7	Arrangement of specimen after cutting.	20
3.8	LaserJet Cutting Machine	21
3.9	A perfect truncated cone cut-out after cutting process	22
3.10	Type of Anti-Rust Solution has been used	22
3.11	Rust proof process by using 4D	22
3.12	A truncated cone with gridlines	23
3.13	Thickness measurement at gridlines intersection	24
3.14	Conventional Slip Roll Machine	25
3.15	Rolling process of a specimen	25
3.16	Specimen after Rolling	26

3.17	Metal Inert Gas (MIG) Welding	27
3.18	A complete conical structure formed after welding process	27
3.19	Measurement of inner diameter of a specimen	28
3.20	Measurement of outer diameter of a specimen	28
3.21	Dimple Imperfection Process	29
3.22	Arrangements of coupons on mild steel sheet	30
2.23	Tensile Testing	31
3.24	Three Point Bending Testing	31
3.25	INSTRON Universal Testing Machine	32
3.26	Cone Specimen Tested Using INSTRON Universal Testing Machine	33
4.1	Gridlines intersection point	37
4.2	Diameter of Mild Steel Conical Shell	39
4.3	Height of specimen location	41
4.4	Slant height of specimen	43
4.5	dimple measurement	45
4.6	Specimen Setup According To Axial Compression	47
4.7	Load versus axial compression extension for no dimple	49
4.8	Load versus axial compression extension for one dimple with 0.56 amplitude.	50
4.9	Load versus axial compression extension for one dimple with 1.12 amplitude.	50

4.10	Load versus axial compression extension for one dimple with 1.68 amplitude.	51
4.11	Load versus axial compression extension for two dimple with 0.56 amplitude	51
4.12	Load versus axial compression extension for two dimple with 1.12 amplitude	52
4.13	Load versus axial compression extension for two dimple with 1.68 amplitude	52
4.14	SPLA result of compression	53
4.15	MPLA result of compression	53
4.16	Typical photograph of defect shape before testing	54
4.17	Typical photograph of defect shape after testing	55

## LIST OF APPENDICES

<b>APPENDICES</b>	<b>TITLE</b>	<b>PAGE</b>
Appendix 1	Cone Calculations	54
Appendix 2	Thickness Measurement of Specimens	55
Appendix 3	Top Diameter Measurement of Specimens	63
Appendix 4	Bottom Diameter Measurement of Specimens	68
Appendix 5	Vertical Height	73
Appendix 6	Slant Height	74



## LIST OF SYMBOLS

B	-	Cone semi-vertex angle
$r_1$	-	Top radius of cone
$r_2$	-	Bottom radius of cone
h	-	Height of cone
L	-	Slant length of cone

## **LIST OF ABBREVIATIONS**

CAD	Computer Aided Drawing
DXF	Drawing Interchange Format
MIG	Metal Inert Gas

# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Conical shell structure is used in the aeronautical, marine, offshore and mechanical industries as structural components. Cones are used to connect two cylinders of different diameters which regularly used in the pressure vessels, pipelines, offshore platforms and transition elements. The load carrying capacity of conical shell when in use is generally restricted by elastic buckling in aeronautical application. This is due to the high value of the thin conical shells radius to thickness ratio. Conical shells also find applications in marine engineering. Shell structures also find multifunctional applications in civil engineering. Silos, roofs, containers, tanks, pipes, pressure vessels, submarines and aircraft wings are some examples that have thin shells as structural components (Deshpande, 2010).

Literally, conical shell structures are subjected to different loading conditions which include axial compression. Several factors determine the limit to which the structures can be loaded or deformed. Instability is one of them. In order to perform buckling analysis of conical shells, one must really understand the behaviour of the shell structure (Ifayefunmi, 2014). Buckling is one of solid mechanics' complex phenomena. This phenomenon represents a threat to shells that are thin and compressive. Buckling's loss of stability is important in many areas such as mechanical engineering, chemical, aerospace engineering,

marine industry, etc. For example, when designing columns, vessels with varying suction pressure, longitudinal tubes in steam boilers, ship and submarine bodies, space crafts and vehicles are applicable (Daliri, et al., 2019).

The buckling force of the thin-walled shell under axial compression was found to be particularly sensitive to shell imperfections (Song, Teng and Rotter, 2004). Small geometric imperfections can cause a significant reduction in buckling strength in thin-walled shell structures are among those studying the buckling imperfection stability of shell-of-revolution structures with small geometric imperfections. (Amazigo & Budiansky, 1972; Narasimhan & Hoff, 1971 and Stein, 1968) Practically, imperfections occur locally rather than axisymmetric or have buckling modes shape (Cooper & Dexter, 1974).

## **1.2 Statement of the Purpose**

The purposes this research are:

- a) To design and fabricate truncated cones with and without dimple in the middle of its meridional length using mild steel.
- b) To study the effect of different dimple amplitude on the buckling behaviour of axially compressed truncated conical shell structure.

## **1.3 Problem Statement**

It was discovered from the literature study that there was not many study on the buckling load of conical shells having a dimple imperfection. Researchers focus more on an initial geometric imperfection, imperfection of loading conditions and uneven length. This

study tries to focus on the effect of dimple imperfection on conical shell's buckling behaviour for further investigation due to lack of experimental data on the subject matter.

#### **1.4 Scope**

This research is conducted based on experimental approach to study the effect of imperfection with various number of dimple on the buckling behaviour of the truncated conical shell structure subjected to axial compressive loading. The material that was used in designing and fabricating the truncated conical shell structure was mild steel having thickness of 0.5 mm.

In this experiment, in order to achieve accurate data, a total 14 samples were made altogether to be tested. The zero (0) number of dimple was done to establish the baseline. LaserJet cutting machine was used to cut the conical shells. The manufacturing processes of the samples continue with rolling and welding.

All of the truncated cones will undergo axial compression test by using INSTRON Universal Testing Machine. The result obtained from the compression test will be recorded and analysed as the experimental. Result were compared in form of tables, and graphs.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Introduction**

This chapter is an overview of the theory and knowledge based on previous researcher which relates to the studies on the buckling load of conical shells having a dimple imperfection. This work carried out to investigates the buckling behaviour of axially compressed cone with dimple imperfection.

##### **2.1.1 Application of Conical Shells in Industries**

Conical shell structures are used in aeronautical, marine, offshore and mechanical industries as structural components in engineering applications (Ifayefunmi, 2014). Especially in applications such as pressure vessel, piping, and pipelines (Ifayefunmi and Blachut, 2018). In many fields such as aircraft, rocketry, submarine technology, etc., truncated conical shell has been widely used, as argued by Sofiyev (2011). The non-linear stability analyses of conical shells have been very important in their useful application in recent years and have been of considerable interest in research. One of the thin-walled structures recently considered by researchers is conical or tapered tubes (Jafarian and Rezvani, 2019). For their load carrying capacity performance, they are preferred.

According to Wagner et al. (2018), Hao et al. (2016), conical shell structures are being used as adapters in launch vehicle systems between cylindrical shells of different diameters. Blachut (2016) argued that conical shells are also used in various engineering fields such as tanks and pressure vessels. Also mentioned by Sofiyev (2011) and Hao et al. (2018) submarines, nuclear reactors, jet nozzles and other civil, chemical, mechanical, marine, aerospace engineering structures, missiles and spacecraft are other examples of area where conical shells are being used. Truncated thin-walled conical shells are often used as transition parts between cylinders of different diameters (Khakimova, et al., 2016).

## **2.2 Buckling Behaviour**

### **2.2.1 Buckling Behaviour of Conical Shells**

Over the years, the buckling behaviour of steel plate has been studied. Buckling and instability are among the most important failure modes for shell structures. A long list of research on conical shell buckling such as Seide (1956), Lackman & Penzien (1960) and Tani & Yamaki (1970) has been recorded in history. Volmir (1967) and Leissa (1973) studied conical shells that were formulated using classical shell theory (CST) stability and vibration. It is a phenomenon which occurs in structures which are stiff in a the loaded and slender in another direction (Bhoi and Kalurkar, 2014). This phenomenon is one of the most difficult issues in industry on imperfect shells.

Generally, for structures' buckling load depends on the initial geometric imperfections. When a structure is imperfect, that structure's buckling load will decrease (Sofiyev, 2010). Conical shell buckling behaviour is affected by the material and geometric properties, the type of load applied to it and any geometric imperfections on the shells (Maali

et al., 2012). It is very important to study the conical shell failure phenomenon as the slightest imperfection on it can lead to a significant decrease in the structure's buckling capacity. Small geometric imperfections in thin-walled shell structures can cause a significant decrease in buckling strength (Jansseune, et al., 2016). The conical shells stand out from other forms of structure and are usually used in the aerospace, marine and other industries (Ifayefunmi and Blachut, 2013). Another example of a field where buckling of conical shell is of concern is offshore, oil and chemical industries (Blachut, 2012).

The buckling of conical shell can be analysed subject to loads aside axial compression such as pure bending, torsion or complex load conditions (Nedelcu, 2018). The shell geometry plays an important role in the stability of the structure while its mechanical properties will be affected by external loads (Taraghi & Showkati, 2019). The load carrying capacity and conical shell buckling and post-buckling behaviour are very sensitive to initial geometry imperfections when shells were exposed to various types of loading.

### **2.2.2 Buckling Of Axially Compressed Conical Shells**

Wagner et al. (2018) stated that conical shells are subject to heavy payloads and axial compression. There can be a critical gap between theoretical and experimental results of axially compressed conical shells because the buckling load is very sensitive to geometry and loading conditions imperfections. Ifayefunmi and Blachut, (2013) also stated that perfect truncated thick cone with radius,  $r_1$  and  $r_2$ , uniform wall thickness,  $t$ , height,  $h$ , slant length, angle  $L$  and semi-vertex,  $b$ , shown in Figure 2.1 are subjected to axial compression loading conditions.