UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE EFFECT OF MATERIAL DISCONTINUITY ON THE FLANGES OF AXIALLY COMPRESSED CYLINDER

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

by

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Engineering Technology (Automotive Technology) (Hons.). The member of the supervisory is as follow:

……………………………….

(Project Supervisor)

ABSTRACT

Presence of defects, such as cracks, may affect the buckling behaviour of a cylindrical shell. The buckling behaviour of axially compressed mild steel cylindrical shells with material discontinuity on the flanges is presented in this project. This project is carried out by numerical analysis on eight CAE models and experimental analysis on eight cylindrical shells subjected to axial compression with flanges fully welded on bottom while material discontinuity is introduced on the top flange. The thickness of the cylindrical shells is 2 mm, while the outer diameter is 104 mm. The results of the numerical analysis show that the maximum compressive load of model is decreasing as the percentage of crack length of model is increasing. As conclusion, it is shown in numerical analysis that the higher the percentage of the crack length introduced on the top flange, the lower the maximum compressive load of the model in the analysis.

ABSTRAK

Kehadiran kecacatan seperti retak, kemungkinan boleh memberi kesan kepada tingkah laku lengkokan shell silinder.Projek ini akan membentangkan tingkah laku silinder keluli lembut yang dikimpalkan dengan bebibir yang dikenakan dengan mampatan paksi. Projek ini dijalankan melalui analisis berangka pada lapan model CAE dan analisis eksperimen di lapan peluru silinder dikenakan mampatan paksi dengan bebibir dikimpal sepenuhnya di bahagian bawah dan semasa ketakselanjaran bahan diperkenalkan pada bebibir atas. Ketebalan kerang silinder adalah 2 mm, sementara garis pusat luarnya adalah 104 mm. Keputusan dalam analisis berangka menunjukkan bahawa beban mampatan maksimum model semakin berkurangan sebagai peratusan panjang retak model semakin meningkat. Kesimpulannya, ia ditunjukkan dalam analisis berangka bahawa semakin tinggi peratusan panjang retak diperkenalkan pada bebibir atas, semakin rendah beban mampatan maksimum model dalam analisis.

DEDICATIONS

This report is dedicated to my parents and siblings who have mentally and physically supported me to finish this project work. Not to forget all friends in my class and also my housemates who have helped me in all the process of doing this Final Year Project without any complain.

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kN	=	kilo Newton
m	=	meter
mm	=	milimeter
r	=	radius
t	=	thickness
%	=	percentage

CHAPTER 1

INTRODUCTION

1.0 Background

Since decades ago, cylindrical structures are widely used in the field of civil, mechanical, architectural, aeronautical and marine engineering (Farshad, 1992). One of the main failure criteria when designing these structures is buckling (Budiansky and Hutchinson, 1972). Over the years, it has been argued that the presence of defects, such as cracks, may severely compromise the buckling behaviour of these structures and thereby jeopardize their structural integrity (El Naschie, 1974). The focus of this study is on the effect of materials discontinuity on the flanges of axially compressed cylinder. When the cylindrical shell structures are applied in some applications, such as pipelines, buildings support and cooling towers, they will be subjected to different kind of loads such as axial compression, external pressure, internal pressure, torsion etc (Blachut, 2014). In this condition, structural designer have to pay great effort on their design to overcome buckling effect that can cause failure to the structure. The failure of the structures has brought up a lot of research in this field about the mechanical behaviour of the thin shell structure under load. The understanding towards the factors contributing to buckling problem is necessary in order to carry out the buckling analysis successfully. In most of the situation, cylindrical shell structures are subjected to compressive forces in the direction of cylinder axis, either uniform or varying throughout the cylinder. The buckling strength of a thin cylindrical shell under axial compression is particularly sensitive to imperfections such as crack in the shell (Remmers, 2006).

This project is focusing on monitoring and evaluation of the effect of local material discontinuities of the percentage of the hoop length on the flanges of the welded cylindrical shells subjected to axial compression using experimental and numerical approach. Investigation has been done for this research to figure out the buckling behaviour of the welded cylindrical shells with material discontinuities of the hoop length on the flanges, when subjected to axial compression.

1.1 Problem Statement

It is undeniable that the presence of crack on any structure will affect or reduce the strength of the structure. In some cases, it might cause serious failure of the structure, the same goes to the cylindrical structure. According to (Remmers, 2006), the presence of crack will affect the buckling behaviour of structural components resulting in failure of the structures especially cylindrical shell structures. Defects could lead to large localized deformations such as local buckling or plastic deformation, which can alter the structure's load carrying capacity or function (Javidruzi et al, 2004). Presence of defects, such as cracks, may severely compromise their buckling behaviour and jeopardize the structural integrity (Hutchinson et al, 1972). In general, the buckling behaviour of the cylindrical shells under torsional loading is less sensitive to the presence of a crack than that of a similar axially compressed cylindrical shell (Estekanchi and Vafai, 1999).

Throughout the literature survey, most of the research focus on the mechanical behaviour of the cylindrical structure by using Finite Element Software such as Hyperworks, ABAQUS, ANSYS etc, and the results obtained are based on theoretical method and numerical simulation. Although the numerical analysis has been proven to produce very close to experimental results, but it still needs to be confirmed by experiment so as to ensure the data are valid. This project is carried out by experimental and numerical approach to focus on the effect of local material discontinuities of the percentage of the hoop length on the flanges of the welded cylindrical shells subjected to axial compression. Therefore, more experimental data can be found in this research field.

1.2 Objectives

Based on the problem statement and background above, there are two objectives for this research:

i. To manufacture cylinders with material discontinuity introduced on its flange during welding process.

ii. To monitor and study the effect of material discontinuity on the flanges of axially compressed cylinder on the load carrying capacity.

1.3 Scope

The aim for this project is to investigate the effect of local material discontinuity of the percentage of the hoop length on the flanges of the welded cylindrical shells subjected to axial compression under experimental and numerical analysis. The chosen material for the cylindrical structures and the flanges is mild steel. The nominal thickness of mild steel plates for cylinders is 2 mm and 10 mm for the flanges.

This experiment involved eight specimens which are subjected to axial compression test using Instron material testing machine. Circumferential crack is introduced during the welding process of the flanges on the top of the cylinders, while the flanges on the bottom of the cylinders are fully welded. The inner diameter of the flanges is 100 mm while the outer diameter is 200 mm. For the cylinders, the outer diameter is nominal at 104 mm. The specimens are labelled as (10, 11, 12, 13, 14, 15, 16, 17) with circumferential crack length percentage of (0%, 5%, 10%, 10%, 15%, 20%, 25%, 50%) respectively. Besides, there are seven CAE models have been created to carry out numerical analysis in Abaqus. The CAE models are created by using Spaceclaim based on the measured geometry of the specimens and with crack length percentage of (0%, 5%, 10%, 15%, 20%, 25%, 50%) respectively.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Thin-walled shell structures have been widely used in pipelines, aerospace and marine structures, large dams, shell roofs, liquid-retaining structures and cooling towers (Farshad, 1992). Thin-walled structures are usually used to support load in most engineering applications. Anyway, there is a problem that needs to be considered, that is failure that occurs when they are subjected to high load. In shell structures, the load carrying capacity is usually limited and governed by the buckling phenomena. Failure of cylindrical structures can happen in any situation. There are various types of imperfections that can occur on a cylindrical structure which can cause failure on it. The imperfections are (i) initial geometric imperfection, (ii) non-uniform loading, (iii) non-uniform axial length, and (iv) crack on cylindrical structures. The following section presents extensive literature review of the four imperfection types mentioned. This is done in order to have an indepth knowledge of what have been done experimentally in this area of study, thereby identifying the gap in knowledge.

2.1 Buckling of cylinder with initial geometric imperfection

One of the most commonly considered type of imperfection is the initial geometric imperfection, i.e, axisymmetric dimple, eigen-mode imperfection, geometric dimple, single perturbation load and single stress-free dimple.

The effect of initial imperfections has been discussed by (Hutchinson, 1965) in a preliminary manner and refers only to axisymmetric imperfections. Therefore, more journals have to be reviewed for information. Loading imperfections and initial geometric are important parameters for analysing axially compressed cylindrical shells. It is found that the buckling behaviour of imperfection sensitive shells under axial loading is commonly affected by their initial geometric imperfections which resulted from the manufacturing procedure (Papadopoulos and Iglesis, 2007).

The buckling strength of circular cylindrical shells are sensitive to the form and amplitude of very minor deviations of geometry (geometric imperfections) from the ideal shape, meaning that measurement and characterization of the extent to which geometric imperfections reduces the load bearing capacity is of engineering significance (Fatemi et al, 2013).

According to (Linus et al, 2015), the presence of geometrical imperfections is found to have a high degrading effect even though the perfect shell structure are within the limits of manufacturing tolerance. In order to account for imperfect shell structures within the preliminary design phase, it is common practice to apply knock down factor, which is the ratio of experimentally determined buckling loads to theoretical buckling loads of the geometrically perfect shell structure. Besides, (Friedrich et al, 2015) also states that the rotational-symmetric imperfection is identified to be more critical than the non-rotational-symmetric imperfections. Consequently, this type of imperfection gains particular importance for the preliminary design of shell structures.

It was reported that both analytical results and experimental results are deviated widely from each other due to inevitable differences called imperfections which are presented in the real structure from the perfect structure (Rathinam and Prabu, 2015). According to (Victor et al, 2014), initial geometrical imperfections are identified as the major source of discrepancy between analytical and experimental results. An investigation about the applicability of the Single Perturbation Load Approach (SPLA) on sandwich shells has been done and it is compared with four other imperfection patterns.

(Iwicki et al, 2011) has carried out a failure analysis on cylindrical silo shells by performing linear and non-linear buckling analyses with different initial geometric imperfections. According to (Ismail et al, 2015), the designers and engineers should acquire sufficient knowledge on the physical behaviours of shell buckling in order to prevent unexpected catastrophic failure of structures of which thin cylindrical shells are essential components.

2.2 Buckling of cylinder with non-uniform loading

Additional studies showed that geometric imperfections is not the only reason of the discrepancy between theory and experiments, and that the effect of thickness variability, material imperfections, imperfect boundary conditions as well as the non-uniformity of the applied axial load proved to be equally important leading to a further reduction of the predicted buckling loads (Arbocz and Babcock, 1969; Hoff and Soong, 1969; Libai and Durban, 1977; Greenberg and Stavsky, 1995; Arbocz, 2000; Arbocz and Starnes, 2002).

Non-uniformity of the axial loading as well as the uncertainty on the boundary conditions, were treated in the past using mainly the asymptotic theory without taking into account the combined effect of more than one sources of imperfections (Arbocz and Babcock, 1969; Hoff and Soong, 1969; Libai and Durban, 1977; Greenberg and Stavsky, 1995; Arbocz, 2000).

The approach used for modelling the non-uniformity of axial loading was essentially equivalent to that of modelling the geometric boundary imperfections in the sense that both of them resulted in introducing a non-uniform axial load pattern acting on the cylinders' edges (Papadopoulos and Iglesis, 2007). This equivalence was made more evident in (Arbocz, 2000) where imperfections of the boundary conditions were modelled as in-plane geometric edge imperfections and were combined with the initial out-of-plane geometric imperfections in a non-linear finite element analysis using a two-step analysis procedure.

According to (Koiter, 1963), a flatness survey on one of the loading end rings used in a test setup of a stiffened axially compressed anisotropic cylinder. The result of this survey is shown in Figure 2.1. On the other hand, Figure 2.2 shows an ideal representation of the imperfect contact area of the cylinders' edge and its corresponding loading.

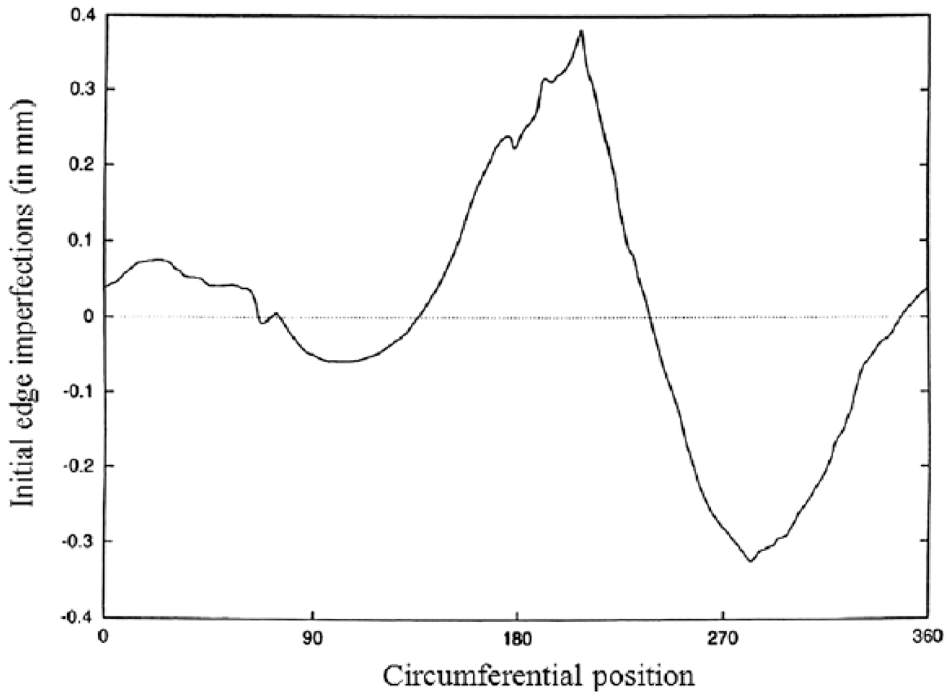

Figure 2.1: Measured flatness of the ring in Koiter (1963).

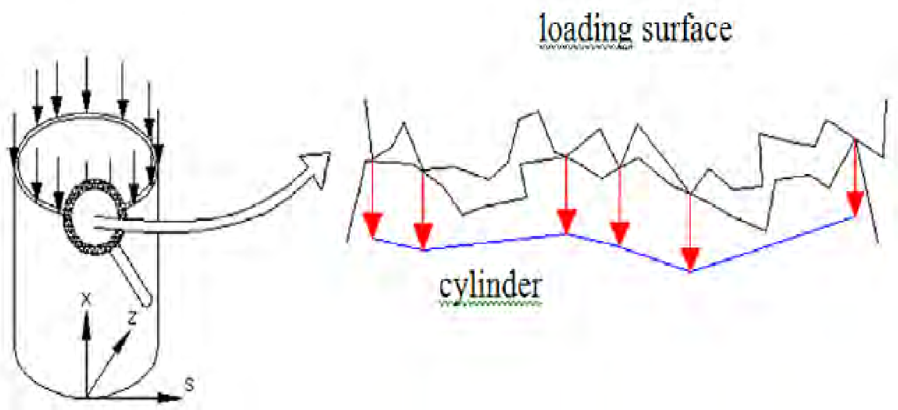

Figure 2.2: Contact area of the cylinder and the loading surface in (Koiter, 1963).

2.3 Buckling of cylinder with non-uniform axial length

There is a problem which is not noticed which is the axial gaps between two cylinders when they are joined or welded together. When these cylinders are subjected to axial compression as in some applications, the axial gaps between the two cylinders will cause changes to the properties of the cylinders, such as shape, longitudinal dimension and also circumferential dimension. According to (Blachut, 2010), these local effects at the imperfect end of the cylinder can propagate along the shell's length and cause collapse. An experiment of a rigid plate and cylinder with various boundaries at the top edge has been carried out. As the rigid plate moves further down to the contact area between the plate and the cylinder changes. As a result of axial compression, the cylinder's load carrying capacity can be limited either by collapse or by bifurcation buckling (Blachut, 2010). The result is shown in Figure 2.3.

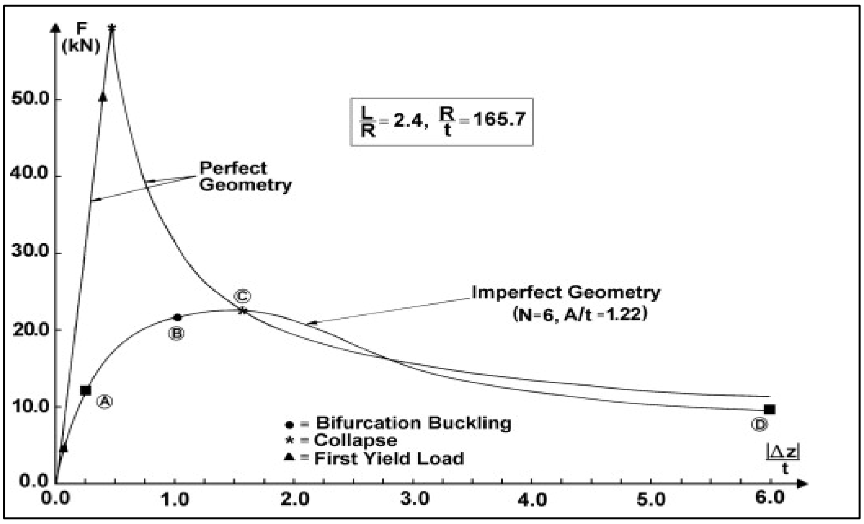

Figure 2.3: Typical load-deflection curves for axially compressed mild steel cylinders. Two curves are shown for perfect cylinder and for cylinder with varying axial length (Blachut, 2010).

According to (Blachut, 2014), only few experimental data exists here to prove the influence of variable length on buckling strength under axial compression. He has carried out an experiment using eighteen mild steel cylinders that were CNC-machined. The first three had nominally perfect axial length while the remaining 15 had variable length at one end as shown in Figure 2.4. During the axial compression testing with rigid plate, there is few hoop waves instantly formed around the top end of the tested model with high amplitude of axial imperfection. The same condition occurred to the cylinders with small amplitude of axial imperfection.

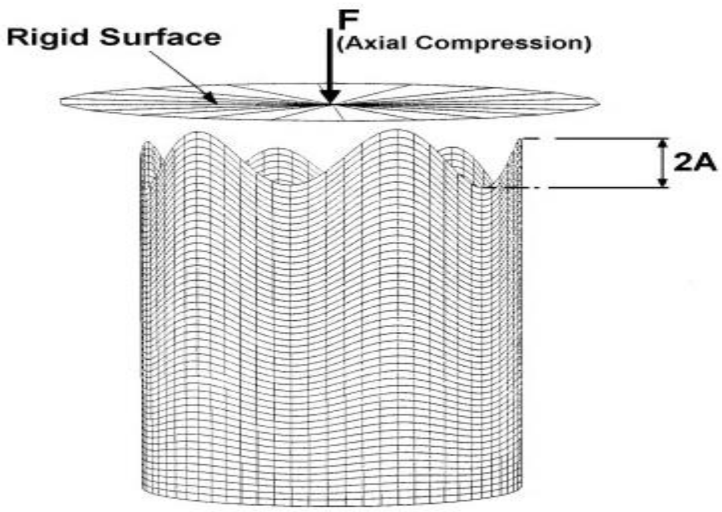

Figure 2.4: Variable axial length at the top of cylinder (Blachut, 2015).

2.4 Buckling of cylinder with crack

Material discontinuity is also known as cracks or defects in thin-walled shell structures which can cause severe and catastrophic failure of the structural member. The post-buckling analysis of cracked plates and shells indicated that the buckling deformation could cause a considerable amplification of the stress intensity around the crack tip. Presence of defects such as cracks, which may develop during manufacturing or service life of composite cylindrical shells, could severely affect the buckling behavior of structures not only by reducing their load carrying capacity but also by introducing local buckling at the crack region (Vaziri and Estekanchi, 2006). The presence of cracks in a shell structure can play the role of geometrical imperfection and thus reduce the load carrying capacity of shell structure (Vafai and Estekanchi, 1996). (El Naschie, 1974), considered the buckling problem of a cracked shell for the first time, he found that the buckling load of circular cylindrical shells with a complete circumferential crack is shown to be half of that of the perfect cylinder.

A meshing scheme by using Finite Element method proposed by (Estekanchi and Vafai, 1999) for cracked thin plates and shells is employed in computational models of cracked cylindrical shells. According to (Vaziri and Estekanchi, 2006), in this meshing scheme, by approaching the crack tip, the element size reduces