BUCKLING BEHAVIOUR OF DENTED ALUMINIUM ALLOY CYLINDRICAL SHELL SUBJECTED TO UNIFORM AXIAL COMPRESSION

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1. Introduction

Thin-walled cylindrical shells are widely used in aerospace and automotive industries and in civil engineering. Usually their function is to transmit the axial loading – to be under pressure. When the pressure reaches a critical value, it comes to the buckling of the walls. Furthermore, due to small thickness of walls, there may be local imperfections, which further reduce the value of critical buckling stress. The imperfections present in thin cylinders are classified as geometrical imperfections, material imperfections and other imperfections. The imperfections such as circularity, cylindricity, local indentations, dents, crack, swellings, non-uniform thicknesses, etc., belong to geometrical imperfections whereas imperfections such as in-homogeneity, vacancies, impurities, etc., are classified as material imperfections. The residual stresses and strains induced during manufacturing, etc. are grouped as other imperfections[1].

Aim of this paper is to investigate how geometrical imperfections such as dents, positioned in the middle of aluminium-alloy cylindrical shell, have influence to critical buckling stress.

2. Types of buckling analysis

There are two approaches in analysing cylindrical tin-walled shells for buckling. These are Eigen (or linear) buckling analysis and Non-linear buckling analysis.

Eigen buckling analysis predicts the theoretical buckling strength of an ideal linear elastic structure. This analysis is used to predict the bifurcation point using linearized model of elastic structure. It is a technique used to determine buckling loads – critical loads at which a structure becomes unstable and buckled mode shapes–the characteristic shape associated with a structure's buckled response. The other name for this Eigen buckling analysis is "bifurcation analysis". In Eigen buckling analysis, imperfections and non-linearities cannot be included. The basic form of the Eigen buckling analysis is given by:

$$[K]\{\phi_i\} = \lambda_i [S]\{\phi_i\} \qquad (1)$$

where $[K]$ is the structural stiffness matrix, the Eigen vector, λ_i the Eigen value and $[S]$ the stress stiffness matrix.

Another linear approach is given by linear strain-displacement relations below:

$$\varepsilon_x = \frac{\partial U}{\partial x} \qquad k_x = -\frac{\partial^2 V}{\partial x^2}$$
$$\varepsilon_y = \frac{\partial V}{\partial y} + \frac{W}{R} \qquad k_y = -\frac{\partial^2 V}{\partial y^2} \qquad (2)$$
$$\gamma_{xy} = \frac{\partial V}{\partial x} + \frac{\partial U}{\partial y} \qquad k_{xy} = -\frac{\partial^2 V}{\partial x \partial y}$$

where x and y are the axial and circumferential coordinates in the shell middle surface; U and V are the shell displacements along axial and circumferential directions, and W is the radial displacement, positive outward; ε_x, ε_y and γ_{xy} are strain components; k_x, k_y and k_{xy} are middle surface curvatures of the shell; R is the radius of the cylindrical shell.

Non-linear buckling analysis is a more accurate approach and since this FE analysis has capability of analysing the actual structures with imperfections. This approach is highly recommended for design or evaluation of actual structures. This technique employs a non-linear structural analysis with gradually increasing loads to seek the load level at which the structure become unstable and this phenomenon is also explained in singular and thereby further load step is not possible. In order to overcome this problem, arc tangent iteration scheme is adopted.

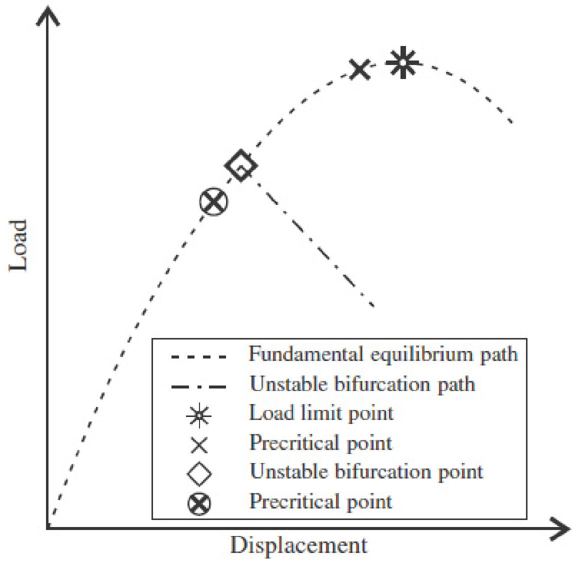

Fig. 1: The proposed procedure for nonlinear buckling analysis

3. Description of specimen and equipment

As a specimen for the experiment (Figure 2.) it is been used a cylindrical tin-walled shell, sized 135x65 mm. Thickness of wall is 0.11 mm. The specimen is subjected to steadily increasing axial load.

For applying load, it's been used hydraulic press Armavir, type PSU-50. Equipment with specimen mounted for experiment is given at Figure 3.

For making dents at the middle of the shell wall, it's been used construction shown at the Figure 4. The bottom end of construction is cantilevered for the lower plate of press. At the top end of the cantilever there is a treaded hole and screw passing through this hole. That screw is leaned against cylindrical shell. By further tightening of screw, it's been made a dent at the shell.

Fig. 2: Tin-walled shell – specimen of the experiment

Fig. 3: Equipment with mounted specimen

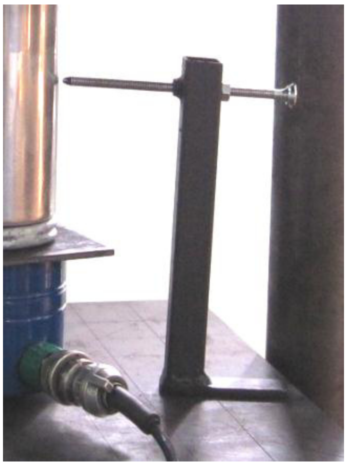

Fig. 4: Mechanism for making dents

4. Course, results and ANALYSIS of experiment

In order to fulfil requirement that the shell carry the entire load, something had to be done to exclude basis from carry it. It came to idea of implementing two rings, made of iron at both sides – up and down. These rings are intermediates between press plates and shell of specimen, which makes basis to be excluded from carrying the load.

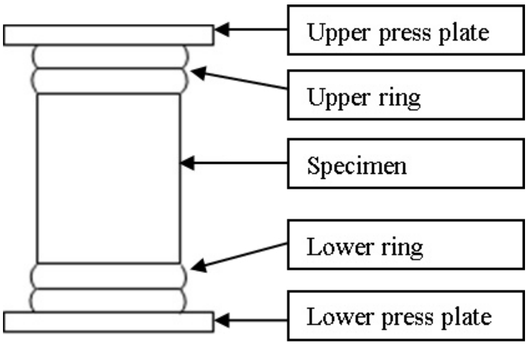

Fig. 5: Pre-experimental postulate

The main idea of experiment is to increase applied axial force gradually (3 kg per step) and to measure strain of specimen for every load step. Every step is consisted of two data: current applied force and value of the strain of specimen. These data pairs are been inserted into diagram. Three cases are been measured:

- Force and strain values with no dents applied,
- Force and strain values with dent of 2 mm,
- Force and strain values with dent of 4 mm.

At figures below, there are results for every case of measurement. It has been carried out 4 series of measurements for each of these cases. All series of the one case are put to the same diagram in order to realize dissipation of data.

Analysing following diagrams, it comes to the conclusion that influence of dent positioned at the middle of shell and perpendicular to it is significant.

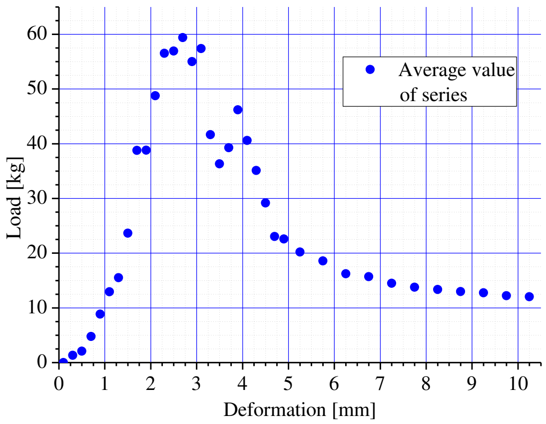

Fig. 6: Results of experiment for 1. Case – Dent=0 mm

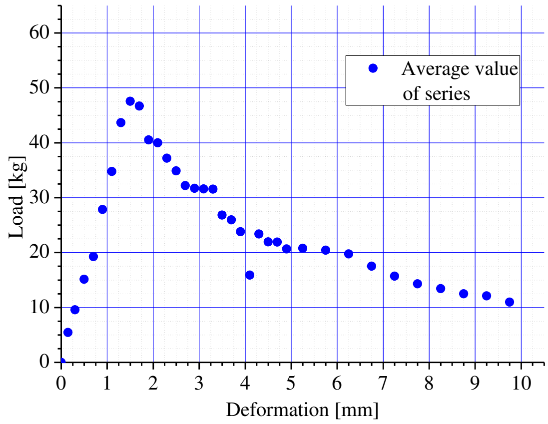

Fig. 7: Results of experiment for 2. Case – Dent=2 mm

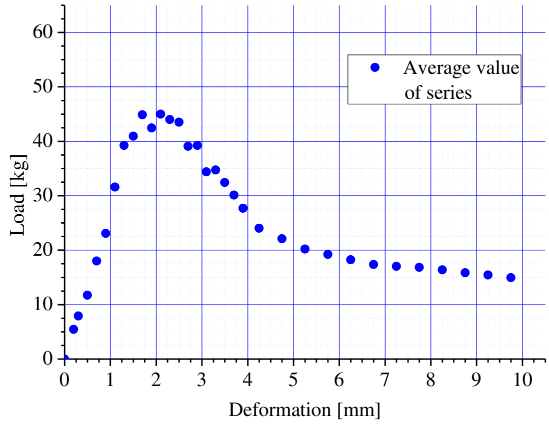

Fig. 8: Results of experiment for 3. Case – Dent=4 mm

At the Table 1, there are average values of critical buckling load for three analysed cases of dent inclination. Average critical load case 1 and case 2 differs approximately 12 kg, but difference between case 2 and case 3 is significantly less (3 kg).

Also, analysing diagrams of experimental results, it is observed decrease of resistance of shell at the force interval 22 to 26 kg. It is observed for every size of dent.

Case	Dent (mm)	Load (kg)
1	0	60
2	2	48
3	4	45

Tab. 1: Average buckling load

5. Conclusion

The following conclusions are made based on experiment and FE analysis carried out on thin cylindrical shells with a dent of different sizes of inclination located at half of the height of cylindrical shell taken for examination.

- There is significant reduction of critical stress if it is for specimen with no dent, and

2 mm dented specimen. Reduction is approximately 20%. However, if it is for specimens with 2 mm and 4 mm, reduction of critical stress is remarkably lower (6%).

- It is observed decrease of resistance of shell at the interval of load 22 to 26 kg for every case of dent inclination.

6. Acknowledgements

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7. References

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