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STATIC ANALYSIS OF CYLINDRICAL SHELL USING THE FINITE ELEMENT METHOD

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ABSTRACT

In the article, two cylindrical shells with different dimensions are statically analyzed using the finite element method. Cylindrical shells with a height to outer diameter ratio (h/d=2) of two and four (h/d=4), and a wall thickness of 1 mm were selected as the research objects. Carbon steel grade 1023 was selected for the cylindrical shells. The cylindrical shells were rigidly fixed on one side (Fixed Geometry fastening type was selected), and free on the other side. A compressive force of 1000N was applied to the inner surfaces of the cylindrical shells. Static analysis was performed using the simulation application in the Solidworks program. As a result of the analysis, the distributed values of the Von Mises stress, normal stress along the x, y and z axes were obtained. At the same time, the distributed values of the total displacement along the x, y and z axes were obtained. The maximum values of von Mises stress, normal stress (along the given axes) and displacement were observed in the sample with a small diameter (d=25mm) and a large height (h=200mm) (h/d=4). A difference of 98% was obtained between the maximum values of stress and displacement in both samples.

2. Introduction

Cylindrical shells are structural elements commonly used in many engineering structures (tanks, pipes, silos, bridges, etc.). These structural elements offer advantages such as lightness and high strength thanks to their thin-walled and curvilinear geometry. However, in order to achieve these advantages, the design and analysis processes of the structures must be carried out correctly. In particular, static analysis plays a critical role in understanding the behavior of shell structures under loading. Recent studies have shown that significant progress has been made in the analysis of cylindrical shells. For example, classical studies by Hutchinson and Koiter have revealed the basic concepts of shell stability [1]. In addition, higher-order shell theories developed by Reddy have enabled more precise analysis, especially of thin-walled structures [2].

In [3] and [4], modeling work using the finite element method was studied. In [5], detailed information was given on the theory of stability of plates and cylindrical shells. Issues of practical importance were solved. In [6], the problem of dynamic stability of cylindrical shells with different resistance to tension and compression was solved. This literature review highlights the scope of methods used in static analysis of cylindrical shells and their importance in engineering applications.

This study focuses on the static analysis of cylindrical shells and examines in detail the fundamental parameters and analysis methods affecting the behavior of these structural elements. Analytical and numerical approaches such as classical shell theory and finite element method are discussed, and the advantages and limitations of these methods are discussed. The study also examines the effects of loading conditions and boundary conditions on the shell behavior and draws attention to the critical factors that should be considered in the design process of these structures. In addition, the effect of changes in material properties and geometric parameters on the analysis results is evaluated.

This study aims to reveal the basic factors to be taken into consideration in structural design by examining the theoretical and numerical methods used in determining the static behavior of cylindrical shells.

3. Materials and Methods

2.1. Design and material selection of cylindrical shells

Three samples were selected as the object of the study. The dimensions of the samples are as follows:

Cylindrical shell 1 (№1): Height h=100mm; outer diameter d=50mm, wall thickness b=1mm;

Cylindrical shell 1 (№1): Height h=200mm; outer diameter d=25mm, wall thickness b=1mm;

3D models of cylindrical covers were drawn in the Solidworks program. For this, a 2D drawing was first drawn using the shell application in the program and converted into a 3D model. (Fig. 1).

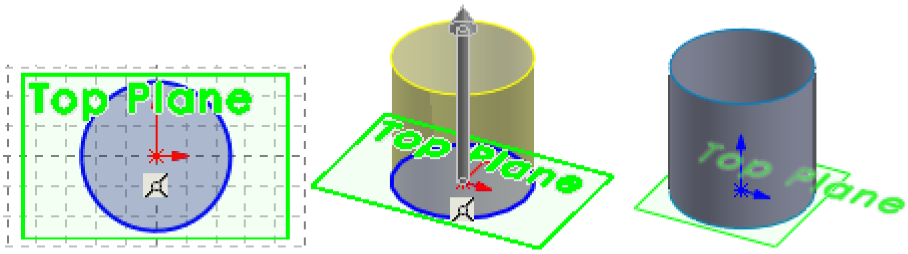


Fig. 1. Steps for drawing a cylindrical shell in Solidworks

Cylindrical shells are components that are often used in structural engineering, the automotive industry, the aerospace industry, or the chemical industry. These shells can be made from different materials, but some of the main materials commonly used are:

1. Steel: Steel is widely used in the production of cylindrical shells due to its durability and strength. It is preferred in applications such as automotive, construction and pipelines.

2. Aluminum: Aluminum is generally used in the aerospace industry and the automotive sector due to its lightness and corrosion resistance. Aluminum alloys are especially preferred for cylindrical structures.

3. Composite Materials: Composite materials, usually cylindrical shells made of carbon fiber or fiberglass, are preferred in sectors with high strength and lightness requirements. It is common in aircraft and high-performance automobiles.

4. Stainless Steel: Stainless steel is used especially in environments requiring corrosion resistance and high temperature resistance. It is frequently used in the chemical industry and energy sector.

5. Concrete: Concrete is used in the construction sector, especially for large cylindrical structures (water tanks, silos, pipelines). Concrete cylindrical structures are generally preferred as structures that carry large loads on the ground.

Each material is selected according to the requirements of a specific application and is usually designed based on engineering calculations. In this article, we select steel grade 1023 from the Soldworks library. The mechanical properties of the selected material are as follows:

Modulus of elasticity: 204999N/mm2;

Poisson's ratio: 0.29;

Tensile strength 425N/mm^2

Shear modulus 79999 N/mm^2

Density: 7858kg/m3;

Yield strength: 282.985N/mm2.

2.2. Static analysis of cylindrical shells

Developing computer technology has made it possible to widely use numerical methods in the analysis of cylindrical shells. One of the most preferred methods is the finite element method (FEM). FEM provides precise solutions for structures with complex geometry and boundary conditions.

In finite element modeling, the shell structure is usually represented by shell elements. These elements are solved by the principle of minimizing deformation energy. The advantages of FEM include:

- Easily model various loading conditions.
- Applicability to complex geometries.
- Precise and detailed analysis.

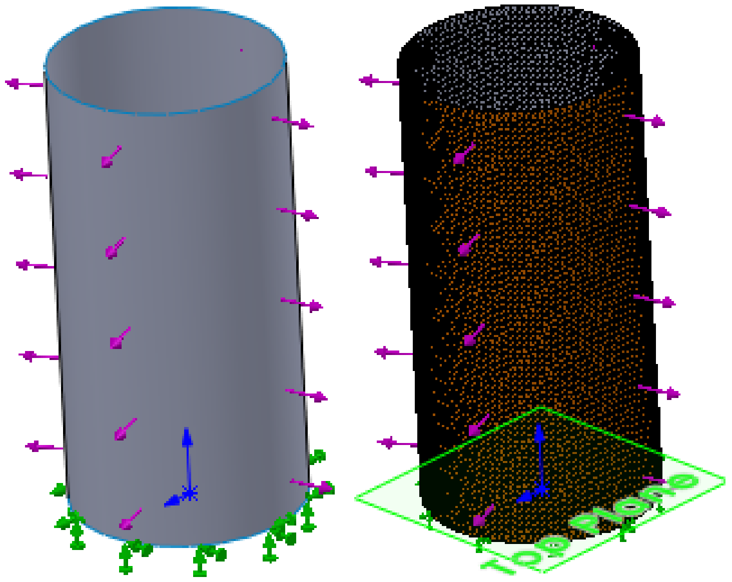
However, FEM requires high computational costs and the solution accuracy depends on the element size and mesh structure.

To start the static analysis of cylindrical shells, the loading conditions and boundary conditions must first be determined. In the static analysis of cylindrical shells, the loading conditions and boundary conditions play a critical role. The most common loading conditions include:

- Internal pressure: Commonly encountered in storage tanks and pipes.
- Axial load: Observed in silos and column-like structures.
- External pressure: Occurs in vacuum conditions or submarine structures.

Boundary conditions vary depending on whether the structure is fixed, simply supported or freely supported. Correct definition of these conditions in the analysis is of great importance in terms of solution sensitivity.

In the considered work, a static analysis of cylindrical shells is performed for axial loading conditions. In the static analysis, 2 samples with the dimensions specified in section 2.1 were selected. We assume the load amount to be 1000N. The plate is rigidly fixed on one side and free on the other. The cylindrical shells are subjected to a compressive force of 1000N from the inside. When performing an analysis using the finite element method, the mesh sizes must also be determined. The mesh sizes are an important factor affecting the accuracy of the analysis results. In this regard, we select a fine mesh with dimensions of 1.50mm and 0.075mm. Steel grade 1023 was selected as the material from the Solidworks library. The application of the aforementioned boundary conditions on a 3D model is shown in Figure 2.



a) b)

Fig. 2. Application of boundary conditions and mesh properties:

a) boundary conditions; b) application of mesh parameters

Within the given boundary conditions, as a result of static analysis, we obtain the distributed values of Von Mises stress, normal stress and displacement along the surface of the cylindrical shell (in the x, y and z axes). The distributed values of Von Mises stress and normal stress for Examples 1 and 2 are given in the figures below.

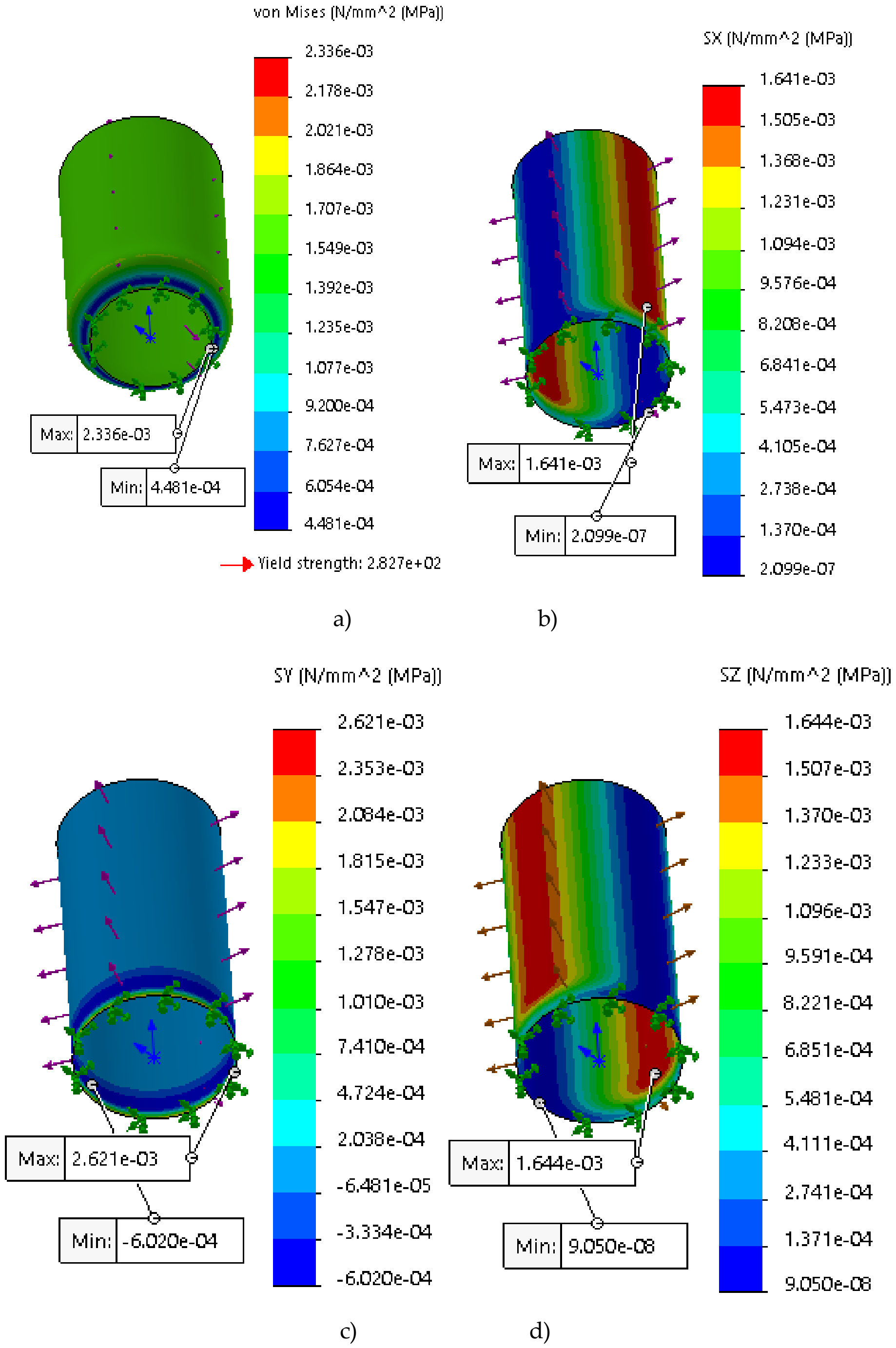


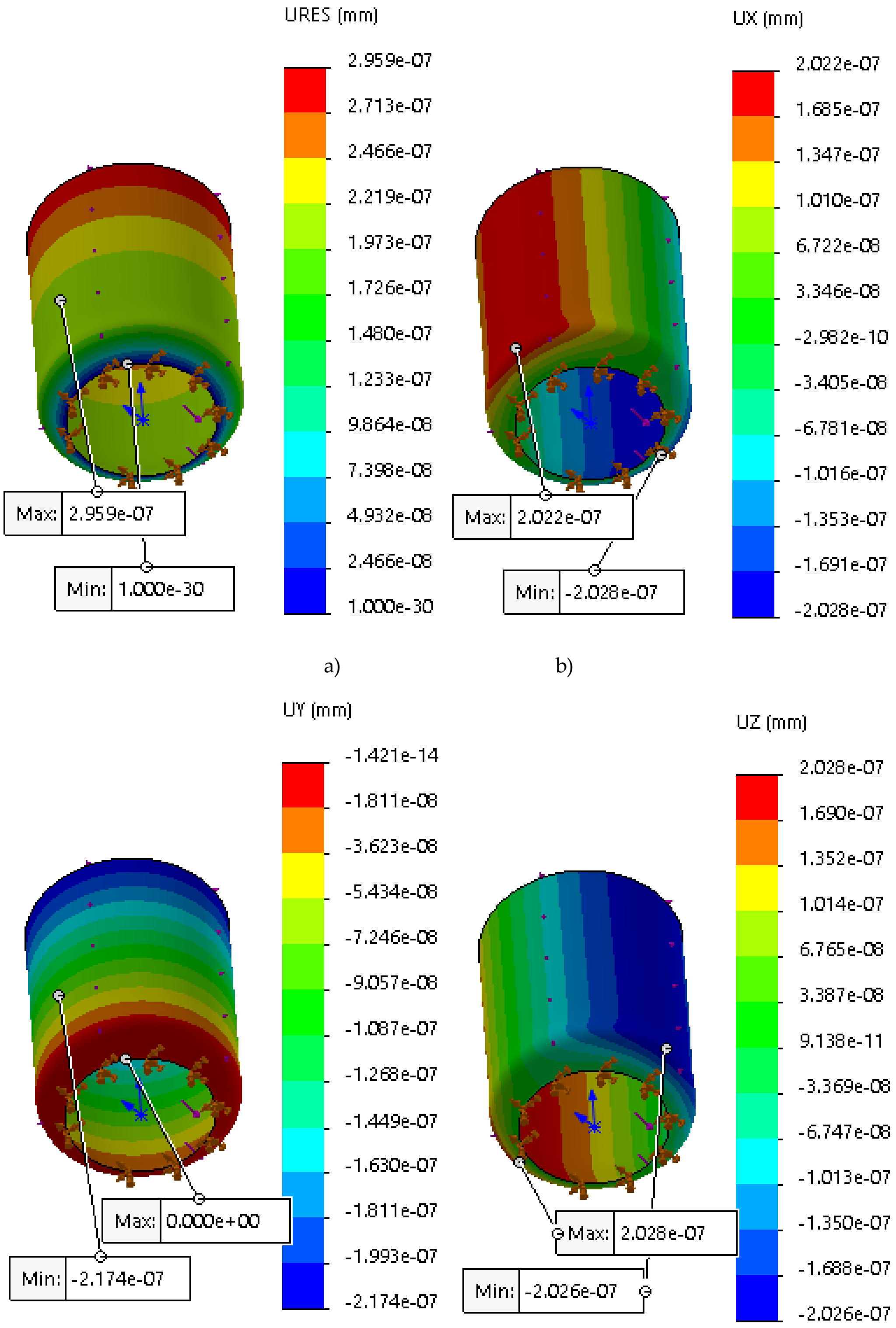
Fig. 3. Stress distribution values along the surface of the cylindrical shell for example 1:

a) Von Mises stress distribution values;

b) Normal stress values along the x axis;

c) Normal stress values along the y axis;

d) Normal stress values along the z axis.



c) d)

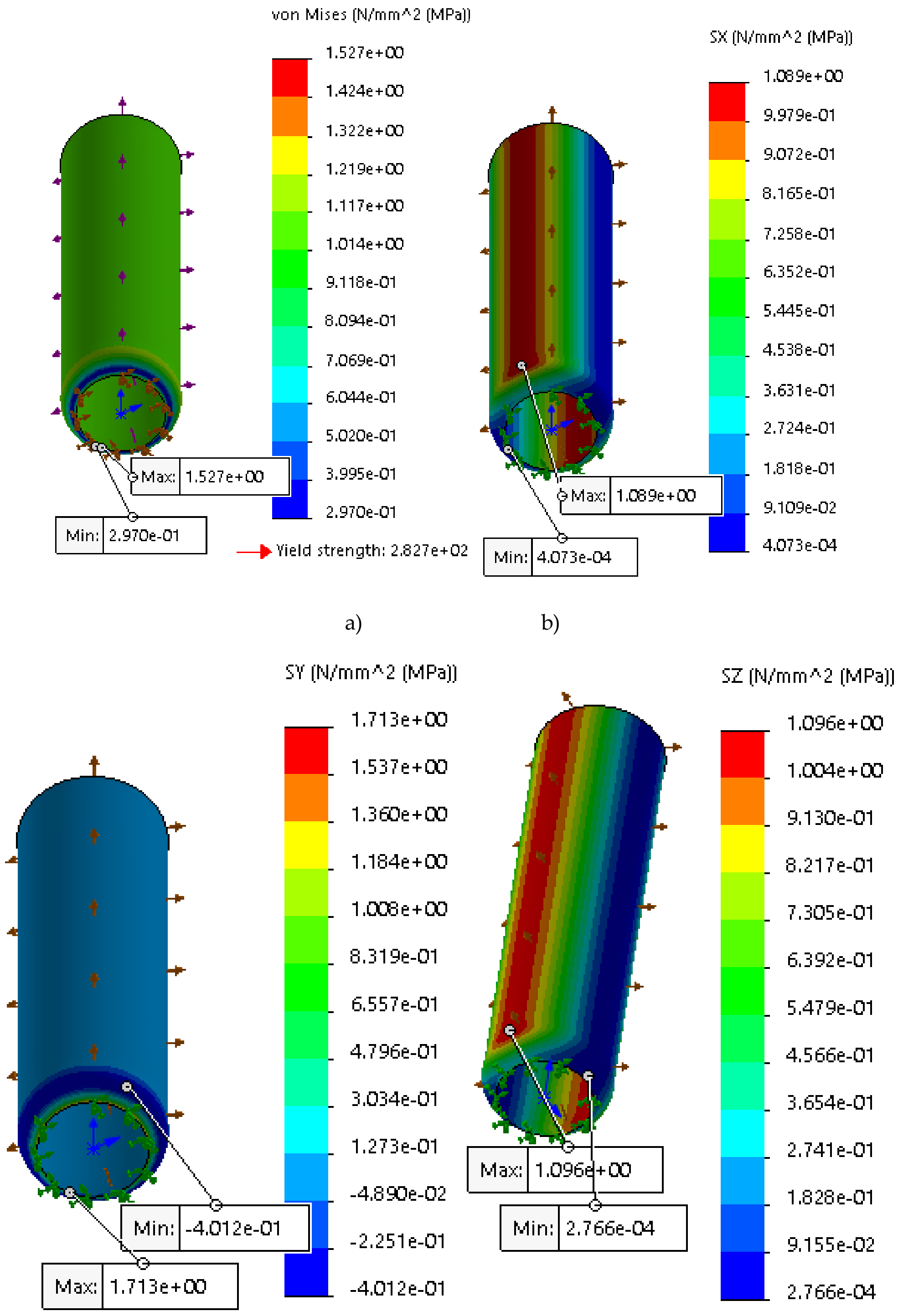
Fig. 4. Displacement values distributed along the surface of the cylindrical shell for example 1:

a) Displacement values distributed along the total displacement;

b) Displacement values along the x axis;

c) Displacement values distributed along the y axis;

d) Displacement values distributed along the z axis.



a) b)

c) d)

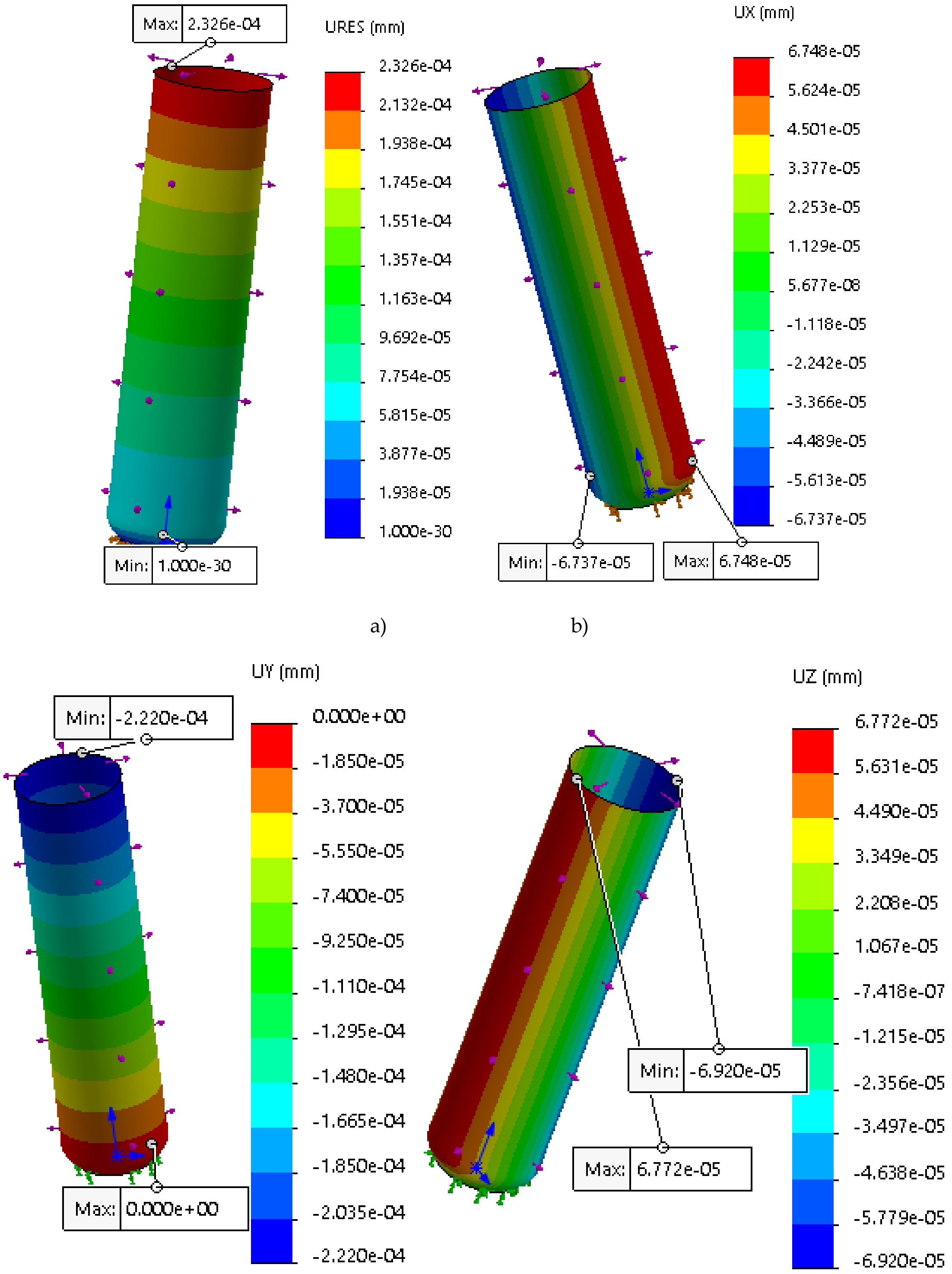
Fig. 5. Stress distribution values along the surface of the cylindrical shell for example 2:

a) Von Mises stress distribution values;

b) normal stress values along the x axis;

c) normal stress values along the y axis;

d) normal stress values along the z axis.



a) b)

c) d)

Fig. 6. Displacement values distributed along the surface of the cylindrical cover for Example 2:

a) Displacement values distributed along the total displacement;

b) Displacement values along the x axis;

c) Displacement values distributed along the y axis;

d) Displacement values distributed along the z axis.

4. Results of static analysis

In Example 1, the maximum value of the Von Mises stress was 0.002336N/mm2, and the minimum value was 0.00048N/mm2. The maximum value of this stress was observed in the fastening zone of the cylindrical shell, and the minimum value was observed in the zone relatively close to the fastening zone. The maximum value of the normal stress along the x axis was 0.00164N/mm2, and the minimum value was 2x10-7 N/mm2, and the y and z axes were 0.00262N/mm2, 6x10-4N/mm2, and 0.00164N/mm2, 9x10-8 N/mm2, respectively. The maximum value of the stress along the x and z axes was distributed symmetrically along the surface of the cylindrical shell in the axial direction. The minimum value of the stress was observed in other zones in the axial direction (Fig. 3).

The maximum value of the total displacement in sample 1 was 2.9x10-7mm, and the minimum value was 1x10-30 mm. The maximum value of the displacement in the x-axis direction was 2.02x10-7mm, and the minimum value was -2x10-7mm, and the values along the y and z axes were -1.4x10-14mm, -2.174x10-7 mm and 2x10-7mm, -2.02x10-7mm, respectively. The maximum value of the total displacement was observed on the top surface of the sample, and the minimum value was observed at points close to the specimen's mounting zone. The maximum value of the displacement along the x and z axes was observed along the cylinder's surface in the axial directions (Fig. 4).

In sample 2, the maximum value of the Von Mises stress was 1.527N/mm2, and the minimum value was 0.297N/mm2. The maximum value of this stress was observed in the fastening zone of the cylindrical shell, and the minimum value was observed in the zone relatively close to the fastening zone. The maximum value of the normal stress along the x axis was 1.089N/mm2, and the minimum value was 4x10-4 N/mm2, and the values along the y and z axes were 1.713N/mm2, 0.04N/mm2, and 1.096N/mm2, 2.7x10-4 N/mm2, respectively. The maximum value of the stress along the x and z axes was distributed symmetrically along the surface of the cylindrical shell in the axial direction. The minimum value of the stress was observed in other zones in the axial direction (Fig. 5).

The maximum value of the total displacement in sample 1 was 2.32x10-4 mm, and the minimum value was 1x10-30 mm. The maximum value of the displacement in the x-axis direction was 6.7x10-5 mm, and the minimum value was -6.7x10-5 mm, and the values along the y and z axes were -2.22x10-4 mm, 6.77x10-5 mm, and -6.9x10-5 mm, respectively. The maximum value of the total displacement was observed on the top surface of the sample, and the minimum value was observed at points close to the fastening zone of the sample. The maximum values of the displacement along the x and z axes were observed along the surface of the cylindrical shell in the axial direction. The displacement values in the tension and compression regions along the surface of the sample were almost equal (Fig. 6).

5. Conclusion and discussions

Static analysis of cylindrical shells requires a combination of both theoretical and numerical methods. Classical shell theory provides a simple and effective approach, while numerical methods such as FEM provide a suitable option for more complex cases.

In the article, a static analysis was performed on a cylindrical shell with two different dimensions (h/d=2, h/d=4). Soldworks software was used to perform the static analysis. The following results were obtained.

1. The largest value of the von Mises stress was obtained in sample 2. The difference in value was 95%. The smallest value was observed in sample 1. In both samples, the largest value of the von Mises stress occurred at points close to the fastening zones of the cylindrical shell.

2. The largest values of normal stress along the x, y and z axes were observed in sample 2, and the smallest values were observed in sample 1. There is a difference of 98% between the largest values of stress along the x and z axes, and 99% between the largest values of stress along the y axis. In both samples, the normal stress along the x and z axes is distributed in the tensile zones along the surface of the cylindrical shell.

3. The maximum value of the total displacement occurred in sample 2, and the minimum value occurred in sample 1. There is a 99% difference between the largest values of displacement for both samples. The largest values of displacement along the x, y, and z axes were again observed in sample 2. There is a 98% difference between the values of displacement along the x and z axes. In both samples, the values of displacement in the tension and compression zones along the x and z axes are equal.

As can be seen, based on the stress and displacement values, the most effective cylindrical shell is considered to be example 1. That is, as the diameter of the cylindrical cover decreases and its height increases, the stress and displacement values increase.

This study aims to contribute to the development of more effective methods in the design and analysis processes of cylindrical shells. Future studies could examine the integration of innovations in materials technologies and AI-based analysis methods into this field.

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