Numerical and experimental analysis of buckling and post buckling in cylindrical shells with circular cutout

A. Ghaiasvand*, H. Ahmadi Rashid

Department of Mechanical Engineering, Tabriz University, Tabriz, Iran

Abstract

Buckling in cylindrical shells has been a major issue for researchers for more than a century. Cylindrical shells are often used in the production of aircrafts, racks, boilers, pipelines, cars, and some submarine structures. These structures may experience axial compression loads in their longevity and yield to buckling. Furthermore, these structures usually have disruptions, such as cutouts, which may have adverse effects on their stability. In the present paper using finite element method, the buckling of cylinders with circular cutout of AA5083 aluminum alloy under loading is investigated. The effect of some geometric parameters such as cutout position and cutout size on the critical load of buckling of these shells was studied. According to the results, with increase in the diameter of cutout the critical load of buckling sharply decreases. The results of the numerical analysis are verified by a series of experimental tests.

1. Introduction

The buckling problem of cylindrical shells has attracted many researchers for more than a century. Initially, researchers focused on determining the buckling load in the linear elastic range, but quickly found that the buckling load was greater than the empirical observation [1]. Experimental studies have shown that the buckling capacity of thin cylindrical shells is much less than the predicted value of classical theory and this is due to imperfections that are typically created during the manufacturing process in these shells [2-5].

Cylindrical shells are often used in the production of aircrafts, racks, boilers, pipelines, cars, and some submarine structures [6, 7]. These structures may experience axial compression loads in their longevity and yield to buckling. Furthermore, these structures usually have disruptions, such as cutouts, which may have adverse effects on their stability [8].

Many researchers have investigated the structural behavior of such structures with various openings. Tennyson [9] investigated the effects of unreinforced circular cutouts on the buckling behavior of circular cylindrical shells subject to axial compression. Numerical and experimental methods were used by Jullien and Limam to investigate the stability of cylindrical shells with openings [10]. The analysis showed that the buckling load was quite sensitive to the opening angle or circumferential size of a cutout. An area replacement method (ARM) of strengthening the circular cutouts in a cylindrical shell on the buckling strength of such shell was studied analytically and experimentally by Bennett et al. [11]. Buckling of steel cylindrical shells with elliptical cutouts was studied by Shariati and Rokhi [12]. It was appeared that the buckling load decreases when the width of cutouts is constant and their height increase. Simple design rules were proposed by Eggwertz and Samuelson considering theoretical analyses and experimental data for shells with rectangular cutouts [13]. Aluminum cylindrical shells with rectangular cutouts in different locations along the specimens were studied by Han et al. [6], who showed that the location and the size of an opening significantly affect the buckling load of such structures. Steel shells with elliptical cutout under axial compression were studied numerically and experimentally by Shariati and Rokhi [14]. They showed that...
longer shells were much more sensitive to the position of a cutout.

In this paper, the study of buckling of cylinders with circular cutout under axial loading using ABAQUS finite element software is performed. Also, using an INSTRON8802 servo-hydraulic machine, the results of buckling test of samples are compared with the numerical results obtained from the simulation. The experimental and numerical results are in good agreement with each other. Based on the results, the effect of each parameters mentioned on the buckling behavior of the cylindrical cutouts is discussed.

2. Model Description

In order to study the buckling and post-buckling behaviour of aluminium shells, cylindrical shells with circular cutout were used. In all models, the height and diameter of the cylinder were constant and were respectively 200 and 50 mm. The cutouts in different sizes were considered. This was done using three sizes (10, 20 and 30 mm) in diameter. The location of the openings in three different heights was considered from the end of the cylinder, these heights were L/4, L/2, 3L/4, respectively. The schematic of cylinder with cutout is shown in Fig. 1.

Data from the tensile test curve is shown in Table 1.

| Table 1. Mechanical properties of AA5083 Aluminium alloy |
|----------------|----------------|----------------|----------------|
| E(GPa) | Poisson Ratio | Yield Stress(MPa) | Ultimate Stress(MPa) | Elongation (%) |
| 71 | 0.33 | 228 | 317 | 16 |

For meshing samples, a non-linear element S8R, an eight-node element with six degrees of freedom for each node, is used. Mesh size convergence studies were performed using a linear buckling load analysis to determine an acceptable sizing for each element types. The convergence of the mesh density is based on the relative change of the eigenvalues as the mesh is refined. A suitable mesh size of 2 mm was chosen for the S8R element which provides adequate accuracy without undue computational cost. For meshing around the cutouts, a square section is constructed around the cutout location large enough to encompass its area, and all sections are meshed with the appropriate mesh size seed value to ensure compatibility along the section edges.

For applying boundary conditions on the edges of the cylindrical shells, two rigid plates were used that were attached to the ends of the cylinder. In order to analyse the buckling subject to axial load similar to what was done in the experiments; a 10-mm displacement was applied centrally to the center of the upper plate, which resulted in a distributed, compressive load on both edges of the cylinder. Additionally, all degrees of freedom in the lower plate and all degrees of freedom in the upper plate, except in the direction of longitudinal axis, were constrained.

Linear finite element analysis, especially for relatively thick shells, predicts buckling load more than real value [5]. Nonlinear static analysis is generally required for thin shells undergoing compressive loading since these structures are highly dependent on geometric nonlinearity resulting from initial shape imperfections. Without the introduction of imperfections, the nonlinear analysis tends to follow the linear buckling solution until an unstable load value (eigenvalue) is reached and the structure deforms into a post-buckled state. With the presence of imperfections, thin-walled structures under compression often attain a much lower maximum load due to the triggering of post-buckled mode shapes arising...
from the initial shape imperfections. Therefore, the nonlinear analysis introduces a non-zero imperfection into the model and an especial analysis is used to follow these nonlinear paths into the post-buckled range. First, a linear buckling analysis should be performed to determine the shape of the buckling modes of the structure, and then, using the results of the first analysis, a nonlinear buckling analysis will be carried out. Mode shapes are stored in the file as the original defect and used in the later analysis to apply the shape of the modes to the nonlinear buckling analysis. This step is called Buckle step. For this stage, the subspace solver method was used in the software and three first modes of buckling of each sample were obtained. It should be noted that because of the contacts between the rigid plates and the cylindrical shell, the Lanczos solver method may not be used in these samples. After performing the Buckle analysis, a nonlinear analysis is performed to obtain a force-displacement curve. The maximum value of this curve is buckling critical load. This Statics step is called Riks and uses the arc-length method for backscatter analysis [6].

3. Results and Discussion

Experimental tests were carried out on several samples with circular cutout to confirm the accuracy of the numerical results. An INSTRON8802 servo instrument was used for this purpose. The machine has a capacity of 250 KN and is used to loading the samples for this purpose. The load-displacement curve from experimental and numerical results is shown in Fig. 2.

Comparison of numerical and experimental results shows that the agreement between buckling load of numerical analyzes and experimental value is good and the error rate obtained for samples is very low.

To investigate the effect of change in cutout diameter on buckling load of cylindrical shells, cutouts with 10, 20 and 30 mm were created. Then changes in buckling load were investigated. The diagram of the load-diameter for the samples with different cutout diameters in a fixed cutout position is shown in Fig. 3.

It is observed that with increasing diameter, the buckling load decreases. The displacement contours of the samples with a central cutout of 2 cm in diameter before and after buckling are shown in Fig. 4.
different diameters are shown in Figures 5 to 7, respectively.

Fig. 5. Load curve for different cutout positions with 1 mm diameter

Fig. 6. Load curve for different cutout positions with 2 mm diameter

Fig. 7. Load curve for different cutout positions with 3 mm diameter

Fig. 8. Buckling load for different cutout positions in different diameter

4. Conclusion

In this research a numerical and experimental study was carried out on aluminum cylindrical shells with circular cutouts with different diameters and different locations. Buckling behavior of these shells was studied and the buckling load curves of these shells were obtained. The following results were obtained:

1. The presence of cutout reduces the bearing capacity of the cylindrical shells.

2. With increasing diameter of cutout, buckling load decreases. In other words, larger cutouts cause a drop in shell load buckling.

3. For cutouts of equal size, the buckling load increases as the cutouts reach the bottom of the shell.

References


Numerical and experimental analysis of buckling and post-buckling in cylindrical shells with circular cutout

A. Ghaiasvand, H. Ahmadi Rashid