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Numerical and experimental analysis of buckling of hemisphere shell made by spinning forming method subjected to uniform external pressure

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ABSTRACT: The spherical shell is an ideal geometry for use in pressure vessels under uniform external pressure. The collapse pressure of these types of shells is much lower than its theoretical value due to the high sensitivity to imperfections and the yield stress of the material. Since the imperfections depend on the sheet metal forming method, it is necessary to investigate the effect of the fabrication method on the collapse pressure. This article is focused on the experimental and numerical study of the buckling of hemispherical shells made by the spinning forming method. The most important problem of this method is the lack of control over the thickness. In this method, the imperfections are axially symmetrical, which is one of the advantages of this method. In this article, buckling analysis due to both diameter and thickness variations is done separately and simultaneously. It has been shown that thickness variations in rotational forming should be considered in the analysis of shell collapse. Also, by comparing the numerical and experimental results shown with the help of quadratic volume elements, thickness changes, and boundary conditions can be applied with higher reliability compared to the shell element.

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1- Introduction

Buckling is one of the most important failure factors in structures under compressive stress. For example, the most important failure mode of columns, sheets, and shells under compressive force is buckling[1]. The strength and stability of spherical pressure vessels have been studied since 1915 [2] and many experimental, theoretical, and numerical researches have been conducted on the loading capacity of metallic and composite spherical vessels. In 1974, Huang and his colleague [3] presented an algorithm for the calculation of the inelastic buckling of a spherical shell under external pressure. In 1995, Blachat et al. [4] conducted a study on the buckling strength of incomplete hemispheres. In 2017, Zhang et al [5] conducted tests on 10 laboratory sample spheres to investigate the buckling behavior of the spheres as well as obtain the buckling load of the spheres and compared the results with analytical and numerical responses. In 2018, Luo et al. [6] researched the nonlinear buckling strength of steel shells under pressure with geometric defects. In another research in 2018, Zhang et al. [7]conducted research on the linear and non-linear behavior of buckling and post-buckling of titanium spheres under external pressure, taking into account the effect of defects with analytical, numerical and laboratory methods.

Defects caused by manufacturing have a great effect on the buckling of spherical shells. Therefore, it is wrong to calculate the buckling of the spherical shell without mentioning the manufacturing method. In this study, the buckling of hemispherical shells produced by spinning has been studied numerically and experimentally.

2- Methodology

In this paper, the buckling of two hemispherical samples is studied both experimentally and numerically. The samples are manufactured by the spinning forming method. Non-uniform Symmetrically thickness is a major imperfection in this method [8]. The mechanical properties and the detailed Geometry and thickness of samples are given in Table 1 and Table 2.

In the experimental study, according to Figure 1, a v-shaped groove was created in a circular sheet. Then the hemisphere was placed in the groove and sealed with silicone glue. The collection was placed in a tank under hydrostatic pressure. The hydrostatic pressure of the tank increased slowly. Finally, the pressure suddenly dropped due to the collapse of the structure. The collapse pressure for the hemisphere with a thickness of 1.3 mm and 0.9 mm were obtained 38 bar and 26 bar respectively. The final shape of the hemisphere after collapsing is shown in Figure 2.

In the numerical study, the buckling pressure was

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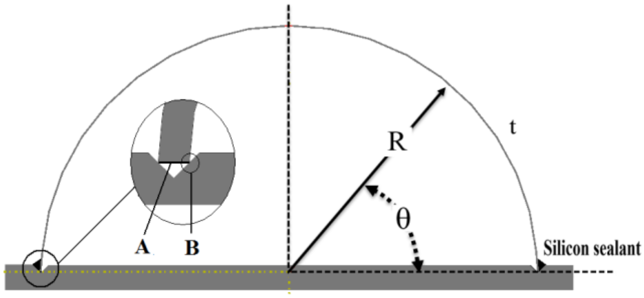

Fig. 1. General design of the test structure

Table 1. mechanical property of St37

	elongation	Ultimate stress	yield stress	Young modulus
St37	20%	360 MPa	MPa 240	200 GPa

Fig. 2. final collapsed vessel

Table 2. Geometry and thickness characteristic of manufactured hemisphere

θ (deg)	R (mm)	The thickness of sample A(mm)	The thickness of sample B (mm)
0	97.5	0.9	0.7
15	99	1	0.7
30	99.5	1	0.78
45	99.49	1.2	0.8
70	99.48	1.2	0.85
90	99	1.3	0.9

calculated by Ricks approach in Abaqus software. Firstly, the geometry imperfection was implemented based on the first mode shape of linear buckling. Secondary, the exact geometry imperfection and thickness was implemented in Ricks approach. Nonlinear effects originated of contact boundary condition, plasticity and nonlinear Geometry is considered in all studies. Finally, the radial defect was implemented precisely and the thickness was approximated in the Ricks approach. Therefore, radial based imperfection and thickness based imperfection were studied separately. All imperfections were treated as axisymmetric based on spinning forming approach.

3- Discussion and Results

In Table 3 and Table 4, the Abaqus results are compared with the test results. In Table 3, the buckling pressure of a hemisphere with defects determined based on the shape of the first mode of linear buckling is much lower than the test. In contrast, the FEM results for the exact and axial geometry are in good agreement with the test.

The effect of radius-based defects and thickness-based defects on the buckling of the hemispherical hull is shown in Table 4. It has been observed that the linear approximation of the thickness is sufficient in the modeling.

4- Conclusions

In this paper is shown that the buckling of the hemisphere hull is dependent on the manufacturing method. Also is shown the pressure buckling of structure with axisymmetric imperfection originating from the spinning method is different from the pressure buckling of hemisphere pressure hull with unperfected based on first mode linear buckling. Also, with precise geometry modeling in numerical analysis, accurate results can be obtained compared to the experiment.

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Table 3. The Abaqus results compared to the test results.

sample	Test pressure buckling (P_{test})	$\frac{P_{\text{Abaqus}}}{P_{\text{test}}}$ Radial imperfection based on first mode linear buckling		$\frac{P_{\text{Abaqus}}}{P_{\text{test}}}$ Exact radial imperfection
		Maximum thickness	Minimum thickness	Exact thickness
A	38	0.72	0.57	0.99
B	26	0.57	0.35	1.03

Table 4. Collapse pressure based on defects caused by thickness change and diameter change separately

Sample	A ($\frac{P_{\text{Abaqus}}}{P_{\text{test}}}$)	B($\frac{P_{\text{Abaqus}}}{P_{\text{test}}}$)
Thickness approximation	$t(y)=0.9+0.4\frac{y}{98}$	$t(y)=0.7+0.2\frac{y}{98}$
uniform radius (98mm)	1.18	1.3
Non uniform radius based on table 2	1.01	1.06

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