University of Banja Luka
Faculty of Mechanical Engineering

DEMI 2025

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PROCEEDINGS

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Banja Luka, 29–30 May 2025

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Faculty of Mechanical Engineering

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CONTENT

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Analysis of the Stress-Strain State of a Composite Pressure Vessel

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Abstract *The subject of analysis in this work is a composite pressure vessel used for storing Liquefied Petroleum Gas (LPG), specifically a propane-butane mixture. Composite vessels for LPG storage are widely used due to their advantages, such as low weight, high corrosion resistance, and good mechanical properties. The analyzed vessel belongs to Type III (according to the classification of ASME – American Society of Mechanical Engineers and ISO – International Organization for Standardization), meaning it is a metal vessel with a full composite overwrap. The analysis was conducted using the Finite Element Method (FEM) in SolidWorks V2019 software. The results showed that the maximum von Mises stress values, as well as interlaminar stress values, do not exceed the allowable stress limits that would lead to structural failure. This was further confirmed by the obtained safety factor values, which are within the prescribed limits.*

Keywords *pressure vessel, composites, SolidWorks, stresses, safety factor*

1. INTRODUCTION

The walls of a pressure vessel are subjected to internal pressure. Depending on the application, there are various types of vessels, such as boilers, reactors, storage tanks, and others. The working medium, based on its physical and chemical properties, can be neutral, aggressive, flammable, explosive, toxic, radioactive, etc. Depending on the properties of the working medium, the characteristics of the pressure vessels themselves will also vary.

An optimal pressure vessel design is achieved through a detailed engineering analysis, primarily by defining the fundamental parameters of the vessel, such as: the loading conditions to which the vessel is subjected, material selection, capacity, vessel dimensions, the plant in which the vessel is installed, operating conditions, and other relevant factors. The material used for manufacturing the vessel must be compatible with the substances contained within it, in order to prevent corrosion, contamination, and other potential issues. Compliance with regulations is essential to ensure that the vessel meets all relevant standards and legal requirements.

Composite overwrapped pressure vessel-COPV are specialized tanks or vessels made from composite materials. A composite pressure vessel consists of a thin liner overwrapped with structural fibers. It is designed to contain liquids or gases under pressure.

The primary advantage of composite pressure vessels, compared to conventional metal vessels, lies in achieving significantly higher strength and

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durability while maintaining a lower weight for vessels of the same dimensions. On the other hand, the manufacturing process of composite pressure vessels is more complex, which results in higher production costs. Additionally, these vessels require more demanding testing and inspection procedures to ensure safety and reliability.

Numerous researchers have addressed the analysis of composite pressure vessels in their studies.

The study presented in [1] provides a comparative analysis of a conventional steel pressure vessel and a composite pressure vessel. Furthermore, the effect of the fiber orientation angle on the stress-strain behavior of the composite vessel was examined. The analysis was carried out using both analytical approaches and numerical simulations performed in ANSYS 14.5.

In study [2], alongside the investigation of the influence of fiber orientation angle, the author also examined the impact of fiber winding patterns on the load-bearing capacity of composite pressure vessels. Given that these vessels typically feature thick-walled constructions, the analysis was performed using 3D multilayer shell elements to achieve higher accuracy in stress and strain predictions, employing the most widely accepted failure criteria.

Study [3] addresses the development of an experimental testing methodology for pressure vessels, noting that existing experimental approaches exhibit certain limitations, which contribute to discrepancies between experimental findings and numerical simulations.

The authors of study [4] conducted experimental investigations on pressure vessels incorporating either only short fibers or a combination of short and long fibers within their structural composition. The analysis revealed that vessels reinforced with long fibers demonstrate significantly superior mechanical performance and structural integrity.

The objective of the author in study [5] was to develop an analytical model for determining the optimal fiber orientation of a composite pressure vessel that would ensure a minimum buckling load. In addition, the study included a numerical static and buckling analysis of the pressure vessel, performed using ANSYS software.

2. MODELLING AND ANALYSIS OF THE COMPOSITE PRESSURE VESSEL

Composite vessels for Liquefied Petroleum Gas (LPG) storage are widely used due to their advantages, such as low weight, high corrosion resistance, and favorable mechanical properties. The vessel analyzed in this study belongs to Type III (metal liner with a full composite overwrap). The volume of the vessel is approximately 130 l, its mass is 20 kg, and the vessel is subjected to an internal pressure of 15 bar.

The modeling and analysis of the stress-strain state of the analyzed vessel were performed using SolidWorks V2019 software. Given the complete symmetry of the geometry, only a quarter of the vessel was analyzed (Figure 1) [6].

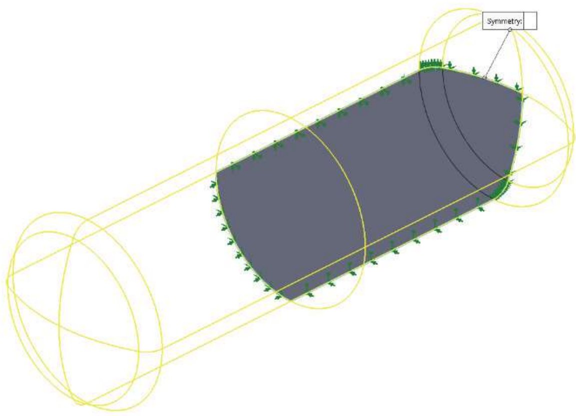

Fig. 1. Cutting a quarter of the pressure vessel

The dimensions of the analyzed vessel can be seen in Figure 2.

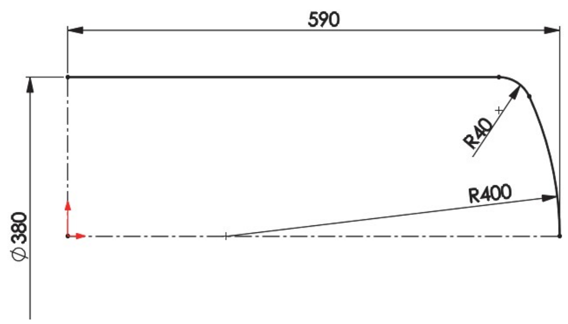

Fig. 2. Geometric dimensions of the vessel

The vessel wall consists of two main components:

- Aluminum 6061-T6, 2 mm thick, which provides impermeability, corrosion resistance, and satisfactory mechanical properties,

- Composite part – E-Glass/epoxy resin, which serves as the outer layer and further strengthens the vessel due to its high tensile strength, corrosion resistance, and low specific density. The thickness of this laminated part is 8 mm, consisting of 34 layers of 0,125 mm and 15 layers of 0,25 mm.

The material database in SolidWorks contains the properties of aluminum 6061-T6, so it was only necessary to define the composite material of glass fibers/epoxy resin, which exhibits orthotropic characteristics. The card displaying the defined mechanical properties of the applied composite material can be seen in Figure 3.

Property	Value	Units
Elastic Modulus in X	73000	N/mm^2
Elastic Modulus in Y	10000	N/mm^2
Elastic Modulus in Z	10000	N/mm^2
Poisson's Ratio in XY	0.22	N/A
Poisson's Ratio in YZ	0.35	N/A
Poisson's Ratio in XZ	0.35	N/A
Shear Modulus in XY	30000	N/mm^2
Shear Modulus in YZ	4000	N/mm^2
Shear Modulus in XZ	4000	N/mm^2
Mass Density	2600	kg/m^3
Tensile Strength in X	3400	N/mm^2
Tensile Strength in Y	70	N/mm^2
Compressive Strength in X	500	N/mm^2
Compressive Strength in Y	70	N/mm^2
Shear Strength in XY	72	N/mm^2

Fig. 3. Filled material properties card for E-Glass/epoxy resin

The connection with the cut section of the structure can be replaced by movable supports, as shown in Figure 4.

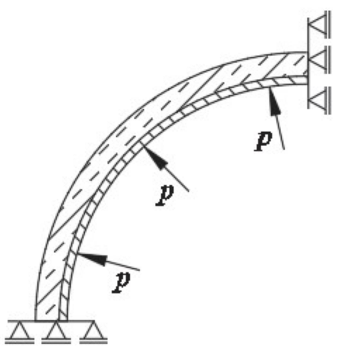

Fig. 4. Representation of the constraints of the analyzed part of the vessel

The model of the vessel with applied boundary conditions, specified loading, and the generated finite element mesh is shown in Figure 5. The internal surfaces of the vessel, subjected to a pressure intensity of 1.5 MPa (equivalent to a pressure of 15 bar), were selected.

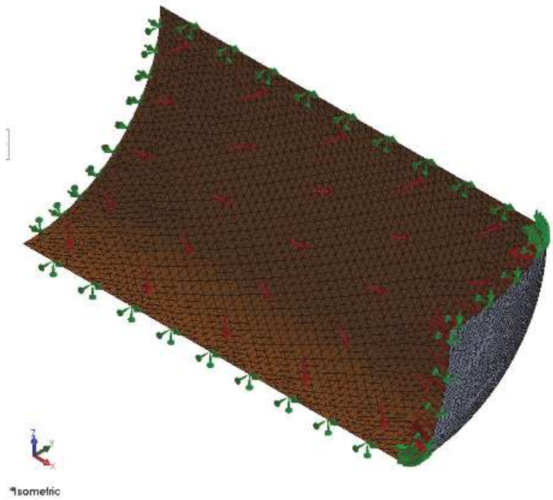

Fig. 5. Vessel with applied loading, constraints, and generated finite element mesh

After performing the static analysis, the values of the equivalent von Mises stress were obtained. The distribution of this stress, with highlighted maximum and minimum stress values and the regions where they occur, can be seen in Figure 6. It can be observed that the minimum stress is 17,7 MPa, while the maximum stress is 87,8 MPa.

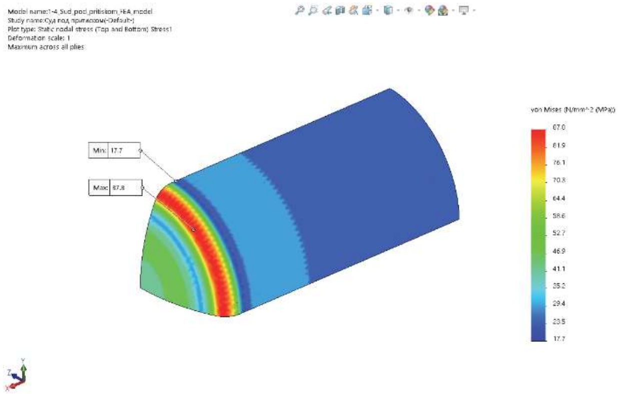

Fig. 6. Distribution of the equivalent von Mises stress

It is also possible to perform an analysis of the deformation state of the pressure vessel. In Figure 7, the zone of maximum deformation is clearly visible, where the maximum displacement is 0,461 mm.

Fig. 7. Representation of the deformed state of the composite vessel

In composite structures made of multiple layers, it is important to check interlaminar stresses. Interlaminar stresses are crucial for the analysis of composite structures for several reasons:

- Interlaminar stresses can cause delamination, i.e., separation of composite layers. This is one of the most common and critical forms of damage in laminated composites.
- Structural integrity: These stresses affect the overall structural integrity of the composite construction. If interlaminar stresses are not considered, unexpected structural failure may occur.
- Load distribution: Interlaminar stresses influence how the load is transferred between layers. Improper distribution can lead to stress concentration and local damage.

Figure 8 shows the state of interlaminar stresses in the XZ plane, and it can be observed that the maximum value of these stresses is 6,8 MPa.

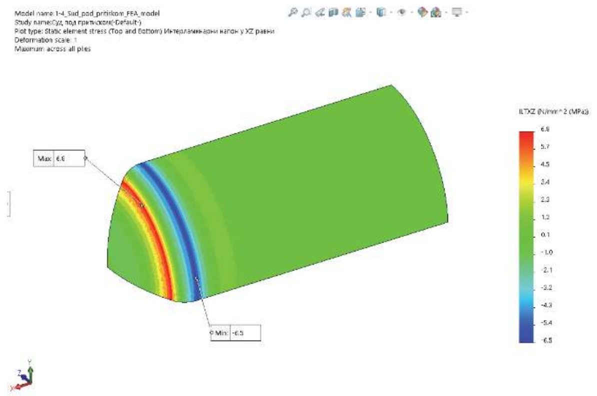

Fig. 8. Representation of interlaminar stress in the XZ plane

The representation of interlaminar stresses in the YZ plane is performed in the same way as in the XZ plane. The values of interlaminar stresses in the YZ plane are shown in Figure 9. The maximum stress value in this plane is 5 MPa.

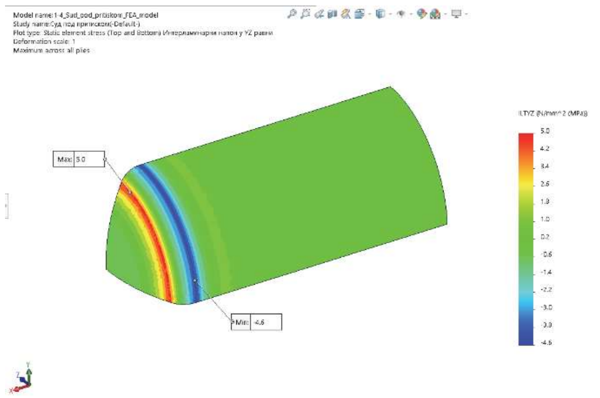

Fig. 9. Representation of interlaminar stress in the YZ plane

The values of interlaminar stresses in both planes do not exceed 7 MPa, which is several times lower than the shear strength in the plane, which for the E-Glass/epoxy resin composite material is 72 MPa, as previously stated in the table in Figure 3. It can be concluded that these stress values do not pose a risk of delamination or structural failure.

The load-bearing capacity of the pressure vessel was also checked through a safety factor analysis. Figure 10 shows degree of safety with values in specific zones.

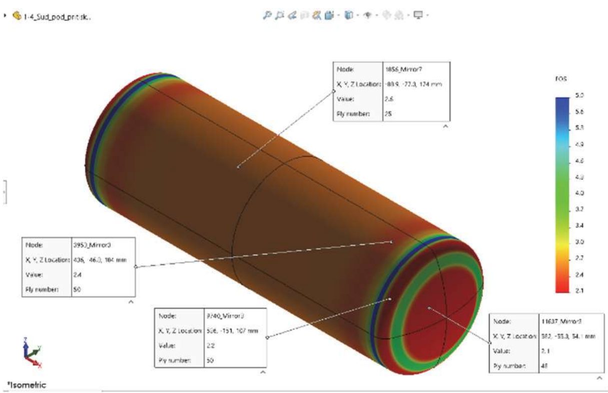

Fig. 10. Representation of degree of safety

The recommended values of degree of safety for such types of vessels range from 1,5 to 3. Considering that the minimum value of degree of safety is 2,1, it can be concluded that the degree of safety is satisfied in all regions of the vessel.

3. CONCLUSION

The subject of this paper is the analysis of the stress-strain state of a composite pressure vessel used for the storage of Liquefied Petroleum Gas (LPG), specifically propane-butane. The vessel is made of metal (aluminum) with a full composite overwrap of E-glass fibers/epoxy resin. The analysis was performed using SolidWorks software.

The obtained values of degree of safety, which are within the recommended range in all areas of the analyzed vessel, confirmed that the stress and deformation values are within the allowable limits.

The analysis of interlaminar stresses in the XZ and YZ planes, which are significantly lower than the shear strength of the analyzed composite material, showed that these stress values do not pose a risk of delamination or structural failure.

The obtained results correspond to real values, thus confirming that successful analysis of composite structures can be carried out using SolidWorks software.

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