UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EXPERIMENTAL INVESTIGATION OF BUCKLING BEHAVIOR OF CRACKED STEEL CONES SUBJECTED TO AXIAL COMPRESSION

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenance Technology) (Hons.)

by

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TAJUK: EXPERIMENTAL INVESTIGATION OF BUCKLING BEHAVIOR OF CRACKED STEEL CONES SUBJECTED TO AXIAL COMPRESSION

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor's Degree of Mechanical Engineering Technology (Maintenance Technology) with Honours. The member of the supervisory is as follow:

………………………………

(OLAWALE IFAYEFUNMI)

ABSTRAK

Lengkokan sesuatu struktur yang tidak sempurna adalah masalah yang paling mencabar dalam industri dan pemahaman mengenai beban lengkokan struktur diperlukan untuk menjamin integriti struktur ini sepanjang hayat perkhidmatan mereka. Untuk mendapatkan pemahaman yang lebih baik mengenai masalah ini, satu kajian telah dijalankan untuk mengkaji beban lengkokan kon yang dimampatkan secara menegak serta mempunyai retak yang mempunyai orientasi dan panjang yang berbeza. 1-mm keluli lembut dipilih dalam kajian ini. Satu plat keluli lembut telah dipotong menggunakan mesin Waterjet and digulung menggunakan mesin menggulung dalam bentuk 21 cengkerang kon. Terdapat tiga jenis retak diperkenalkan kepada kon iaitu retak paksi, lilitan dan bersudut. Setiap retak mempunyai enam panjang yang berbeza iaitu 5%, 10%, 15%, 20%, 25% dan 50% daripada lilitan kon. Tiga daripada 21 spesimen tidak mempunyai apa-apa retak. Semua spesimen dimampatkan secara menegak menggunakan mesin Instron 150 kN untuk menentukan beban lengkokan. Daripada keputusan yang diperoleh, telah didapati bahawa retak 5% menghasilkan lengkokan beban tertinggi bagi setiap retak dan beban lengkokan yang paling rendah adalah pada retak 50%. Setiap jenis retak telah dibandingkan pada 50% daripada panjang retak, dan didapati bahawa, retak paksi mempunyai beban lengkokan tertinggi iaitu 35.73 kN diikuti dengan retak bersudut dan retak lilitan yang 31.38 kN dan 21.02 kN masing-masing. Oleh itu, dapat disimpulkan bahawa, jika panjang retak meningkat, maka beban lengkokan akan menurun. Sekali lagi, ia juga boleh disimpukan bahawa, retak paksi mempunyai beban lengkokan yang paling tinggi berbanding dengan retak lilitan yang mempunyai beban lengkokan yang paling rendah.

ABSTRACT

The buckling of imperfect shells is the most challenging problem in industry and an understanding of the buckling load of shells structure is needed to assure the integrity of these shells during their service life. To get a better understanding on this problem, a study was conducted to examine the buckling load of axially compressed cone with crack that have different orientation and length. 1-mm mild steel was chosen in this study. A mild steel plate has been cut using Waterjet machine and rolled using rolling machine in a form of 21 conical shells. There are three types of crack introduced to the cones which are axial, circumferential and angled crack. Every type of crack has six different length which are 5%, 10%, 15%, 20%, 25% and 50% of the cone circumference. Three of the 21 specimens have no crack. All the specimens were axially compressed using 150 kN Instron Machine to determine the buckling load. From the results obtain, it was found that the 5% crack length produced highest buckling load for every crack and the lowest buckling load is at 50% crack. Every type of crack was compared at 50% of crack length, and it was found that, the axial crack has highest buckling load which is 35.73 kN follow by angled crack and circumferential crack which are 31.38 kN and 21.02 kN respectively. Hence, it can be concluded that, if the length of the crack is increase, then the buckling load is decrease. Again, it can also be concluded that, axial crack has the highest buckling load compare to circumferential crack that has the lowest buckling load.

DEDICATION

To my beloved parents, siblings and friends who give me support and guidance to complete my final year project work.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

MPa	-	Mega pascal
GPa	-	Giga pascal
g	-	Gram
cm	-	Centimeter
mm	-	Millimeter
R	-	Radius
2D	-	Two Dimension
Dfx	-	Drawing Interchange Format
kN	-	Kilonewton
MIG	-	Metal Inert Gas

CHAPTER 1
INTRODUCTION

1.1 Background

A conical shell structures is a common structural element that is widely used in many fields such as pipelines, aerospace, marine structures, large dams, shell roofs liquid-retaining structures and cooling towers (Farshad, 1992). Shell buckling phenomenon of imperfect shells is one of the most challenging problems of the theory of elastic stability. Buckling phenomenon depends on several variables such as geometric properties of shells, properties of material and types of applied load. It is difficult to achieved general depiction due to variation of changes of parameters. The structural integrity can be endangered if there is any presence of defects, such as cracks (El Naschie, 1974).

1.2 Problem Statement

The buckling phenomenon of imperfect shells is one of the most challenging problems in industry. Initial geometric imperfections play dominant role in reducing the buckling load of certain structures (Sofiyev, 2011).

Maali et al., 2012 stated that buckling of conical shells depends on the geometric and material properties of the shells, type of applied load and geometric imperfections. This structure been used widely in engineering field as load carrying parts because of its special geometric shape (Bich et al., 2013). From the literature study, the buckling capacity of conical shells may differ due to slightest imperfection, and defects investigation becomes very important to study the failure phenomenon of conical shells (Maali et al., 2012).

An understanding of the buckling load of shells structure is needed to assure the integrity of these shells during their service life. Golzan and Showkati, 2008 stated that the best way to understand buckling behavior is to perform the test.

Although geometric imperfection plays an important role in load carrying capacity, there are a few studies conducted on cones with crack introduced. In this project, there are 3 type of cracks examined which are axial, circumferential and angled crack with different length. The imperfect conical shell was subjected to axial compression.

1.3 Objectives

Base on the problem statement that has been discussed, the objectives of this study are:

1. To design and manufacture truncated cones with three different type of crack with different crack length.
2. To study the effects of crack with different orientation on axially compressed truncated cone experimentally.
3. To compared the buckling load on different crack orientation.

1.4 Scopes

This research is based on experimental approach to study the effect of crack with different type of orientation and length subjected to axial compression. 1 mm mild steel is use in designing and fabricating the truncated cones.

Before fabricating and welding, a slit is made to each of the cones to introduce the crack. After that, the mild steel will be rolled and then the end of the sheet is weld together. There are 21 different samples made. The first three samples are cones with no crack and there are six samples each for cones with axial, circumferential and angled crack. All the samples will undergo axial compression by using INSTRON machine.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction to Thin Wall Shell Structure.

Truncated conical shell structures are widely used in fields of civil and mechanical engineering. It has also been widely applied in fields such as space flight, rocketry, aviation, nuclear reactors, jet nozzles, etc. (Sofiyev et al., 2013). Conical shell commonly used as transition elements to joining two cylinders of different diameter (Blachut, 2011). Thin conical shell structures that are used in aeronautical applications usually will be prone to elastic buckling due to a high value of the radius to thickness ratio (Blachut and Ifayefunmi, 2010).

Usually, buckling of conical shell relies on a various type of variables such as the geometric properties of the shell, the material properties and type of applied load. It is understood that geometric defect significantly affect the load carrying capacity of thin shell structure when subjected to axial load (Castro et al., 2015). The presence of defects such as crack, can seriously affect the conical shell buckling behavior and can be dangerous to the structural integrity (Ali, 2013).

2.2 Buckling

Buckling is a sudden large, lateral deflection of a structure due to increasing of compression load (Barakat, 2011). If a buckling happens to a structure, the structure may fail to support its load. Theoretically, buckling is brought on by a bifurcation in the solution to the equations of static equilibrium. Global buckling is a buckling mode where the member deforms with no deformation in its cross-sectional shape, consistent with classical beam theory. Golzan and Showkati (2008) conducted a study on buckling of thin-walled conical shells under uniform external pressure. They applied external uniform pressure to truncated conical shells and shallow conical caps. They conclude that initial buckling occurred when one or more buckling lobes were detected and the buckling loads obtained experimentally are lower than the result obtained from numerically. This is because there were a different in some aspects related to the tapering ratio of a specimen (R/r).

Ali (2013) studied on buckling of cracked aluminum conical frusta under axial compression. In the study, the specimen was introduced with cracks with different angle and different length. It was concluded that after buckling phenomenon occurs, loads carrying capacity of the shell is rigorously reduced. The presence of a crack with different angles has a considerable effect on buckling load of the shells. The vertical has the highest buckling load when compressed. Shell buckling depends on several factors and one of them is shell geometry. If the shell start to shows a small crack, the crack will reduce the shell strength. Buckling load is considerably reduced in the same amount of loading and support conditions and with increasing shell length.

Hilburger and Starnes Jr. (2002) studied on effects of imperfections on the buckling response of compression-loaded composite shells. It is experimental and analytical study of the effects of initial imperfections on the buckling and post buckling response of three unstiffened thin-walled compression-loaded graphite-epoxy cylindrical shells with different orthotropic and quasi-isotropic shell-wall laminates. It was concluded that the traditional and non-traditional imperfections that has been considered in this study could be used to formulate the basis for an imperfection signature of a composite shell. The defect signature might incorporate the effects of variations of uncertainties in the shell geometry, fabrication-process, load-distribution and boundary stiffness parameters. The nonlinear analysis procedure that been used in this study can be used to form the basis for a shell analysis and design approach that includes this generalized imperfection signature. The result had been presented to indicate that the reinforcement can affect the local deformations and stresses near the cutout and suppress the onset of local buckling in the shell near the cutout. The local buckling response near the cutout in the shell in some cases and then results in a stable post-buckling response near the cutout. Therefore, additional load can be applied to the shell before it undergoes a global collapse.

Brush (1980) examined the effect of pre-buckling rotation in a cylindrical shell. Famili (1965) studied on the asymmetric behavior of truncated and complete conical shells under uniform hydrostatic pressure, also considering the large deformation in the pre-buckling state. Zhang (1993) studied, also in the same manner, the buckling, and initial post-buckling behavior, with considering the nonlinear pre-buckling behavior under axial compression.

2.2.1 Plastic Buckling

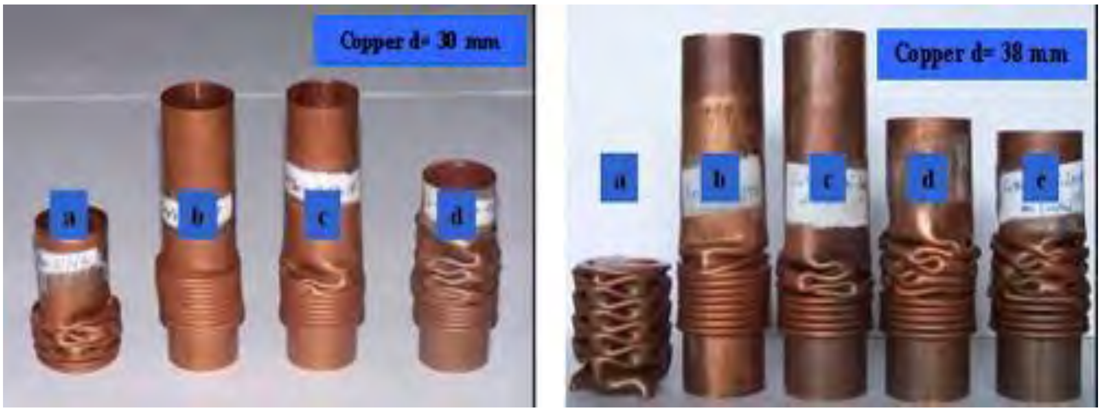

Figure 2.1 Plastic Deformation (Baleh and Abdul-Latif, 2006)

Figure 2.1 shows the plastic deformation of the thin-walled structure. A structure may buckle when a load is applied to it. The initial buckling will be elastic if the load is applied at constant strain-rate. Elastic means it can recover back to its original shape of position. Experimental and numerical studied of plastic buckling of conical shells has been conducted by Blachut and Ifayefunmi (2009). It was stated that two identical cones failed at the same magnitude of pressure. Ramsey (1977) studied on plastic buckling of conical shells under axial compression. It can be concluded that there is no minimum load for the initial buckling, but when the load reached plastic zone, the structure cannot recover to its original form. Plastic buckling is a deformation that is permanent. The structure that undergoes this buckling cannot be recovered to its original position or shape.

2.2.2 Dynamic Buckling

Dynamic stability of thin-walled structures has always been discussed since 1960's. The majority of studies have been made to allow in practice for an effective analysis of stability of the thin-walled structure. Ari-Gur and Simonetta (1997) have introduced "pulse intensity" and Cui et al., (2009) have introduced "pulse velocity". The dynamic pulse buckling will occur when the loading process of intermediate amplitude and pulse duration is close to the period of fundamental natural vibrations. In the case, the effects of damping are neglected.

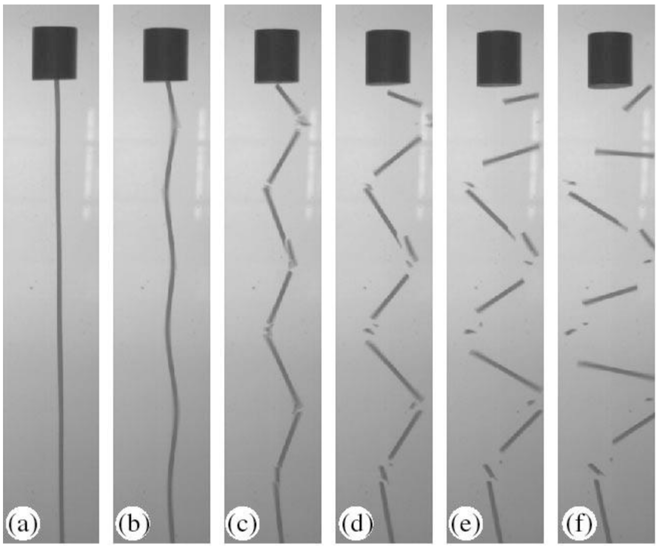

Figure 2.2 The Dynamic Buckling and Fragmentation of Dry Pasta (Gladden, 2005)

2.2.3 Bifurcation Buckling

According to Sun et al., (1995) the word buckling describe of failure of structure which has been compressed in some way. From a scientific and engineering point of view, the two phenomena loosely termed "buckling" are collapse at the maximum point in a load vs deflection curve. The instability failure is shown in Figure 2.3.

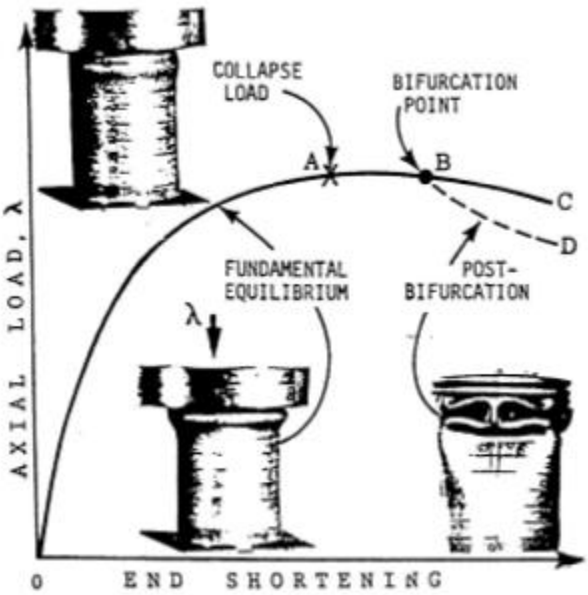

Figure 2.3 Load-End Shortening Curve with Limit Point A, Bifurcation Point B, And Post-Buckling Equilibrium Path BD (Bushnell, 1985)

2.3 Conical Buckling

Naderian and Ronagh (2015) studied on buckling analysis of thin-walled cold-formed steel structural members using complex finite strip method. It was stated that buckling of thin-walled steel members could be local, shear, distortion and global. When the cross section of a shell is subjected to large compressive stresses, the structure that makes up the cross section may buckle before the full strength of the member is attained and it is called local buckling. Then the members capacity is reached when a cross sectional element fails in buckling. Consequently, local buckling becomes a limit state for the strength of steel shapes subjected to compressive stress. Global buckling is a mode in which the member deforms with no deformation in its cross-sectional shape as it undergoes lateral deformations and twist, consistent with the classical beam theory. Naderian and Ronagh (2015) also stated that there are few common well-known types of global buckling in cold-formed steel sections such as flexural, torsional and flexural-torsional which might happen in columns and lateral-torsional that might occur in beams. Treatment of the buckling process of shell-type structures as a linear case has been questioned due to the discrepancies observed between theoretical predictions and experimental result. Therefore, a response to these types of structures may be predicted only when one accounts for their geometric non-linear behavior (Sofiyev and Kuruoglu, 2011).

Ifayefunmi and Blachut (2011) studied the effect of shape, thickness and boundary imperfections on plastic buckling of cones and they stated that the buckling strength of conical shell is affected by defects. It was found that shaped distortion appears to be possible from a practical point of view than an initial shape deviation in the form of eigenmodes. It is also stated that if the end condition is relaxed around the full length of the circumference, the sensitivity of buckling strength may vary.

Jabareen and Sheinman (2006) conducted a research of pre-buckling nonlinearity on the bifurcation point of a conical shell on the three basic shell theories which are Donnell's, Sander's and Timoshenko's. It can be concluded that the critical buckling load was affected by the nonlinear pre-buckling deformations. In addition, it also stated that the effect of the nonlinear pre-buckling deformations will be weaker if the shell is longer. Finally, the non-linear pre-buckling effect depends on the in-plane boundary conditions. A certain aspect ratio of a conical shell, different buckling modes correspond to the same value of critical buckling (Spagnoli, 2003). A simple formula for the critical buckling loads of laminated conical shells, based on Seide's (1956) has been suggested by Tong (1994).

2.4 Conical Imperfection

2.4.1 Dimple

Hutchinson et al. (1971) conducted experimental and numerical investigation on the effect of local axisymmetric imperfection on buckling behavior of circular cylindrical shell under axial compression. The variety of dimple imperfections was calculated in the study. It can be concluded that very small axisymmetric dimple imperfections reduce the buckling load of a circular cylindrical shell in axial compression drastically.

Ifayefunmi and Blachut (2013) conducted numerical research on imperfect thick cones subjected to axial compression and external pressure. The defect of the cones is inward dimple at different location. It was stated that for axially compressed cone, the collapse mode has an axisymmetric outward bulging about the small radius. Figure 2.4 shows the result of the research. It can be concluded that the axisymmetric outward bulge can reduce the load carrying capacity marginally more that the corresponding eigenmode type of shape imperfection.

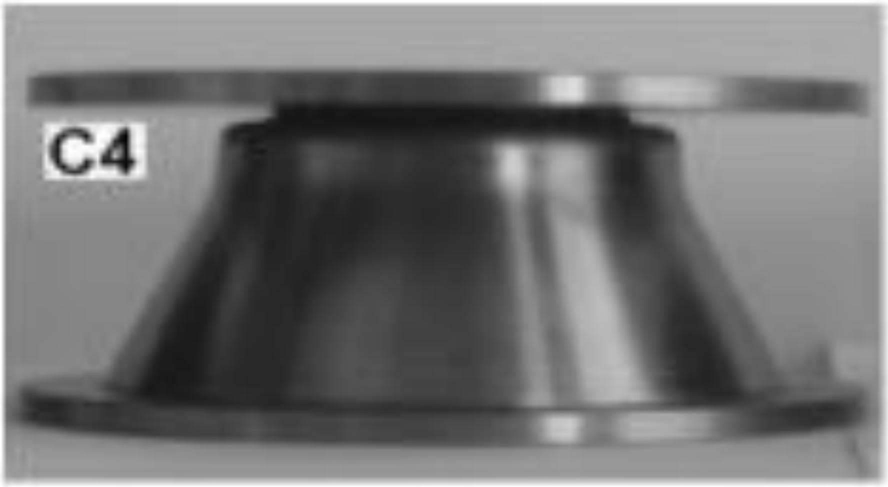

Figure 2.4 Collapse Cone Subjected to Axial Compression (Ifayefunmi and Blachut, 2013)

2.4.2 Imperfect Boundary Condition

Ifayefunmi and Blachut (2011) has conducted a research on imperfect boundary conditions of cones. The cones are subjected to axial compression only and radial pressure only.

Jabareen and Sheinman (2006) studied on the nonlinear pre-buckling state on the bifurcation point on three shell basic theories with are Donnell's, Sander's and Timoshenko's. They conclude that the nonlinear pre-buckling effect strongly depends on the in-plane boundary conditions.