مجلة جامعة بني وليد للعلوم الإنسانية والتطبيقية
Bani Waleed University Journal of Humanities and Applied Sciences
تصدر عن– جامعة بني وليد – ليبيا
Website:https://jhas-bwu.com/index.php/bwjhas/index
المؤتمر الدولي الرابع للعلوم و الهندسة

المجلد الحادي عشر – العدد الثاني – 2026 عدد خاص الصفحات (160- 171) ISSN 3005-3900

Optimization of Fiber Winding Angles for Enhanced Structural Performance of Composite Pressure Vessels Using Finite Element Analysis

Mohamed Rahuma G. Rahuma[1]*, Omar Ahmed Mohamed Edbeib[2], Wannees Shabeesh[3]
[1] Libyan Authority for Scientific Research, Libyan Centre For Plasma Research,Tripoli-Libya
[2] Faculty of Engineering Bani Waleed university ,Libya
[3] High institute of Engineering
omeredbeib@bwu.edu.ly

تحسين زوايا لف الألياف لتحسين الأداء الهيكلي لأوعية الضغط المركبة باستخدام تحليل العناصر المحدودة

محمد رحومة *[1]، عمر أحمد إدبيب [2]، ونيس شابيش[3]
[1] الهيئة الليبية للبحث العلمي، المركز الليبي لأبحاث البلازما، طرابلس – ليبيا
[2] كلية الهندسة، جامعة بني وليد، ليبيا
[3] المعهد العالي للهندسة، ليبيا

Received: 13-11-2025	Accepted: 21-12-2025	Published: 01-03-2026

الملخص:
من التجارب التي أُجريت على الأوعية المضغوطة، لوحظ بوضوح أن المواد المركبة توفر جودة وسلامة فائقتين مقارنة بالأوعية المصنوعة من الفولاذ. ومع ذلك، لا يزال التحدي الرئيسي يتمثل في تحديد زوايا اللف الأمثل للألياف، حيث يتم تصنيع معظم الأوعية المركبة باستخدام تقنية لف الخيوط **.(Filament Winding)** تبحث هذه الدراسة في تحسين زوايا لف الألياف في الأوعية المضغوطة المركبة **(CPVs)** بهدف تحسين الأداء الهيكلي دون زيادة السُمك أو الوزن. وقد أظهرت المواد المركبة أنها توفر سلامة فائقة وتقلل الوزن مقارنة بالأوعية الفولاذية التقليدية، مما يبرر تكلفتها الأعلى قليلاً. انطلاقاً من الدراسة السابقة، والتي استخدمت فيها ترتيب طبقات لف بتركيب **α[0,66,0,-66,0]**في أسطوانة الغاز المركبة، تقيم هذه الدراسة أربعة تركيبات بديلة **α[45,-45,0,65,-65]** :و **α[0,75,0,-75,0]**و **α[0,50,0,-50,0]** و**α[0,90,0,90,0]** ، باستخدام تحليل العناصر المحددة **(FEA)** في برنامج **ANSYS Workbench.** كشفت النتائج أن التركيب **α[0,50,0,-50,0]** أظهر أفضل أداء، حيث حقق إجهاد **hoop = 18** ميجا باسكال وإجهاد محوري = 5 ميجا باسكال مع الحفاظ على نفس الهندسة والوزن. وهذا يؤكد أن تحسين اتجاهات اللف يعزز الأداء الميكانيكي للأوعية المضغوطة المركبة دون المساس بميزة خفة الوزن.

الكلمات الدالة: برنامج **ANSYS**،الإجهادات المحورية، الوعاء المضغوط المركب، المواد المركبة، زوايا اللف، طريقة العناصر المحددة، إجهادات **Hoop**.

Abstract

From the experiments carried out on pressure vessels, it was clearly observed that composite materials provide superior quality and safety compared to steel-made vessels However, a major challenge remains in determining the optimum fiber winding angles, since most composite vessels are manufactured using the Filament Winding technique..This study investigates the optimization of fiber winding angles in composite pressure vessels (CPVs) with the aim of improving structural performance without increasing thickness or weight. Composite materials have been shown to provide superior safety and reduced weight compared to conventional steel vessels, justifying their slightly higher costs. Building upon the previous study , where a winding layers configuration of [0,66,0,-66,0]α in composite gas cylinder was employed, this study evaluates four alternative configurations: [45,-45,0,65,-65]α, [0,75,0,-75,0]α, [0,50,0,-50,0]α, and [0,90,0,90,0]α, using finite element analysis (FEA) in ANSYS Workbench. Results reveal that the [0,50,0,-50,0]α configuration demonstrates the best performance, achieving Hoop Stress = 18 MPa and Axial Stress = 5 MPa while maintaining identical geometry and weight. This confirms that optimization of winding orientations enhances the mechanical performance of CPVs without compromising their lightweight advantage.

Mesh independence and Tsai-Wu failure criterion were used to ensure result reliability. The findings provide valuable insight for industrial designers seeking lightweight, high-strength vessel configurations.

Keywords: (ANSYS Software, Axial stresses, Composite pressure vessel, Composite Materials, Winding angles, Finite Element Method, Hoop stresses).

1. Introduction

Composite pressure vessels are made of advanced composites, such as carbon fiber reinforced plastic (CFRP), which make them ideal for high-pressure storage applications due to their high strength-to-weight ratio. These materials also have high corrosion and fatigue resistance, making them suitable for storing various gases. Compared to metallic pressure vessels, composite

pressure vessels CPVs are typically lighter and more durable and have a longer lifespan.[2][3]. Making them a cost effective storage option, as they require less maintenance and can be used longer. Figure.1 explain Typical features of the Type IV CPVs.

Type IV CPVs are widely used for various domestic and space applications. In terms of weight reductions, Type IV CPVs are an appropriate substitute for Type III, Type II and Type I. When compared to the traditional Type I vessel, Type IV CPV can reduce weight by up to 75%. CPVs also exhibit safer burst behavior[4]. Figure. 2 provides the schematics of various types of PVs. Pressure vessels are classified as follows: fully metallic tank (Type I), metallic liner hoop-wrapped with composite (Type II), metallic liner fully overwrapped with composite (Type III), polymer-lined composite vessel (Type IV), and linerless composite pressure vessel (Type V) .[12] [13]

Filament winding is the most reliable and economical method for creating intricately complex composite structures.[5][6]. The method is based on winding a mandrel with fibers embedded in epoxy. Most recent winding machines in operation have at least 3-axes and are computer-aided. Machines with 6-axes are widely used to create more complicated shapes. This sophisticated technology allows winders to wind non-cylindrical and non-symmetric shapes.[7][6]

The fibres are drawn through a resin bath and then through an eye that monitors the orientation of the fiber to the mandrel. The carriage moves around the spinning mandrel, adding the epoxy.

Applying the correct amount of tension while winding is critical since the tension determines the friction force between the fibres and the mandrel, as well as the control of the resin. as shown in Figure.3.

The winding angles play a crucial role in tailoring the pressure-bearing properties of CPVs. As shown in Figure.4 a Schematic detail of various winding configurations, showing the angular orientation with respect to the cylinder axis.

All COPVs provide great benefit over all metal pressure vessels in terms of weight, but COPVs require unique and proper mechanical design, fabrication, and testing requirements.

The most noteworthy attribute of COPV is that they require a more intricate mechanical consideration because of the interchange between the composite layers and the inward liner. A metallic liner is ordinarily utilized as a part of a COPV as a barrier to fluid penetration which requires conventional metallic pressure vessel design. Different failure criteria exist for COPVs, and consideration of the factors of these criteria are much more different than when they are used for metallic pressure vessels.

Despite their wide-spread use, the development of many COPV designs is still rather primitive. Often only limited analysis is performed to obtain an initial design, and then the design is refined through several "build and burst "iterations.[8] . However, the cost in material and resources to fabricate multiple test articles is extremely high. To reduce costs, Finite Element Analysis (FEA) is often employed to reduce the number of iterations required.

This study extends the work of Mohamed Rahuma and Ramadan Wadi[1] , investigating whether alternative winding orientations can yield superior stress distributions while maintaining constant geometry and weight. where they studied the fourth type of cylinders and arranged the [0,66,0,-66,0]α angles and obtained satisfactory results. this study evaluates four alternative configurations of layers angles to see the possibility of improving the cylinder's endurance without increasing its thickness.

Despite many studies on composite pressure vessels, few have systematically compared multiple winding configurations under identical mass and geometry. This study fills that gap by evaluating the structural performance of four configurations using ANSYS Workbench.

Litreture reviw

Several studies have explored fiber winding optimization in CPVs:

• Shah Alam June (2020) [10] optimized winding sequences for Type IV CPVs, identifying combinations of polar and helical layers that maximized pressure containment.

• Mohammad Azeem et al. (2023) [9] demonstrated that multi-angle winding significantly reduces hoop stress levels, highlighting the advantages of hybrid orientations.

• Mohamed Rahuma G. Rahuma and Ramadan Shamiss Wadi, (2024) [1] investigated the replacement of steel LNG cylinders with composite alternatives using [0,66,0,-66,0]α winding, achieving substantial weight reduction while maintaining safety standards.

• Qingshan Zeng, Zuxin Chen (2024) [11] applied advanced parametric modeling and genetic algorithms to optimize ply angles, reporting considerable stress reductions for complex geometries.

• Sulaiman et al. (2013) [12] demonstrated that filament winding patterns critically influence strength in Type III and Type IV vessels.

• Yohannes Regassa et al. (2022) [13] showed that stacking sequence and winding angle significantly affect burst pressure capacity in composite-overwrapped vessels.

• Koushal Kumar (2022) [14] investigated overwrapping patterns, highlighting that composite vessels outperform steel vessels when winding angles are optimized

• Reham Reda et al. (2024) [15] concluded that hoop and intermediate helical angles (40°–50°)enhance burst pressure and weight efficiency, confirming the critical influence of angle selection. From the reviewed studies, it is evident that optimal fibre orientation plays a critical role in stress management. However, most works did not maintain constant geometry or weight across different configurations. The present work addresses this limitation.

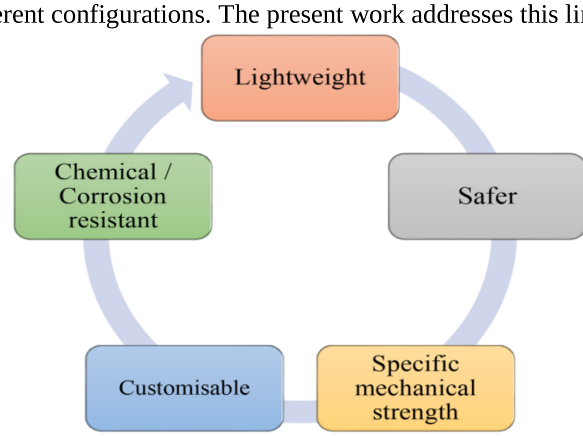

Fig.1 Typical features of the Type IV CPVs[9]

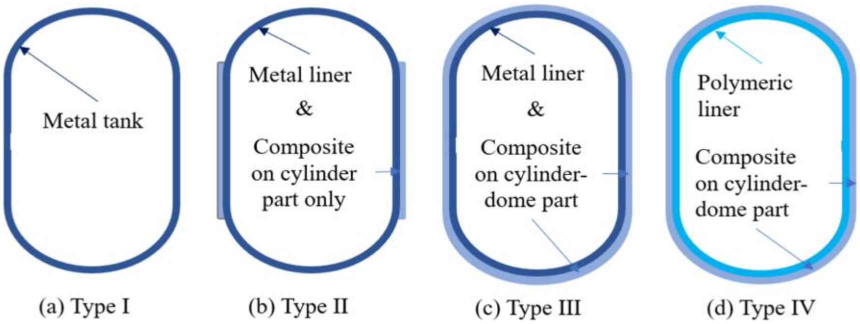

Fig. 2 Types of pressure vessels with constructional details[9]

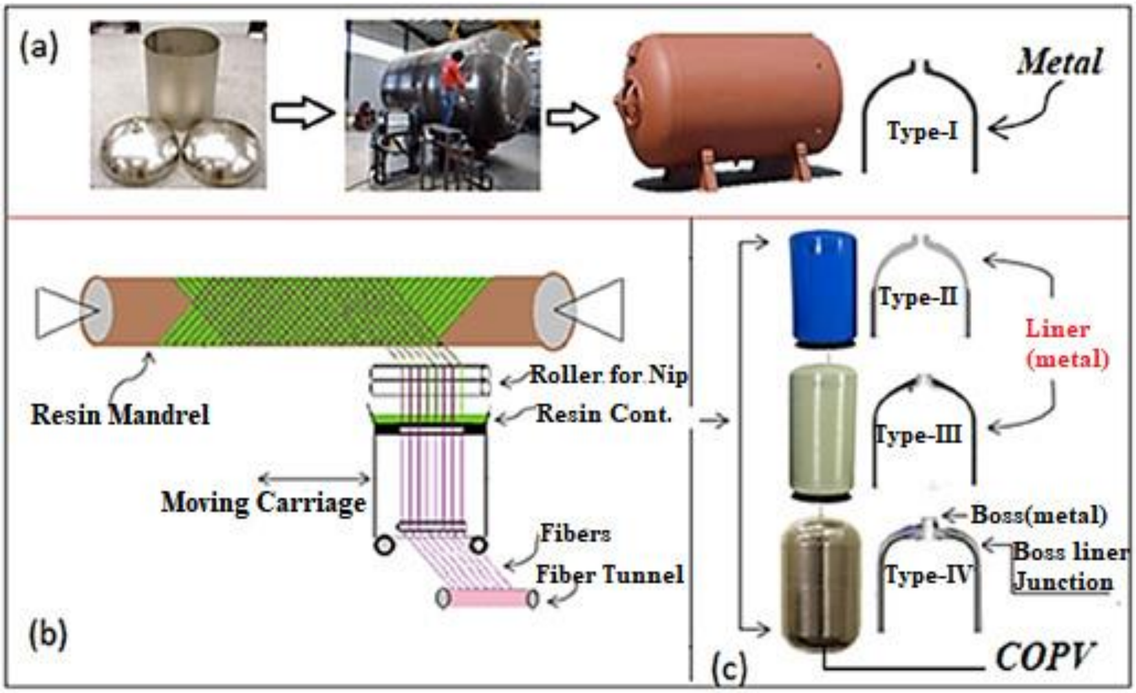

Fig.3 Filament winding method

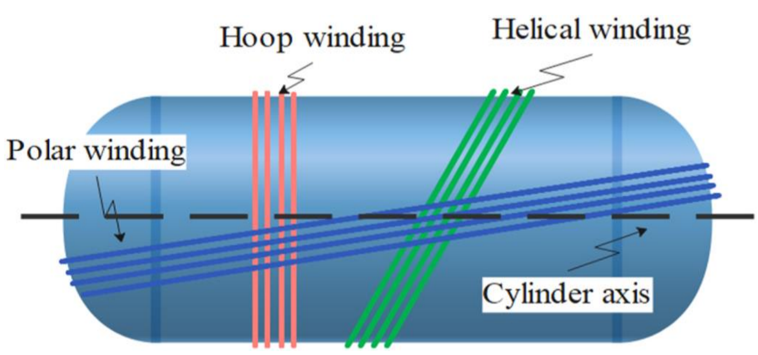

Fig.4 Schematic details of various winding configurations, showing the angular orientation with respect to the cylinder axis.[9]

Problem Statement:

The problem addressed in this study is whether the performance of a composite pressure vessel designed with [0,66,0,-66,0]α winding[1] can be improved by alternative winding orientations while preserving identical geometry, thickness, and weight. The study seeks to identify winding configurations that reduce hoop and axial stresses more effectively.

Objectives of the Study

The objectives of this study are to:

- Compare the performance of [0,66,0,-66,0]α [1] vessels with alternative fiber winding configurations.
- Investigate the influence of winding orientations on hoop and axial stresses using ANSYS Workbench.
- Identify the optimal winding configuration for improved stress distribution without increasing weight or thickness.
- Demonstrate the feasibility of enhancing CPV performance solely through angle optimization.

Significance of the Study

The significance of this study lies in its contribution to the advancement of composite pressure vessel design, which provides a safer and lighter alternative to traditional steel cylinders. Determining the optimal winding angle offers several key benefits:

- Enhancing safety by minimizing the stresses acting on the vessel.
- Improving efficiency without increasing thickness or weight, thereby preserving the lightweight advantage of composite vessels.
- Providing a scientific foundation for future research on composite pressure vessel design and optimization.
- Supporting practical applications of composite materials in industries such as gas storage, oil and energy, and aerospace, where weight reduction combined with safety is a critical requirement.

Methodology

After adopting what was studied by a study of Mohamed Rahuma and Ramdan Wadi[1], where they studied employed both theoretical analysis and finite element simulations, And then designed a composite gas cylinder with an angle arrangement for the composite material applications [0,66,0,-66,0]α.[1]

- The composite cylinder was redesigned under the same conditions and dimensions as those designed by a study of Mohamed Rahuma and Ramdan Wadi[1], but with the composite layer angles changed and the angles selected as follows in Table1 and used a polyethylene as a liner.
- Four other types of composite cylinders were thus formed, but with different angles. The axial and circumferential stress results obtained for the four types were compared with the axial and circumferential stresses obtained for the composite cylinder as designed in study of Mohamed Rahuma and Ramdan Wadi.[1]
- Three-dimensional modelling was performed using the ANSYS workbench using FEA analysis software.

Table1: Angles of plies in composite cylinder and thicknesses

Cases	Thickness of Liner	Angles of plies in composite cylinder	Thickness of each ply	Number of layer
Case 1	3mm	[45,-45,0,65,-65]	1mm	5
Case 2	3mm	[0,75,0,-75,0]	1mm	5
Case 3	3mm	[0,50,0,-50,0]	1mm	5
Case 4	3mm	[0,90,0,90,0]	1mm	5

1.Geometric dimensions and current design of gas cylinders: [1]

They have to consider 15.9 kg of LNG gas cylinder as mentioned in [1], Empty gas cylinder weight = 15.9 Kg with frame holder = 5.1429

- Volume of gas = 47.8 L
- The height of the cylindrical side is (400) mm.
- The inner diameter is (290) mm and the thickness is (3) mm polyethylene + 5mm E-Glass composite materials. As shown in figure 5
- The volume capacity is (1.32*108) mm3.
- Assume a thin wall of gas cylinder because the wall thickness (t) is less than (1/20) of the inner diameter (d).
- Hoop stress = $\sigma h=Pd/2t$
- Axial stress = $\sigma a=Pd/4t$

The results that obtain by ANSYS and that obtain theoretical presented in sections (6), table(3).

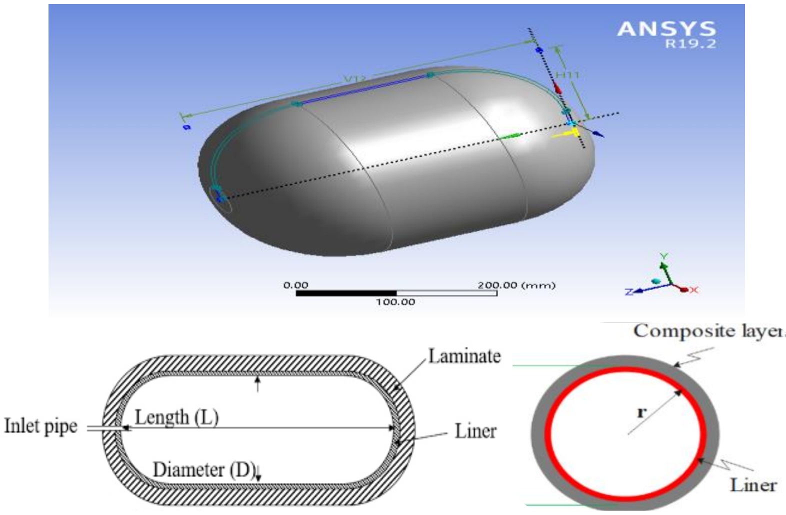

Fig.5 Geometric design of gas cylinders

2.The properties of the composite materials used in paper [1]

- E Glass
- Epoxy Density=2100kg/m^3
- Young's Modulus in Axial DirectionE1=45GPa
- Young's Modulus in Transverse Direction E2=12GPa
- Poisson's Ratio μ=0.28
- Yield Strength=1020MPa

Gas cylinder design using ANSYS:

Four gas cylinders will be designed as shown in figure 6, 7 and 8 The composite material layers will be arranged at different angles, but with the same dimensions and under the same conditions as those designed in study of Mohamed Rahuma and Ramdan Wadi[1], using ANSYS WORKBENCH.

Design a geometry of cylinder using ANSYS software as shown in Figures 6 and 7.

• The design process for gas cylinders involves using glass-epoxy. The theoretical calculations are based on extensive research in scientific literature and the determination of system boundary conditions. A 3D model of the cylinder is then created using ANSYS WORKBENCH software after obtaining the dimensions.

• Material selection involves selecting E Glass Epoxy using ANSYS WORKBENCH. Assume a composite cylinder thickness of 5 mm (5 layers of 1 mm thickness around a 3 mm thick polyethylene layer) as shown in Figures 4 and 5).

• Using ACP(pre) and dividing the cylinder surface into squares, using the grid feature or icon, arrange the composite material layers and arrange the fiber angles, as shown in Figures 8, 9, 10 , 11 and 12.

• In the final steps, the axial and circumferential stress results for the four cylinders are compared with the cylinder that designed in study of Mohamed Rahuma and Ramdan Wadi [1].as shown in table2.

• The results and conclusions are presented in Section 8 and 9.

• The applied internal pressure was 1 MPa, as shown in Table 3, and the composite cylinder relies on the arrangement of resin layers stacked on top of each other, as shown Figure.13.

• An analysis was performed using ANSYS software, and the results were shown in Figures 14,15,16 and 17 at an internal pressure of 1 MPa.

• The arrangement of the layers in the cylinder of composite materials at different angles as shown in figures 8, 9, 10, 11 and 12.

• An analysis in ANSYS and results as shown in Figures from Figure.7 to Figure.21 at internal pressure is 1MPa.

• A mesh convergence study was performed to confirm numerical stability; hoop stress variation was below 3% between medium and fine meshes."

• Failure evaluation was based on the Tsai-Wu criterion to ensure all stresses remained below the composite's strength limits."

• Fixed supports were applied at both domes, with internal pressure of 1 MPa on the inner wall.

Table2: Angles of plies in composite cylinder and thicknesses in paper [1]

Design	Angles of plies in composite cylinder	Thickness of each ply	Number of layer
Previous Case	$[[0,66,0,-66,0]_{\alpha}$	1mm	5

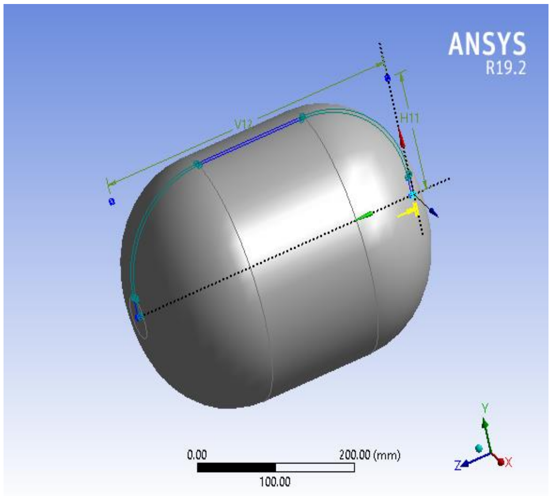

Fig .6 Preparing a composite cylinder by FEA

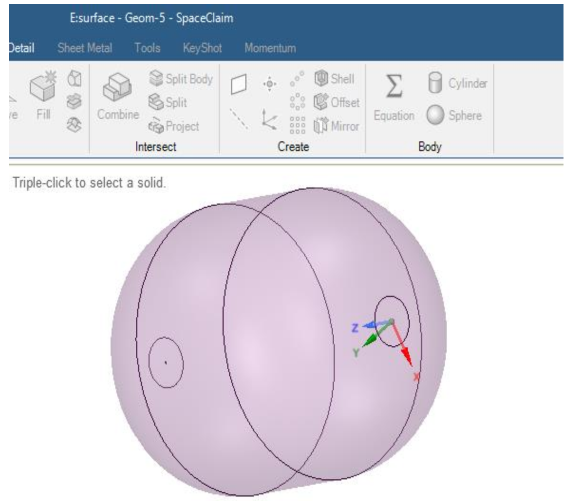

Fig.7 Preparing a composite cylinder by FEA

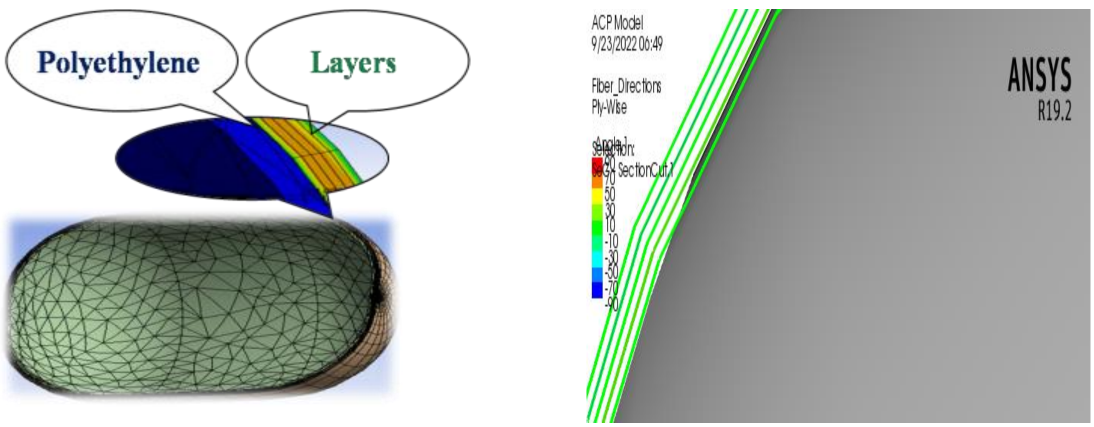

Fig.8 Cross section of composite cylinder by FEA

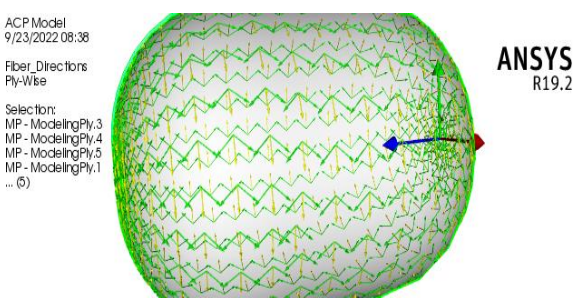

Fig.9 Angles of plies [0,50,0,-50,0]

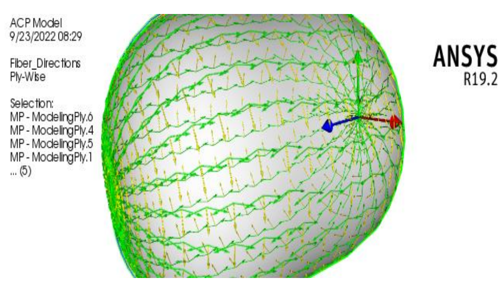

Fig.10 Angles of plies [0,75,0,-75,0]

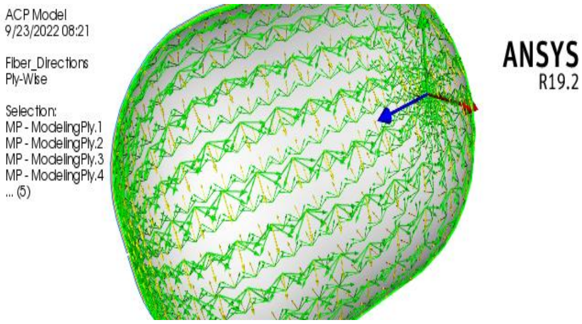

Fig.11 Angles of plies [45,-45,0,65,-65]

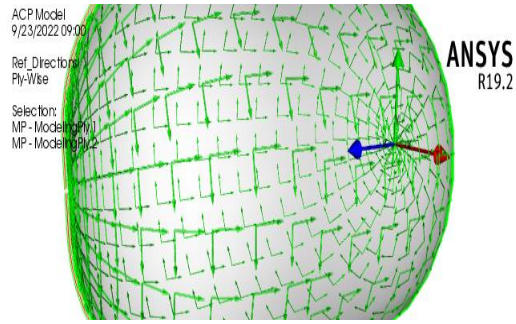

Fig.12 a)Angles of plies [0,90,0,90,0]

Table .3: Angles of plies in composite cylinder, thicknesses and applied pressure

Design	Thickness of polyethylene	Thickness of each layer in composite cylinder	Angles of plies	Internal pressure	Mass of Composite gas Cylinder
Case1	3mm	1mm	[45,-45,0,65,-65]	1Mpa	5.1429 kg
Case2	3mm	1mm	[0,75,0,-75,0]	1Mpa	5.1429 kg
Case3	3mm	1mm	[0,50,0,-50,0]	1Mpa	5.1429 kg
Case4	3mm	1mm	[0,90,0,90,0]	1Mpa	5.1429 kg

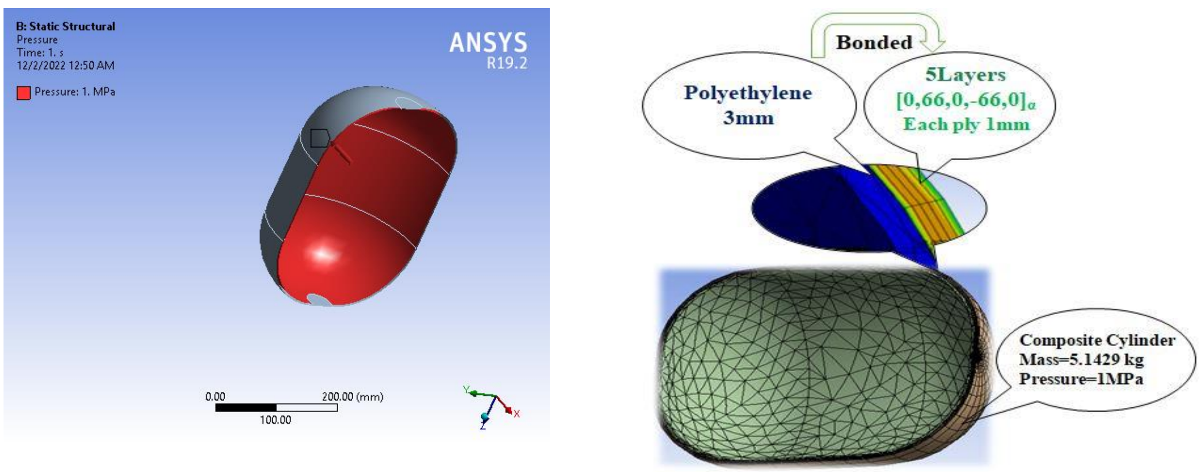

Fig.13 Internal pressure and analiysis interface

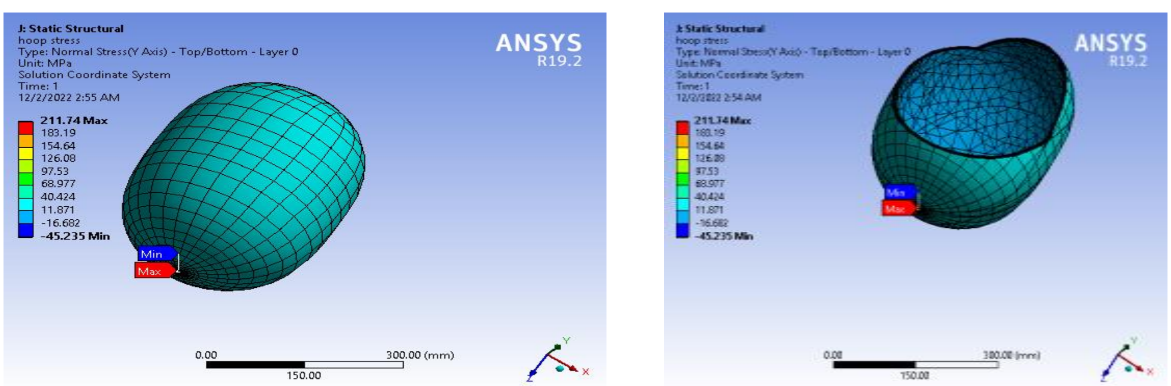

Fig .14 Explain [Hoop stress $\sigma_h = 211.74MPa$] when the Angles of five plies [45,-45,0,65,-65] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

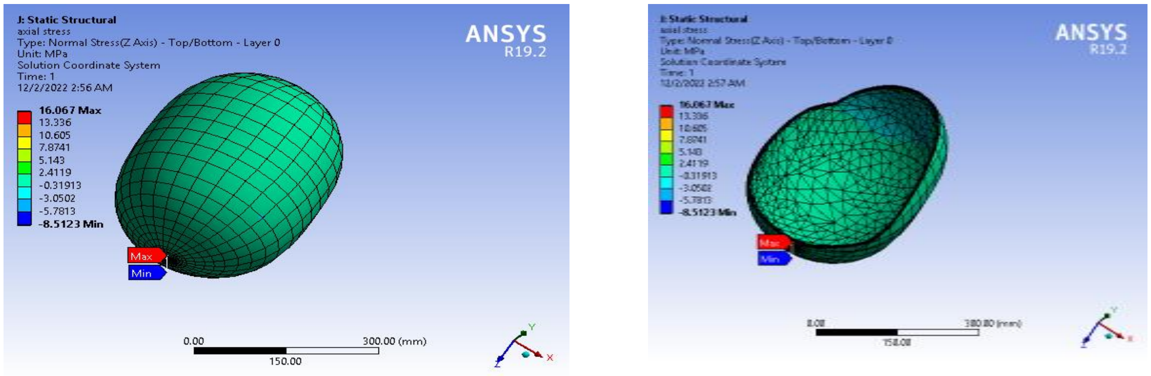

Fig .15 Explain [Axial stress σa=16.06MPa] when the Angles of five plies [45,-45,0,65,-65] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

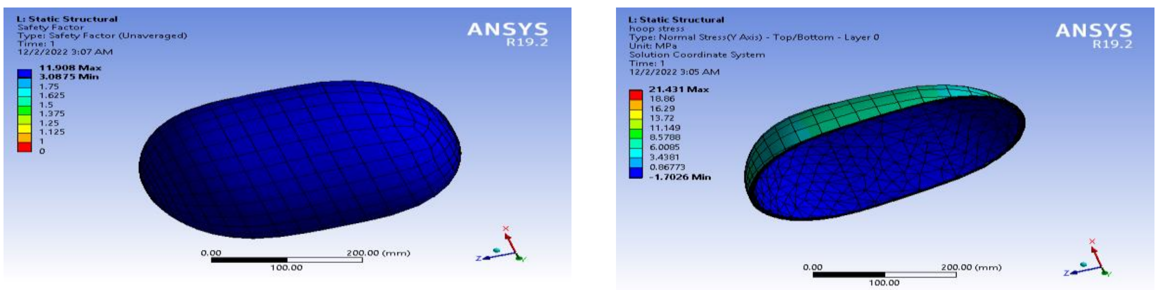

Fig .16 Explain [Hoop stress $\sigma_h = 21.411\ MPa$] when the Angles of five plies [0,75,0,-75,0] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

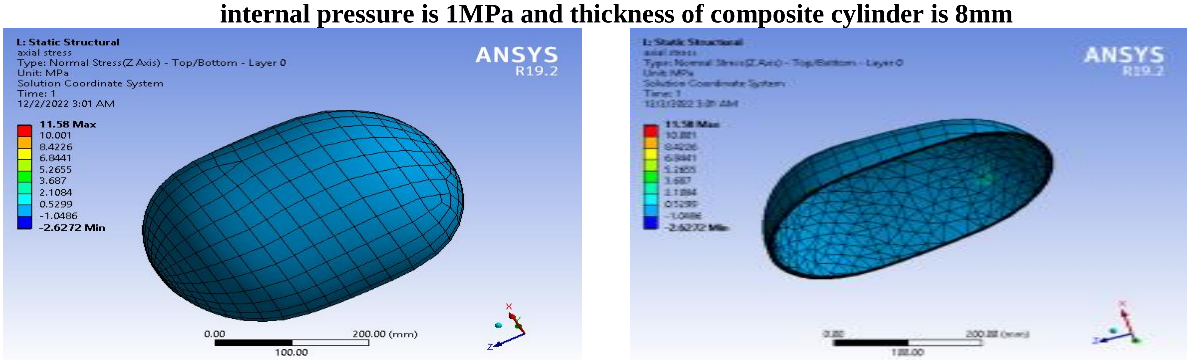

Fig .17 Explain [Axial stress σ_a=11..58 MPa] when the Angles of five plies [0,75,0,-75,0] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

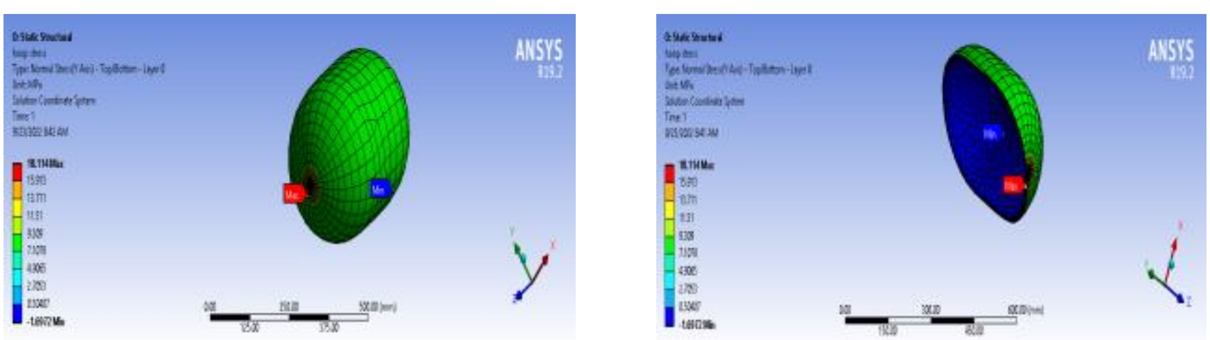

Fig .18 Explain [Hoop stress σ_h=18.114 MPa] when the Angles of five plies [0,50,0,-50,0] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

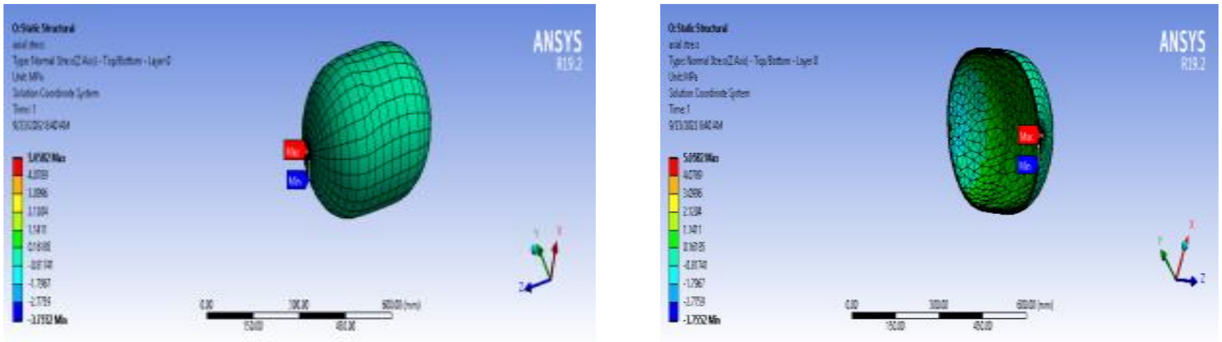

Fig .19 Explain [Axial stress σ_a=5.0582 MPa] when the Angles of five plies [0,50,0,-50,0] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

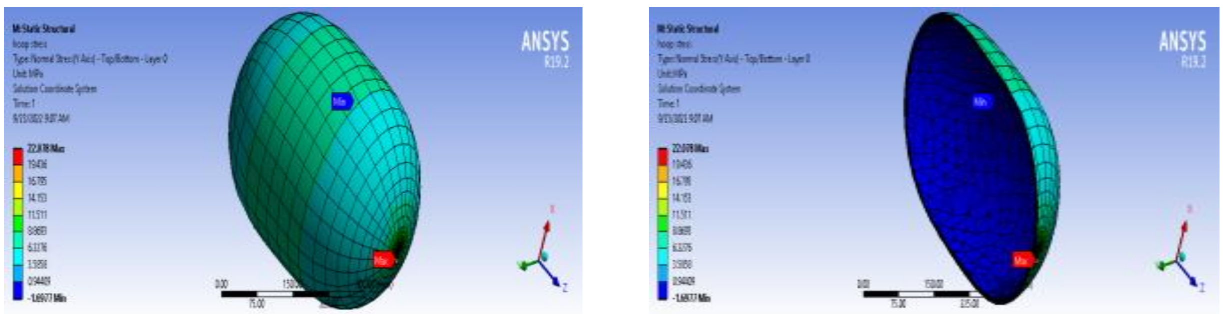

Fig .20 Explain [Hoop stress σ_h==22.078MPa] when the Angles of five plies [0,50,0,-50,0] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

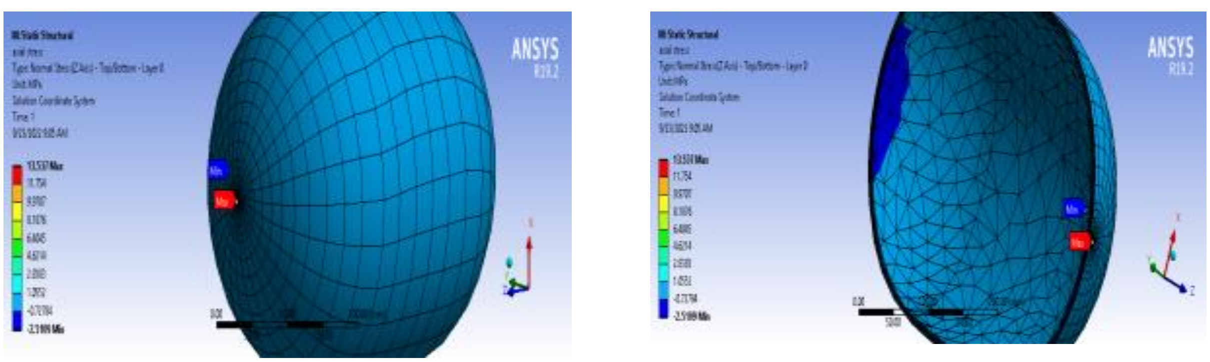

Fig .21 Explain [Axial stress σ_a=13.537 MPa] when the Angles of five plies [0,90,0,90,0] at internal pressure is 1MPa and thickness of composite cylinder is 8mm

Result and Discussion

- The [0,50,0,-50,0]α configuration achieved the lowest hoop and axial stress values, confirming its superior performance, as shown in Table 4. Importantly, this optimization did not require increased vessel thickness or weight. These findings align with Reham Reda et al. [15], who reported efficiency improvements at intermediate helical angles (40°–50°). This demonstrates that angle
- Optimization alone can substantially enhance vessel safety and efficiency, offering a cost-effective improvement strategy.

Additionally, E-glass can withstand higher stresses by increasing cylinder thickness and changing the layer angles. Most research has been conducted on carbon fiber, with increased cylinder thickness achieving satisfactory results, although glass is still cheaper than carbon fiber. The [0,50,0,-50,0]α configuration provided the best balance between axial and hoop stiffness, minimizing stress concentration. High-angle configurations such as 75° and 90° exhibited higher axial stresses due to fiber alignment along the cylinder axis, reducing circumferential resistance. These results are consistent with Reda et al. (2024), confirming the superiority of intermediate helical angles.

Table.4: Results of hoop and axial stress when change angles of layer and thickness of polyethylene is 3mm

Design	Hoop stress σ_h Mpa	Axial stress σ_a Mpa	Angles of plies in composite cylinder	Thickness of each ply	Number of layer
Case1	211.74	16.06MPa	[45,-45,0,65,-65] α	1mm	5
Case2	21.411	11..58	[0,75,0,-75,0] α	1mm	5
Case3	18.114	5.0582	[0,50,0,-50,0] α	1mm	5
Case4	22.078	13.537	[0,90,0,90,0] α	1mm	5
previous Case[1]	20.547	9.167	[0,66,0,-66,0]α	1mm	5

Conclusion

This study confirms that composite pressure vessels can be optimized by adjusting fiber winding orientations, without increasing thickness or mass. The [0,50,0,-50,0]α configuration outperformed the baseline design, reducing hoop and axial stresses. These results contribute to ongoing efforts in CPV design optimization, supporting safer and more efficient applications in gas storage, transportation, and aerospace sectors.

The findings can support the design of lightweight composite gas storage tanks and hydrogen vessels. Future work will focus on experimental validation and fatigue performance analysis.

References

1. M. R. G. Rahuma and R. S. Wadi, “Study to Use Composite Materials in LNG Domestic Cylinder Structure,” vol. 6, no. April, pp. 1–12, 2024.
2. S. Sharifi, S. Gohery, M. Sharifiteshnizi, and Z. Vrcelj, “Numerical and experimental study on mechanical strength of internally pressurized laminated woven composite shells incorporated with surface-bounded sensors,” Compos. Part B Eng., vol. 94, pp. 224–237, 2016.
3. S. Gohery, S. Sharifi, Z. Vrcelj, and M. Y. Yahya, “First-ply failure prediction of an unsymmetrical laminated ellipsoidal woven GFRP composite shell with incorporated surface-bounded sensors and internally pressurized,” Compos. Part B Eng., vol. 77, pp. 502–518, 2015.
4. B. S. Kim, B. H. Kim, J. B. Kim, and C. R. Joe, “Study on the development of composite CNG pressure vessels,” Cryogenics (Guildf)., vol. 38, no. 1, pp. 131–134, 1998.
5. M. Nebe, A. Soriano, C. Braun, P. Middendorf, and F. Walther, “Analysis on the mechanical response of composite pressure vessels during internal pressure loading: FE modeling and experimental correlation,” Compos. Part B Eng., vol. 212, p. 108550, 2021.
6. M. Azeem et al., “Application of filament winding technology in composite pressure vessels and challenges: a review,” J. Energy Storage, vol. 49, p. 103468, 2022.
7. M. Quanjin, M. R. M. Rejab, N. M. Kumar, and M. S. Idris, “Experimental assessment of the 3-axis filament winding machine performance,” Results Eng., vol. 2, p. 100017, 2019.
8. J. C. Thesken et al., “A theoretical investigation of composite overwrapped pressure vessel (COPV) mechanics applied to NASA full scale tests,” 2009.
9. M. Azeem et al., “Influence of winding angles on hoop stress in composite pressure vessels: Finite element analysis,” Results Eng., vol. 21, p. 101667, 2024.
10. S. Alam, G. R. Yandek, R. C. Lee, and J. M. Mabry, “Design and development of a filament wound composite overwrapped pressure vessel,” Compos. Part C Open Access, vol. 2, p. 100045, 2020.
11. X. Zhao et al., “A novel multi-filament winding technique for type III composite pressure vessel: From CFRP cross-undulation concept to structural performance validation,” Int. J. Hydrogen Energy, vol. 48, no. 45, pp. 17237–17250, 2023.

12. S. Sulaiman, S. Borazjani, and S. H. Tang, “Finite element analysis of filament-wound composite pressure vessel under internal pressure,” in IOP conference series: materials science and engineering, IOP Publishing, 2013, p. 12061.
13. Y. Regassa, J. Gari, and H. G. Lemu, “Composite overwrapped pressure vessel design optimization using numerical method,” J. Compos. Sci., vol. 6, no. 8, p. 229, 2022.
14. K. Kumar, M. Kumar, and A. Kumar, “Design and analysis of composite overwrapped pressure vessel with analysis of various overwrapping pattern,” 2022.
15. R. Reda, M. Khamis, A. E. Ragab, A. Elsayed, and A. M. Negm, “Numerical analysis of the impact of winding angles on the mechanical performance of filament wound type 4 composite pressure vessels for compressed hydrogen gas storage,” Heliyon, vol. 10, no. 13, 2024

[18] Shibah, M. S. (2023). On exact solutions for nonlinear Burger–Fisher equation using the Exp-function m