

Design and Analysis of Static Composite Fuel Storage Tanks: Alignment with ASME Section X

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Abstract

The increasing demand for lightweight, corrosion-resistant fuel storage solutions has increased the interest in composite pressure vessels; however, their industrial adoption remains limited due to the lack of standardized design frameworks under international codes. This study presents a structured approach for designing and validating an ASME Section-X, compliant composite fuel storage tank using E-glass fibers and vinyl ester resin. The research addresses the absence of scalable methodologies by integrating analytical modeling, hybrid manufacturing strategies, and finite element analysis (FEA) for structural validation. A vertical fuel storage tank was developed with detailed calculations, and design requirements are achieved according to Class II structural requirements under the ASME Section X safety factor guidelines ($2.5 \times$ burst pressure). The hybrid fabrication method combined $\pm 55^\circ$ filament winding for hoop stress optimization with hand lay-up for localized reinforcement at nozzle connections and stiffener zones. Structural performance was evaluated using FEA in ANSYS Workbench, focusing on stress distribution, deformation behavior, and buckling sensitivity under operational loading. Simulation results confirmed a safe mechanical response, with effective stress transfer and reduced local concentration through bonded contact and layered material definition. Reinforcement strategies significantly improved joint efficiency and load redistribution.

1. Introduction

In an era where industrial growth demands materials that challenge conventional limits, combining most of the characteristics such as strength, hardness, durability, and toughness, etc. composite materials arise as a transformative solution. These materials have rapidly gained relevance and are increasingly recognized for their promising potential in material science and engineering due to their variety of properties, such as toughness,

stiffness, lightweight properties, corrosion resistance, high durability, and tunable mechanical performance [1]. Despite their potential, large-scale fuel tanks, critical components in petroleum, aerospace, and chemical industries, remain mostly metallic, with steel and aluminum dominating current designs [2]. The domination of steel refers to the limited standardization, lack of comprehensive engineering methodologies, and insufficient integration of composite design codes like ASME Section X. Unlike generic fuel tanks, the composite fuel storage tanks are also created to overcome the stiff environments, corrosion, and fluctuating temperatures. These new tanks are advanced with (50-70%) weight reduction, near-immunity to corrosion, and fatigue resistance, all of which translate into lower lifecycle costs, reduced maintenance, and enhanced safety [3]. Fig. 1 provides a comparative evaluation of essential material properties for fuel tank applications. The charts highlight the superior characteristics of E-glass/vinyl ester composites over conventional metallic materials, particularly in terms of most properties. This comparison aligns with the quantitative data presented in Table 1.

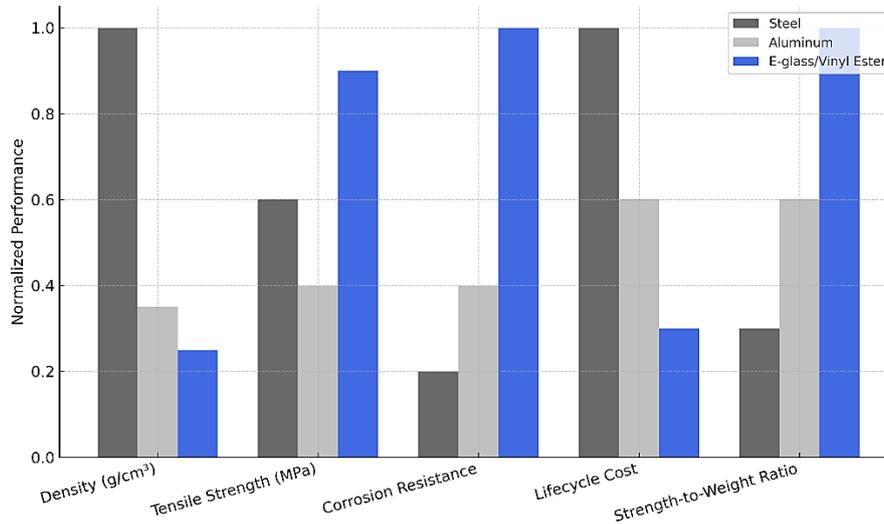


Fig. 1 Comparison of material properties for fuel tank applications

Table 1 The main properties of the three main materials used in manufacturing tanks

Parameter / property	Material type		
	Steel	Aluminum	E-glass/vinyl ester
Density (g/cm ³)	7.8	2.7	1.8-2.0
Tensile strength (MPa)	~ 400-600	~ 250-450	~ 700-900
Corrosion resistance	Very poor	Poor	Excellent
Weight (kg / same volume)	Highest	Medium	Lowest
Cost (lifecycle)	High	Medium	Low

As demonstrated in Table 1, composite materials like E-glass/vinyl ester offer excellent strength-to-weight and corrosion-resistant characteristics. Supporting this, many studies indicate that composite tanks can reduce structural weight by up to 60% compared to metallic counterparts, with lifecycle cost savings of 30–50% due to lower maintenance and extended service life. Despite the increasing use of composite materials in structural applications, their adoption in large-scale fuel tank manufacturing remains limited. This is primarily due to a lack of standardized design procedures, particularly under ASME Section X guidelines. Most of the existing literature focuses severely on metallic vessel design or composite use in unrelated fields such as aerospace or small-scale hydrogen storage. Consequently, there is a noticeable gap in providing an integrated, code-compliant design methodology tailored to industrial fuel tanks using composite materials. This study seeks to bridge that gap by developing and validating a comprehensive design framework based on analytical, numerical, and manufacturing insights.

The motivation for the use of composite materials for such applications includes reduced handling and installation costs as well as better corrosion resistance and mechanical performance. Another benefit comes from the use of adhesive bonding, which minimizes the need for a hot work permit if welding is employed [4]. The design of scaled-up fuel tanks involves many engineering complexities that require careful consideration. Key challenges include maintaining controlled hoop stress, relieving buckling forces under dynamic loading

conditions, and managing deformation and strain distributions. at the same time, strict adherence to established industry standards remains crucial to ensure structural integrity and operational safety. The manufacturing of composite tanks has been significantly advanced through the application of filament winding and hand lay-up processes, which optimize the fiber-to-matrix ratio and enhance structural performance. These techniques ensure superior material distribution and mechanical properties, making them ideal for tank production. Furthermore, adherence to ASME standards during the fabrication of large-scale fuel tanks guarantees reliability and industry compliance, enhancing confidence in the final product. Literature emphasizes the importance of the mechanical properties of composites, but also reveals a clear gap: a lack of standardized ASME Section X integration and full-scale structural analysis.

A critical review by Imad et al. [5] confirmed that fiber-reinforced polymers (FRPs) as transformative materials in structural engineering, with carbon-fiber composites (CFRP) achieving tensile strengths up to 3920 MPa at densities 60-70% lower than steel ($1.5\text{--}2.1\text{ g/cm}^3$ vs. 7.85 g/cm^3). Their work highlights FRPs' unparalleled strength-to-weight superiority, anti-corrosion, and fatigue resistance. Dipen et al. [6] confirmed the suitability of filament winding and hand lay-up for large composite structures. These methods allow precise fiber alignment, optimized resin flow, and superior strength-to-weight performance. They emphasized minimizing defects, such as voids and delamination, through process control. This directly supports the manufacturing strategy adopted in the present study. Long-Cheng et al. [7] studied the effect of graphene dispersion on mechanical properties, showing potential for further enhancement. Elias et al. [8] emphasize the future impact of advanced composites on European manufacturing industries, calling for strategic coordination to support large-scale adoption.

Subsequently, Yahya et al. [9] demonstrated that low-pressure ($< 10\text{ bar}$) applications require distinct design priorities when following ASME Section VIII, Division 1 guidelines for metallic vessels. That study laid the groundwork for the present research, which advances the same design logic into the composite domain under ASME Section X. By extending the methodology from metallic to fiber-reinforced structures, this paper establishes a coherent, code-aligned pathway for composite fuel storage tanks. Hammami and Al-Ghulani [10] report a 28% reduction in diesel absorption over six months for vinyl ester resins compared to epoxy, reinforcing their suitability for long-term fuel containment. In alignment with this finding, the current study further confirms the superior resistance of vinyl ester to diesel absorption through material characterization and environmental exposure simulation. As illustrated in Fig. 2, vinyl ester exhibits a notably slower rate of diesel uptake across six months, supporting its selection as a matrix material in this research. This observation validates the material's compatibility with long-term fuel storage applications and supports its integration into ASME-compliant composite tank design. These results strengthen the credibility of vinyl ester in harsh fuel environments and provide quantifiable evidence that supports practical engineering decisions.

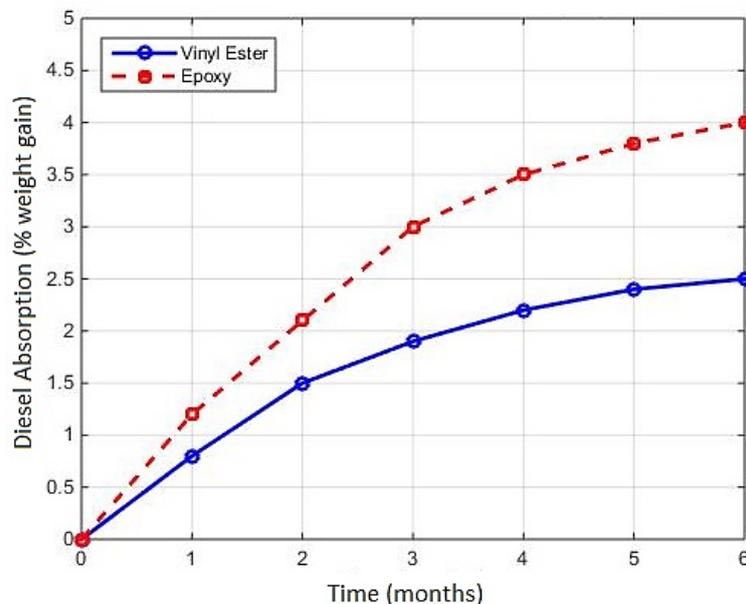


Fig. 2 Diesel absorption in vinyl ester vs epoxy resin [10]

Mustafa and Ramadan [11] expanded on the investigation of carbon-glass hybrid laminates for enhanced durability under aggressive conditions. Moreover, many studies have indicated that composite tanks offer superior material performance and demonstrate significant lifecycle cost advantages. Evanthia and Dimitrios [12]

demonstrated that composite fuel storage tanks lead to lower maintenance and end-of-life costs compared to stainless steel tanks. Similarly, Hyun and Sung [13] reported that despite higher fiber material costs, composites offer lower operating expenses over time due to reduced corrosion and longer durability. Biswal and Bhattacharyya [14] study the effects of baffle parameters on sloshing behavior and structural response, offering insights into load control. Alexander et al. [15] note that Automated Fiber Placement (AFP) has the potential to replace traditional filament winding in pressure vessel production due to its superior flexibility and precision. Chao and Shi [16] develop an analytical tool to optimize filament winding angles, which is crucial for improving mechanical performance in internal pressure vessels. The literature shows a critical gap: while studies focus on small-scale composite behavior, they lack code-compliant frameworks for real-world metal-to-composite transitions. This creates a critical void in practical engineering models such as large-volume fuel tanks, where safety and regulatory alignment are essential. This study addresses this gap by presenting a structured methodology for designing and validating an ASME Section X, compliant composite fuel storage tank using E-glass/vinyl ester laminates.

Furthermore, the framework integrates analytical modeling, parametric CAD design in SolidWorks, and finite element analysis (FEA) in ANSYS Workbench to assess mechanical performance under internal pressure loading and buckling behavior. All parameters were derived by using ASME Section X Article RD-1170.5, following Appendix 3 guidelines. By aligning design strategies with Class II safety factor requirements ($2.5\times$ burst pressure), the research supports the transition from theoretical exploration to industry-grade implementation. The findings aim to illustrate how composites can surpass traditional metallic solutions in terms of safety, cost-efficiency, and operational performance. Ultimately, this work delivers standardized, simulation-validated composite tanks for industrial use. It bridges the gap between academic research and practical engineering with code-compliant design guidelines.

2. Methodology

This study follows an ASME Section X-compliant framework to design and validate a composite fuel storage tank, integrating analytical calculations, parametric modelling, and numerical simulation to ensure structural integrity and code adherence. Fig. 3 presents a structured overview of the research methodology, outlining each phase from material selection, design calculations, and analytical design to simulation and final validation.

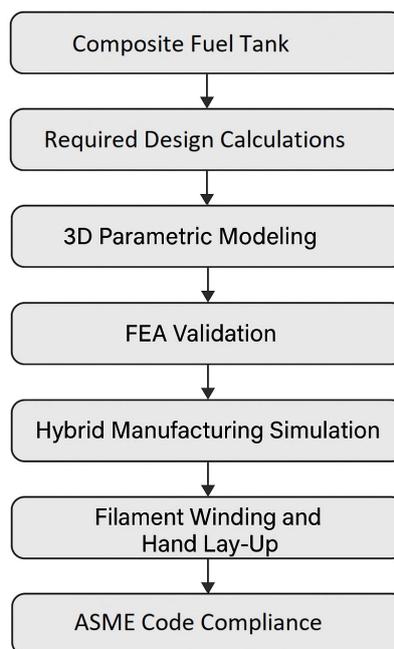


Fig. 3 Overview of the research methodology

The design process began with analytical calculations for key structural components, particularly shell thickness and flat head geometry. Shell thickness was determined using laminate theory, incorporating a 0.5 mm corrosion allowance to account for environmental conditions. The flat head thickness was calculated as 1.25 times the shell thickness, following standard practices to ensure adequate strength under internal pressure loading. These analytical results were then implemented in a parametric SolidWorks model, enabling precise control over geometric features and facilitating design iterations. The model incorporated a $\pm 55^\circ$ filament winding pattern,

simulating realistic manufacturing conditions. Reinforcements were designed following the ASME Appendix 3 guidelines, ensuring localized strength at nozzle connections and minimizing stress concentrations. To evaluate the structural performance and confirm compliance with safety limits, Finite Element Analysis (FEA) was conducted using ANSYS Workbench. This step assessed stress distribution, deformation, and buckling behaviour under operational loads, validating that the design remains within safe working boundaries defined by ASME Section X. Material selection and certification followed international standards and protocols.

Given the scope and operating conditions of this study, Class II was adopted as the most suitable category. It offers a balanced approach between performance demands and practical manufacturability, making it ideal for the type of tanks investigated during this study.

2.1 Hand Lay-up Process

Hand lay-up combines E-glass/vinyl ester layers (60:40 ratio) with manual precision to craft leak-proof composite tanks. Aligned to ASTM/ASME standards, it controls fiber orientation ($0^\circ/90^\circ$, $\pm 45^\circ$) as shown in Fig. 4, and the voids (<2%) via roller compaction and staged curing. This process merges materials science with hands-on craftsmanship for pressure vessels that balance strength, weight, and durability. Table 2 presents a tailored ply-by-ply fabrication toolkit.

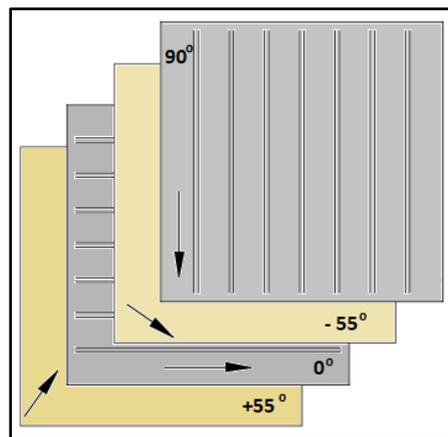


Fig. 4 Hand lay-up laminates applied to controlled gap areas in composite fuel storage tank fabrication

Table 2 Tailored ply-by-ply fabrication toolkit

Layer	Material	Orientation	Thickness (mm)
1	Surface veil (30 g/m ²)	Random	0.05
2-4	Woven roving (600 g/m ²)	$0^\circ/90^\circ$	0.6 (each)
5	Core mat (optional)	-	3.0
6-9	Woven roving	$\pm 55^\circ$	0.6 (each)
10	CSM (450 g/m ²)	Random	0.5

2.2 Filament Winding Process

Filament winding was used to manufacture the composite fuel storage tank with fiber orientations at 0° (axial), 90° (hoop), and $\pm 55^\circ$ (biaxial optimal). Fig. 5 illustrates the effect of fiber orientation on normalized stress resistance. The curve peaks at $\pm 55^\circ$, confirming it as the optimal winding angle for balancing hoop and axial loads in composite pressure vessels. These findings validate the fiber reinforcement strategy implemented in the current design. In contrast, traditional angles like $\pm 45^\circ$ yield significantly lower resistance, further validating the $\pm 55^\circ$ selection from both theoretical and performance perspectives. The hybrid approach ($\pm 55^\circ$ winding + $0^\circ/90^\circ$ lay-up) ensures comprehensive load management. These angles comply with ASME Section X stress distribution principles and were incorporated in ANSYS FEA by defining orthotropic material properties along local fiber directions. This method allows for the precise simulation of hoop/axial stress behaviour under internal pressure loading. The three main layup processes for laminated fiber-reinforced composite materials are winding, laying, and molding. The choice of a layup process depends on many factors: part size and shape, cost, schedule, and familiarity with particular techniques [17].

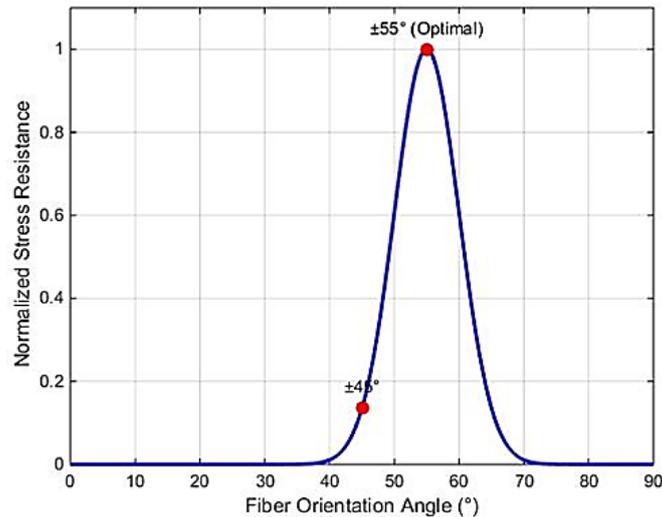


Fig. 5 Fiber orientation vs stress resistance

2.3 Structural Design of Composite Fuel Storage Tank

ASME Section X establishes design standards for vertical fiber-reinforced plastic (FRP) pressure vessels, particularly those operating within the pressure range of 0.1 MPa to 2 MPa, the most common range for vertical storage applications. Fig. 6 illustrates the designed vertical composite fuel storage tank, featuring flat head geometry, nozzles, and localized stiffeners. The fabrication employs a $\pm 55^\circ$ filament winding with hand lay-up reinforcement. The configuration comprises four primary components: (i) a cylindrical shell, engineered to withstand hoop and axial stresses; (ii) flat heads, serving as end closures; (iii) nozzles, facilitating fluid transfer and instrumentation; and (iv) a base plate, providing structural support and anchoring. This standardized configuration is explicitly addressed in ASME Section X, particularly in Article RD-1170 for shell design and Appendix 3 for nozzle reinforcement requirements.

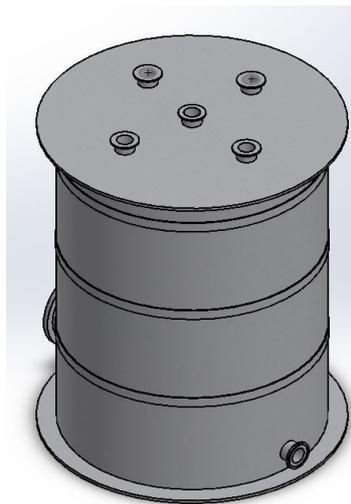


Fig. 6 Designed composite fuel storage tank model

2.4 Shell Design and Fabrication Parameters Before Rolling

The key parameters defining the composite shell dimensions before rolling, including sheet length, width, thickness, and total area, were derived from analytical modelling and hybrid manufacturing logic. These values ensure compliance with ASME Section X, Article RD-1170.5, and guarantee bonding continuity. The following equations summarize the critical sheet and shell parameters. The shell design process was initiated by establishing the key analytical equations and parameters necessary to achieve the desired tank specifications. Table 3 is used to illustrate all the obtained values by using the following equations. The determination of sheet length (L_{sheet}) is defined in Eq. (1). Whereas, the width of the sheet (W_{sheet}) is governed by Eq. (2)

$$L_{sheet} = \pi \times D + \Delta_{overlap} \quad (1)$$

$$W_{\text{sheet}} = H + \Delta_{\text{flange}} \quad (2)$$

The determination of shell weight requires estimating the shell volume before rolling, which obeys the Eq. (3), then shell weight (W_{shell}) based on Eq. (4). The total cylindrical volume (V) is expressed by the Eq. (5).

$$V_{\text{shell}} = A_{\text{shell}} \times t = (\pi \cdot D \cdot H) \times t \quad (3)$$

$$W_{\text{shell}} = \rho \times V_{\text{shell}} \quad (4)$$

$$V = \pi \cdot r^2 \cdot H \quad (5)$$

Table 3 Key parameters of the sheet and shell of the designed composite tank

Parameter	Value
Sheet length	7.74 m
Sheet width	3.35 m
Shell volume before rolling	0.748 m ³
Shell weight	1347.67 kg
Bonded area	0.662 m ²
Total cylinder volume	15 m ³ = 15,000 L

2.4.1 Shell Design

The cylindrical shell was designed using E-glass/vinyl ester laminates under ASME Section X guidelines, with thickness adjusted to ensure structural performance under 1.0 MPa internal pressure. Its geometry, winding angle, and reinforcement strategy were optimized through FEA-based validation and hybrid manufacturing alignment. Table 4 presents the key mechanical and geometric specifications used in the final design.

Table 4 Mechanical and geometrical specification of the designed composite shell

Parameter	Value	Justification
Shell material	E-glass/vinyl ester	Class II vessel guidelines
Total volume	15,000 L (15 m ³)	Design requirement
Diameter (D)	2.4 m	Fits standard transport width limits (≤ 2.5 m). Reduces the height-to-diameter ratio for stability.
Height (H)	3.31 m	
Shell thickness	~30 mm	
Head type	Flat	Simpler fabrication for Class II
Head thickness	37 mm	1.25× shell (ASME X Art. 4-3)
Shell weight	≈1346 kg	
Burst safety	2.5× (25 bar)	ASME X Art. T-7 (Class II)
Design pressure	1.0 MPa	ASME Section X Class II Guidelines conditions with safety factor = ×2.5.

2.4.2 Shell Design Analysis and Validation

2.4.2.1 Circumferential (Hoop) Stress Calculation

The circumferential (Hoop) Stress (σ_h) is governed by Eq. (6).

$$\sigma_h = \frac{P \cdot r}{t} \quad (6)$$

where the hoop stress, σ_h , design pressure, P , inner radius, r , and thickness, t , were taken as 1.0MPa, 1200mm, and 30mm, respectively; therefore, its value is (40MPa). Fig. 7 demonstrates the inverse relationship between shell thickness and maximum hoop stress, with 30mm achieving 40 MPa (Eq.6). The curve validates the ASME Class II safety margin ($2.5 \times$ burst pressure, Section 2.4.1.A). Stress escalates below 20mm, underscoring the 30mm design choice.

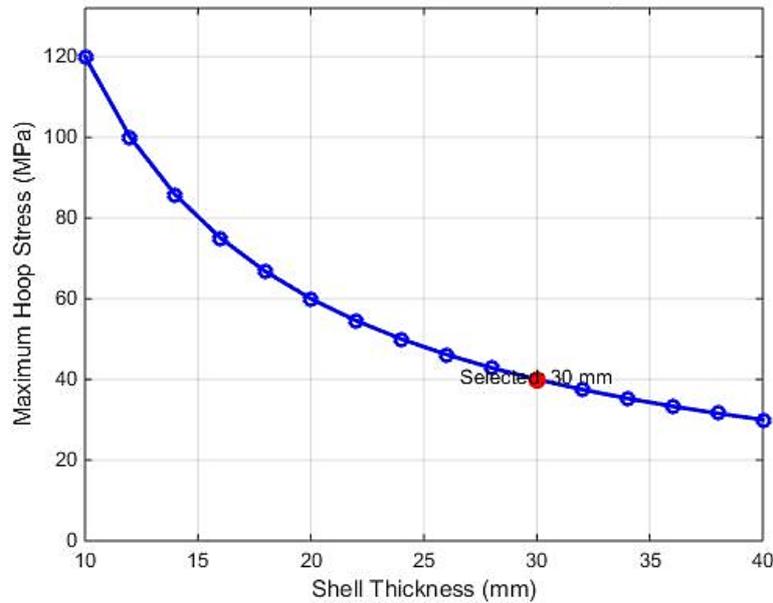


Fig. 7 Thickness vs. maximum hoop stress in the composite shell

2.4.2.2 Longitudinal Stress

The longitudinal stress (σ_a) is described by Eq. (7)

$$\sigma_a = \frac{P \times r}{2t} + \frac{F_{axial}}{\pi \times r \times t} \tag{7}$$

where the axial stress, σ_a , and the additional axial load as: (wind/seismic) = 50kN (estimated), then the obtained value is about (22.442 MPa).

2.4.3 Flat Head Design and Calculations

The flat head serves as a simplified closure method for large-scale composite fuel storage tanks, particularly suitable for stationary storage applications. Due to the absence of natural hoop-stress resistance, the flat head requires increased thickness and local stiffening to maintain structural continuity with the shell. As per ASME Section X Article 4-3, the reinforcement layout included 8 radial ribs and 2 ring-type stiffeners, ensuring improved load transfer and reduced buckling sensitivity. Table 5 presents the key parameters of the tank head, highlighting material selection, geometric dimensions, and manufacturing integration that support compliance with Class II safety factor guidelines.

Table 5 Structural parameters of the flat composite head

Parameter	Value	Unit	Source
Head diameter (d)	2.4	m	Tank design
Head diameter Cover	~2.8	m	
Head thickness (t)	37	mm	1.25× shell thickness strategy
Design pressure (P)	1.0	MPa	ASME X Class II
Allowable stress (σ_{allow})	45	MPa	E-glass/vinyl ester
Joint efficiency (E)	0.95	-	Filament-wound
Heads weight	400	kg	Matches composite modeling

2.4.4 Manway Design and Specifications

The purpose of a manway is to provide workers with easy access to vessels or storage tanks for cleaning and maintenance purposes [18]. Authorized by ASME BPVC Section X (RD-1010) for tanks exceeding 450 mm diameter [2], while ASME Section VIII (UG-46) enforces its inclusion, it omits prescriptive sizing guidelines, necessitating design optimization for structural integrity [2]. Table 6 presents the key specifications of the proposed manway design. The manway parameters were carefully selected to balance accessibility, structural performance, and compliance with industry standards.

Table 6 Design specifications of the manway nozzle for composite fuel storage tank access

Parameter	Value	Notes
Nominal diameter (DN)	450 mm	ASME B16.5/B16.47 for composite fuel tank access
Flange OD	650 mm	Includes bolt circle clearance
Bolt circle diameter (PCD)	600 mm	Pitch circle diameter for bolts
Flange thickness	30 mm	Locally reinforced (15 mm base + 10 mm buildup)
Raised face height	5 mm	Optional for gasket sealing
Hole size	16 mm	For M12 bolts (2 mm clearance)
Add bolt pattern	18×M16	STM A193 B8 (stainless steel), 600mm PCD
Weight	15 kg	-

2.4.5 Nozzles' design and specifications

The nozzles' design in composite pressure vessels bridges structural integrity with functional efficiency, demanding a precise balance between reinforcement mechanics and operational fluid dynamics. This work optimizes nozzle geometry, thickness, and placement through ASME-compliant stress analysis, ensuring leak-proof performance while minimizing weight penalties. Table 7 presents the key parameters of the main inlet/outlet nozzles.

Table 7 Design specifications of the main inlet/outlet nozzles for composite fuel storage tank access

Parameter	Value	Notes
Internal diameter (ID)	100–150 mm	Flow rate-dependent (e.g., 75 m ³ /h)
External diameter (OD)	ID + 2×thickness	Composite buildup
Thickness	8–12 mm	Match shell or reinforce
Hole radius	ID/2	Smooth edges to avoid stress risers
Hole area	$\pi \times (ID/2)^2$	For 120mm ID: 11.31 mm ²
Reinforcement pad	180mm × 180mm	Local thickening (15–20 mm)
Weight	~ 12 kg	

3. Results and Discussion

Finite Element Analysis (FEA) was conducted using ANSYS Workbench to assess the structural response of the proposed composite fuel tank under internal pressure loading. The simulation model included a 30 mm thick shell composed of E-glass fiber and vinyl ester resin, laid at $\pm 55^\circ$ using filament winding, with flat heads reinforced by hand lay-up. The internal design pressure was set at 1.0 MPa, based on industrial fuel storage requirements.

Stress distribution: As illustrated in Fig. 8(a), the von Mises stress distribution shows a peak of 46 MPa localized at the junction between the cylindrical shell and the flat head. This region is known to experience stress intensification due to geometric discontinuity, which was addressed in the design by adding hand-laid reinforcement layers. The stress level remains well below the allowable stress limits defined by ASME Section X for Class II composite pressure vessels, validating the structural safety under the design pressure. Additionally, Fig. 8(b) displays the normal stress along the Z-axis, with a maximum value of 15 MPa, concentrated near the lower joint, a typical stress path under internal load.

Fig. 9 illustrates the simulated stress distribution across the composite tank under 1.0 MPa internal pressure, highlighting three key stress profiles: hoop, axial, and von Mises. The hoop stress curve peaks at 40 MPa in the mid-shell region labelled "Tank Region" in the figure, aligning with analytical calculations (Eq. 6), while the axial

stress curve remains below 22 MPa, showing its lowest gradient in the flat head area, consistent with the flat head design's efficiently Table 5. The von Mises stress curve mirrors the hoop stress trend but intensifies at the joint and nozzle connections labelled "Joint" in the figure, revealing critical zones where geometric discontinuities cause stress concentration. The figure confirms that hoop stress dominates due to internal pressure, particularly at the joint, while axial stress remains secondary but structurally significant. The von Mises stress distribution validates the applied $\pm 55^\circ$ fiber orientation and the necessity of hand lay-up reinforcements (Section 2.1) at stress-concentrated regions, ensuring compliance with ASME Article RD-1170.5. These results guide targeted reinforcement strategies, with the joint emerging as the most critical zone requiring additional design mitigation

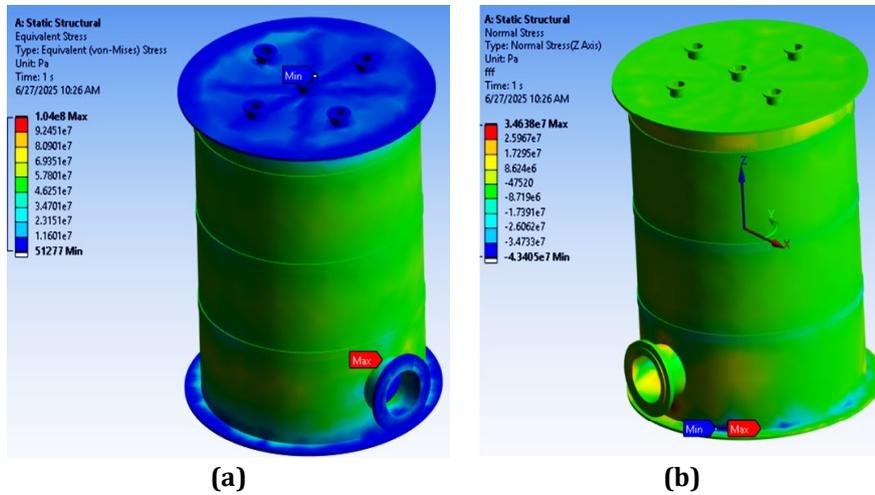


Fig. 8 (a) Equivalent von-mises stress; (b) Normal stress about Z-axis

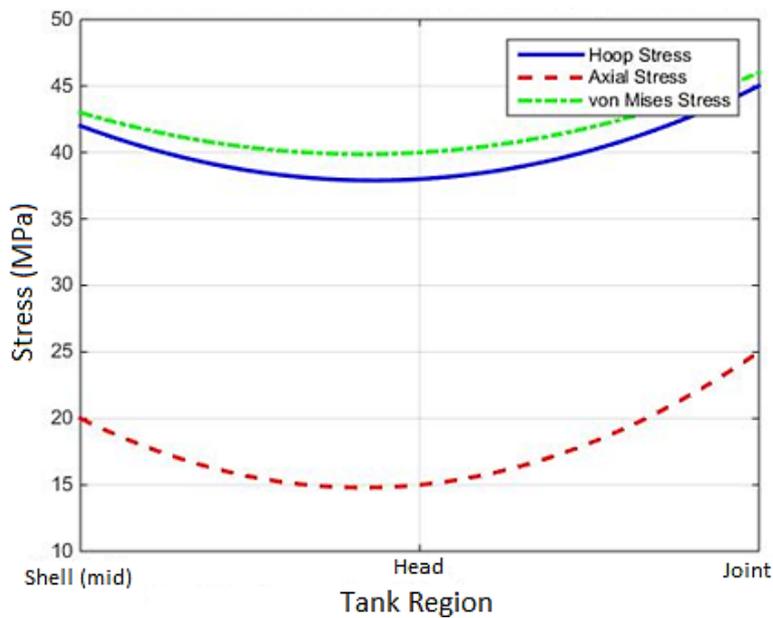


Fig. 9 Stress distribution in composite tank regions

Deformation behaviour: The total deformation plot in Fig. 10(a) indicates a maximum displacement of 2.2 mm, occurring near the mid-shell area. This value is within acceptable design deflection limits and confirms the tank's dimensional stability during operation. Such limited deformation also reflects the balanced fiber orientation strategy, which helps in uniformly distributing the load without excessive bending or deformation.

Strain analysis: The equivalent elastic strain, as shown in Fig. 10(b), ranged between 0.00021 and 0.00132, remaining within the expected elastic limit for E-glass/vinyl ester laminates. The strain field was largely uniform, with slight concentration near the joint, again validating the lay-up technique employed to reinforce critical regions. No regions exceeded the first-ply failure criteria.

Safety assessment: The computed stress results were benchmarked against the ASME Section X safety factor requirement of $2.5\times$ the design pressure. With a failure threshold well above the observed stress, the structure exhibits a high safety margin, making it suitable for use in fuel containment applications where reliability and code compliance are principal.

The collective findings demonstrate that the hybrid composite tank design, incorporating both filament winding and hand lay-up techniques, successfully satisfies all structural and safety requirements. This approach provides significant improvements in weight reduction, corrosion resistance, and manufacturing efficiency compared to conventional alternatives. Furthermore, these results establish a comprehensive framework that may serve as a valuable foundation for future research on scaled-up fuel storage tank manufacturing.

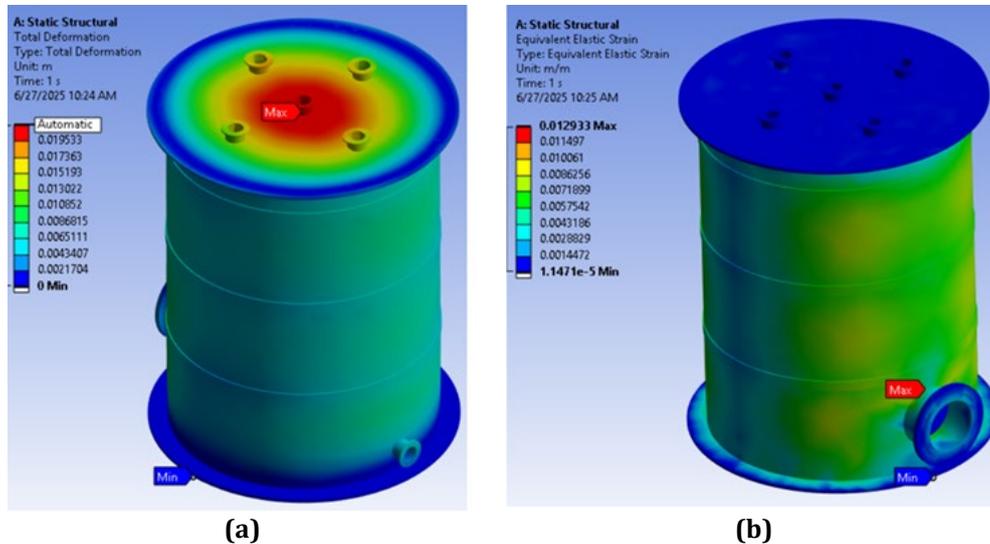


Fig. 10 (a) Total deformation; (b) Equivalent elastic strain

4. Conclusions

This study provides a comprehensive, code-aligned framework for the design and structural validation of composite fuel storage tanks, offering an effective alternative to conventional metallic vessels. During the strict integration of analytical design equations, finite element simulation, and hybrid manufacturing techniques (filament winding at $\pm 55^\circ$ and hand lay-up), the research demonstrates that E-glass/vinyl ester laminates meet and go beyond the requirements of ASME Section X (Class II). The proposed design achieves a maximum hoop strength of 40 MPa and structural weight reductions between 50–70%, while maintaining a safety factor above 2.5, as recommended by ASME standards.

More than just demonstrating performance, this work addresses a critical gap in industrial practice: the absence of standardized design procedures for composite tanks. By codifying shell thickness calculations, flat head reinforcement strategies, and nozzle transitions in compliance with ASME articles and appendices, the methodology offers a powerful design toolkit for engineers and manufacturers. The validated FEA models further ensure that operational stress, deformation, and buckling conduct remain within safe limits under pressure loading.

In environments where steel tanks suffer from corrosion, high maintenance, and increased lifecycle costs, this research confirms the adoption of composites as a durable, lightweight, and economically favourable solution. The outcomes extend beyond theoretical modelling; they lay the foundation for practical, scalable manufacturing and industrial implementation. Most importantly, this study successfully closes the big gap in composite fuel storage tank design by delivering a standard-compliant, validated, and fully applicable framework. Ultimately, it contributes meaningfully to the evolution of composite pressure vessel standards.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Nureddin Omar Fahel Alboum, Najeeb A. Yahya; **data collection:** Nureddin Omar Fahel Alboum; **analysis and interpretation of results:** Fahel Alboum; **draft manuscript preparation:** Fahel Alboum, Mustafa A. Essury, Abdulhafid M A Elfaghi. All authors reviewed the results and approved the final version of the manuscript. The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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