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Design Optimization Of Coolant Tank Using Pp And Pp Gf 10 Materials Through Fem Analysis

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Abstract

This study focuses on the design optimization of an automotive coolant tank using Polypropylene (PP) and Polypropylene Glass Fiber Reinforced (PP GF 10) through Finite Element Method (FEM) analysis. The objective is to evaluate the mechanical strength, thermal resistance, and deformation of these materials under real-world conditions and recommend an optimal material based on performance, weight, and cost. The coolant tank was designed using NX CAD software with a 25-liter capacity, 3 mm wall thickness, and a rectangular shape with rounded edges to minimize stress concentration. Finite Element Analysis (FEA) was conducted in ANSYS 19.2, applying an internal pressure load of 1.25 bar under realistic boundary conditions. A fine mesh size (2 mm) was used to enhance accuracy. Simulation results showed that PP GF 10 outperformed PP in terms of mechanical strength and thermal resistance, with a maximum deformation of 1.04 mm and stress of 62.90 MPa, compared to PP's deformation of 2.57 mm and stress of 65.30 MPa. However, PP exhibited advantages in lower density (0.91 g/cm³) and weight (3.647 kg), making it a cost-effective choice for non-critical applications. In **contrast,** PP GF 10 offered superior durability and stability for high-stress environments, despite its higher weight (4.408 kg). This study provides insights into material selection trade-offs for automotive applications. Future work may explore hybrid composites to further optimize performance, weight, and cost efficiency.

Keywords: Coolant Tank, FEM, PP Material, PP GF 10 Material, Stress and Displacement.

1. Introduction

The efficient design and optimization of automotive coolant tanks are crucial for ensuring vehicle performance, safety, and durability. Coolant tanks, as integral components of a vehicle's thermal management system, must maintain their structural integrity under varying pressure and temperature conditions while adhering to cost and weight constraints. This research focuses on the use of polypropylene (PP) and polypropylene glass fiber-reinforced composite (PP GF 10) materials for the design optimization of coolant tanks. PP is widely recognized for its lightweight, corrosion resistance, and cost-effectiveness, making it an ideal choice for automotive applications.

Meanwhile, PP GF 10, with its enhanced mechanical strength and thermal resistance due to glass fiber reinforcement, provides an alternative for high-stress and high-temperature scenarios, potentially outperforming standard PP in critical conditions. The motivation for this research lies in the growing demand for materials that balance performance, weight reduction, and cost-efficiency in automotive manufacturing. As vehicles evolve to meet stringent environmental regulations and fuel efficiency standards, manufacturers are compelled to adopt advanced materials and innovative designs. Finite Element Method (FEM) analysis, a computational simulation technique, allows researchers to predict and optimize the structural performance of components under realistic conditions, providing valuable insights into deformation, stress distribution, and material behavior.

By combining advanced simulation tools such as Ansys with practical design strategies, this study aims to evaluate the suitability of PP and PP GF 10 for coolant tank applications. The scope of this research includes designing the coolant tank using CAD software, simulating its performance under internal pressure conditions, and comparing the deformation, stress distribution, weight, and cost of both materials. The findings will guide material selection and contribute to the development of more efficient and reliable automotive components. This study not only addresses industrial challenges but also paves the way for future advancements in material science and automotive engineering.

Figure 1. An Overview of Coolant Tank

1.1 Background

Coolant tanks are essential components in automotive cooling systems, responsible for regulating engine temperature and ensuring efficient heat dissipation.

These tanks are exposed to mechanical stresses, internal pressure, and temperature variations, requiring materials with high durability and thermal stability. Traditionally, metal coolant tanks were widely used due to their excellent strength and heat resistance. However, their high weight, increased production costs, and susceptibility to corrosion led to the search for alternative materials. With advancements in polymeric materials, Polypropylene (PP) and Polypropylene Glass Fiber Reinforced (PP GF 10) have emerged as potential alternatives for automotive coolant tanks.

These materials offer lightweight properties, corrosion resistance, cost-effectiveness, and ease of manufacturing. However, selecting the most suitable material requires evaluating factors such as mechanical strength, deformation behavior, stress distribution, and thermal conductivity. A poorly designed coolant tank may result in leakage, deformation, or failure under pressure, leading to potential damage to the vehicle's cooling system. Therefore, conducting Finite Element Method (FEM) analysis allows engineers to simulate real-world operating conditions, **assess** structural performance, and optimize material selection before actual production.

1.1.1 Research Objectives

This study is conducted with the following objectives:

1. To determine and compare the mechanical strength, thermal performance, and deformation characteristics of PP and PP GF 10 under real operating conditions using Finite Element Analysis (FEA).
2. To recommend the most suitable material for coolant tanks based on stress distribution, deformation behavior, weight, and cost-effectiveness, ensuring optimal performance and longevity in automotive applications.

1.2 FEM Analysis

Finite Element Method (FEM) analysis is a powerful computational technique used to assess material performance under different loading and environmental conditions. In this study, FEA simulations were conducted using ANSYS 19.2 to evaluate the mechanical behavior of PP and PP GF 10 coolant tanks under an internal pressure of 1.25 bar. The static structural analysis focused on critical parameters such as stress distribution, displacement, and overall deformation.

The simulation process involved importing a CAD model of the coolant tank, applying material properties, generating a fine mesh (element size 2 mm), and defining boundary conditions such as fixed mounting points. The results provided valuable insights into how each material responds to internal pressure, allowing for an informed decision on material selection for optimized performance and durability.

1.3 PP

Polypropylene (PP) is a widely used thermoplastic polymer known for its low density (0.91 g/cm³), excellent chemical resistance, and affordability. Due to its lightweight nature, it is commonly used in non-structural automotive applications, such as interior trims and fluid storage tanks. However, PP has moderate mechanical strength and thermal stability, making it susceptible to deformation under high pressure and temperature conditions.

Figure 2. An Overview of PP Material

1.4 PP GF 10

To enhance mechanical properties, PP GF 10**, a** glass fiber-reinforced composite containing 10% glass fiber, is used as an alternative. This material increases tensile strength, stiffness, and thermal conductivity, making it more suitable for high-stress environments. The higher Young's modulus (2500 MPa vs. 1400 MPa in PP) results in reduced deformation and greater resistance to structural failure. However, the addition of glass fiber increases density (1.1 g/cm³), leading to a slight weight penalty. Comparing these materials through FEM analysis helps determine their suitability for coolant tanks, balancing performance, weight, and cost.

Figure 3. An Overview of PP GF 10 Material

2. Review of Literature

The design, analysis, and optimization of storage tanks have been extensively studied to improve mechanical performance, durability, and structural stability under various conditions. These tanks are vital in industries such as automotive, water management, and chemical storage, making their structural integrity a critical area of research. Shilja Sureshkumar (2015) highlighted the environmental hazards posed by tank failures, particularly in storing harmful chemicals, emphasizing the importance of robust designs. Similarly, George (2016) performed dynamic analyses on elevated cement concrete water tanks, focusing on stability under seismic and other loading conditions. These studies underline the necessity for effective design strategies to ensure tank performance and reliability. Veeresh Varur classified tanks into ground-supported, underground, and elevated tanks, with a specific focus on ground-supported reservoirs and settling tanks.

This categorization provides a framework for understanding the unique design challenges faced in various storage applications, including automotive coolant tanks. Dynamic analysis of tanks has also received significant attention. Sarokolayi and Tavakoli (2014) examined the effects of rotational and translational ground motions on elevated water tanks, using finite element analysis (FEA) to enhance their resilience during seismic events. Ashish Vajir et al. (2017) explored the behavior of composite material tanks under seismic loading, emphasizing the role of material properties in mitigating structural failures. Boshra Eltaly et al. (2014) combined experimental and FEA-based modal analysis to study the dynamic behavior of elevated steel water tanks, offering insights into structural performance under various conditions. These findings highlight the relevance of dynamic analysis for improving tank durability and safety.

Material selection plays a pivotal role in optimizing storage tanks for weight, cost, and performance. Hassan Jasim Mohammed (2011) discussed cost-effective designs for concrete water tanks, emphasizing materials that balance affordability with structural integrity. Polypropylene (PP) and its composites, such as PP GF 10, have emerged as promising materials due to their lightweight, corrosion resistance, and mechanical strength. The inclusion of 10% glass fiber in PP GF 10 significantly enhances tensile strength and thermal resistance, making it ideal for high-stress and high-temperature applications. This aligns with the requirements of automotive coolant tanks, which must withstand internal pressure and fluctuating temperatures. Studies have demonstrated the potential of these materials to improve tank performance while maintaining cost-effectiveness.

FEA has been widely adopted as a tool for analyzing and optimizing tank designs. Dhumal and Suryawanshi (2016) employed Ansys software to study the effect of baffle walls on water tank dynamics, demonstrating the importance of accurate meshing and boundary conditions for reliable results. Nitin S. Gokhale et al. emphasized practical approaches to FEA, stressing mesh refinement and realistic boundary conditions to ensure accurate simulations. Similar methodologies were outlined in the MYSTRAN User Manual (2011), which provided comprehensive guidelines for FEA applications. Jie Gao and Ke Chen (2011) demonstrated the versatility of FEA by applying it to vehicle dynamics, highlighting its relevance for simulating structural behavior in diverse engineering challenges. These studies underscore the importance of simulation in evaluating tank performance under real-world conditions. Thermal and structural analyses are integral to understanding the behavior of tanks under operational stresses.

Shaolin Mao et al. (2010) investigated the thermal and structural performance of heavy-duty truck radiators, offering insights applicable to coolant tanks. The optimization of structural components to enhance durability and performance has been another key area of research. Senthilnathan Subbiah et al. (2011) analyzed muffler mounting brackets to identify potential failure points, demonstrating the utility of FEA in improving structural designs. These approaches are directly relevant to automotive coolant tanks, which must maintain structural integrity under internal pressure and thermal loads. While significant advancements have been made, challenges remain in optimizing materials, design methodologies, and computational techniques. Fengyan Yi and Meizhi Xie (2012) highlighted the importance of integrating experimental data with simulation results to validate FEA models.

Future research can explore hybrid materials and advanced composites to achieve further improvements in weight, cost, and performance. Hassan Jasim Mohammed (2011) advocated for combining innovative material technologies with economical design principles to develop sustainable storage solutions. These perspectives provide a roadmap for future advancements in the field. This review establishes a foundation for the current research, which seeks to optimize the design of automotive coolant tanks using PP and PP GF 10 materials, leveraging the insights and methodologies outlined in previous studies.

3. Research Methodology

This study employs a computational approach using Finite Element Method (FEM) analysis to optimize the design of an automotive coolant tank using Polypropylene (PP) and Polypropylene Glass Fiber Reinforced (PP GF 10)**.** The research focuses on evaluating the mechanical strength, thermal performance, and deformation of both materials under real-world conditions. The objective is to determine the most suitable material for coolant tanks based on performance, weight, and cost-effectiveness.

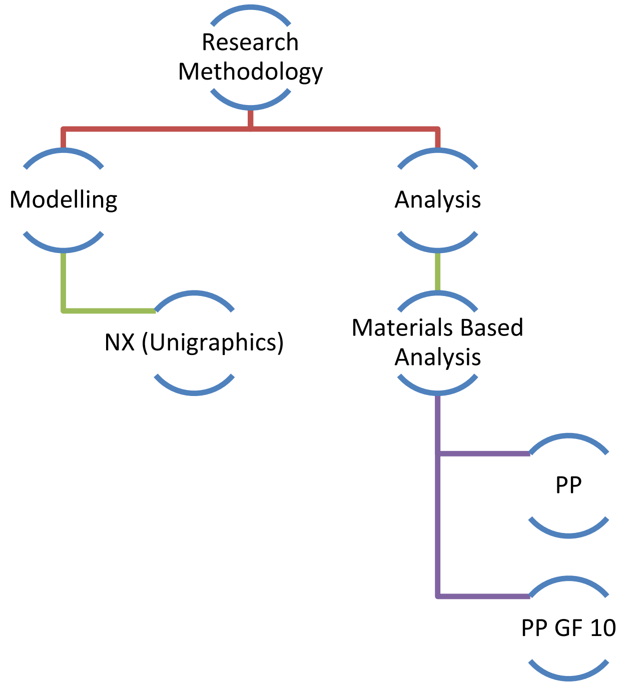


Figure 2. An Overview of Research Methodology Adopted

3.1 Modelling

The coolant tank was designed using NX CAD software, ensuring a practical and structurally efficient model. The tank has a 25-liter capacity, 3 mm wall thickness, and a rectangular shape with rounded edges to minimize stress concentration.

Essential features, including an inlet, outlet, and pressure relief valve, were incorporated to reflect real-world functionality. The 2D sketch was extruded into a 3D model**,** and reinforcement ribs were added to improve structural stability. The final design was exported in STEP format for further analysis in ANSYS 19.2.

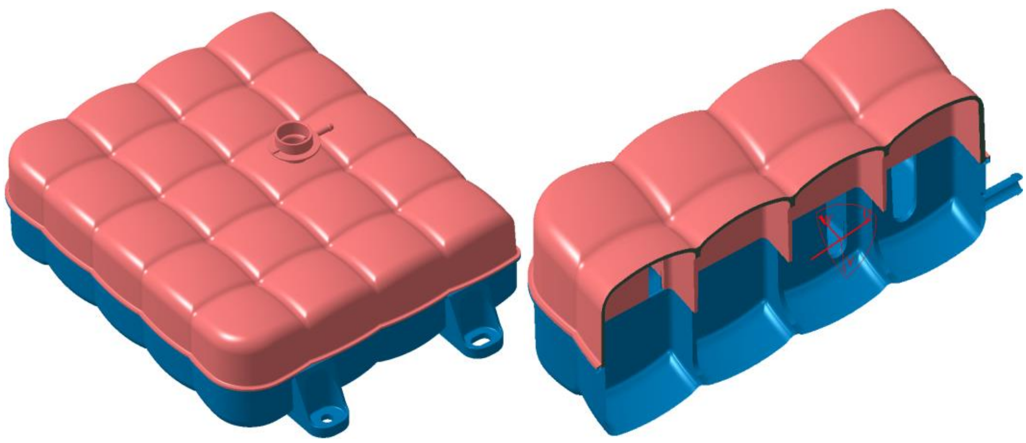


Figure 5. Msodelling view of Coolant Tank

3.2 Analysis

3.2.1 Meshing

A fine tetrahedral mesh was applied, with an element size of 2 mm, ensuring high accuracy in capturing stress and deformation across the structure. Fine meshing enhances the precision of simulation results, particularly in areas of high stress concentration.

Figure 6. Meshing view of Coolant Tank

3.2.2 Boundary Conditions

To replicate real-world operational conditions, a uniform internal pressure load of 1.25 bar was applied to the inner walls of the tank. Mounting points were fixed to simulate installation constraints and restrict unwanted movements. A static structural analysis was performed to assess stress distribution and deformation under these loading conditions.

Figure 7. Boundary Conditions and Loading view of Coolant Tank

3.3 Materials

The study compares PP and PP GF 10 based on their mechanical and thermal properties to determine their suitability for coolant tank applications**.** PP, with a density of 0.91 g/cm³, Young's Modulus of 1400 MPa, and thermal conductivity of 0.22 W/mK**,** is preferred for its lightweight, corrosion resistance, and cost-effectiveness**,** making it ideal for non-critical automotive applications**.** PP GF 10, with a density of 1.1 g/cm³, Young's Modulus of 2500 MPa, and thermal conductivity of 0.25 W/mK**,** is better suited for high-stress and high-temperature applications due to its superior mechanical strength and thermal stability. This methodology provides a systematic framework for evaluating materials under realistic working conditions, ensuring a data-driven approach to selecting the most suitable material for coolant tank applications in the automotive industry.

Table 1. Properties of PP and PP GF 10 materials

Property	PP	PP GF 10
Density (g/cm³)	0.91	1.1
Young's Modulus (MPa)	1400	2500
Thermal Conductivity (W/mK)	0.22	0.25
Poisson's Ratio	0.42	0.35

3.4 Product Lifecycle

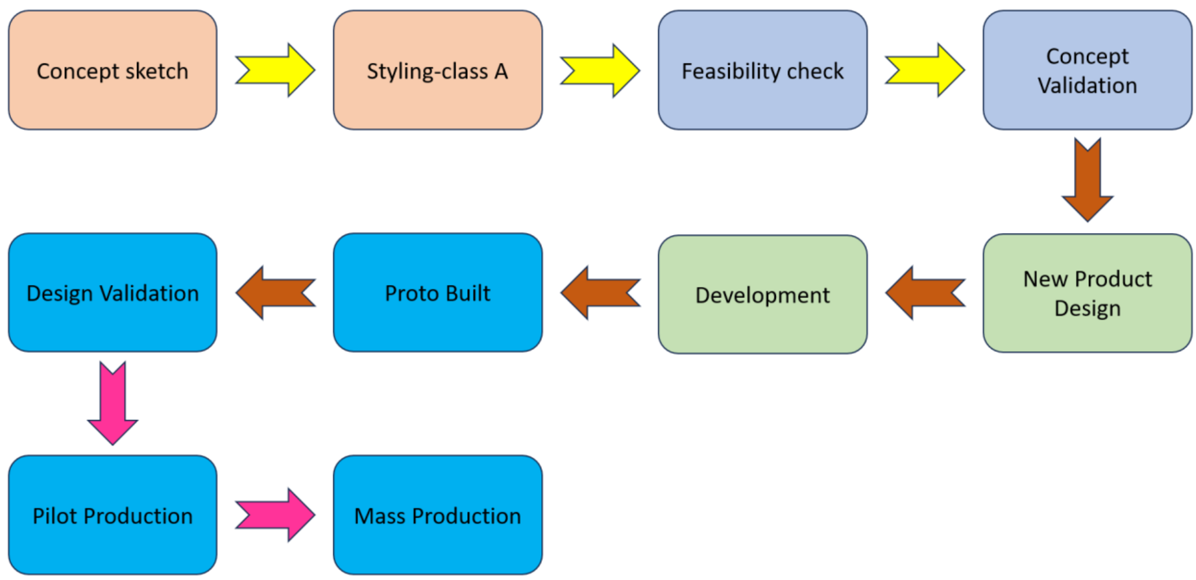


Figure 8. A Systematic Process of Coolant Tank from sketching to development

4. Results and Discussion

This section presents the simulation results for the coolant tank using Polypropylene (PP) and Polypropylene Glass Fiber Reinforced (PP GF 10) under an internal pressure load of 1.25 bar. The results are analyzed in terms of displacement (deformation) and stress distribution, which are key parameters in determining the structural integrity and reliability of the coolant tank in real-world conditions.

4.1 Displacement

The displacement analysis focuses on the extent to which the coolant tank deforms under pressure. The results indicate that PP exhibits significantly higher deformation compared to PP GF 10, with a maximum displacement of 2.57 mm for PP and 1.04 mm for PP GF 10. The higher deformation in PP is attributed to its lower Young's modulus, which makes it more flexible and susceptible to expansion under pressure. In contrast, PP GF 10, with its higher stiffness and reinforcement from glass fibers, experiences much lower deformation, maintaining better dimensional stability under loading conditions. The displacement distribution shows that the top surface of the tank, farthest from the fixed mounting points, experiences the maximum deformation, as this area has the most structural flexibility. PP shows significant bending and expansion in this region, indicating potential risks of shape distortion over prolonged use.

In contrast, PP GF 10 displays a more stable structure with minimal bending, which makes it more suitable for applications requiring durability under fluctuating pressure conditions. Additionally, reinforcement ribs integrated into the design help reduce overall deformation, particularly in the case of PP GF 10, demonstrating the effectiveness of structural reinforcements in improving stability. The results suggest that PP, while lightweight and cost-effective, may pose long-term durability concerns due to its higher deformation levels. Over time, repeated pressure cycles could lead to material fatigue and possible failure in critical areas. On the other hand, PP GF 10, with its lower deformation and superior rigidity, ensures better long-term performance and structural integrity, making it a more suitable choice for coolant tanks operating under demanding conditions.

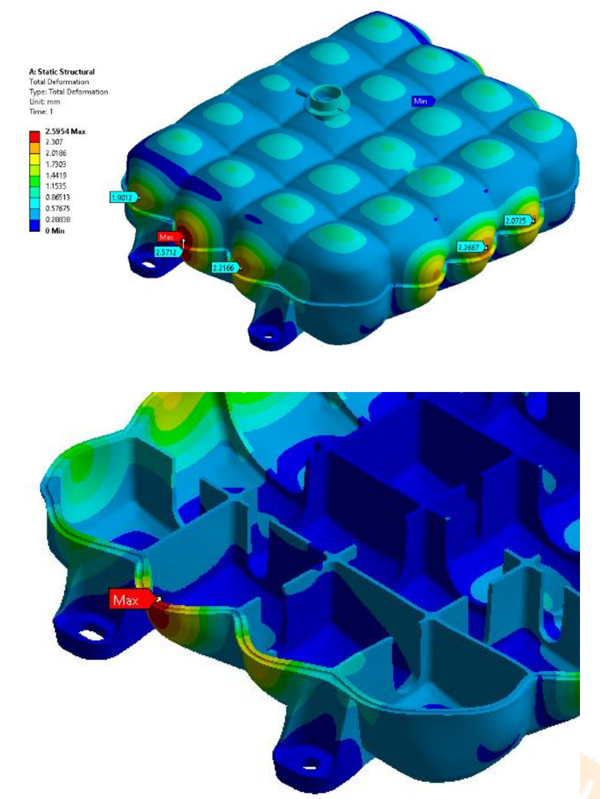
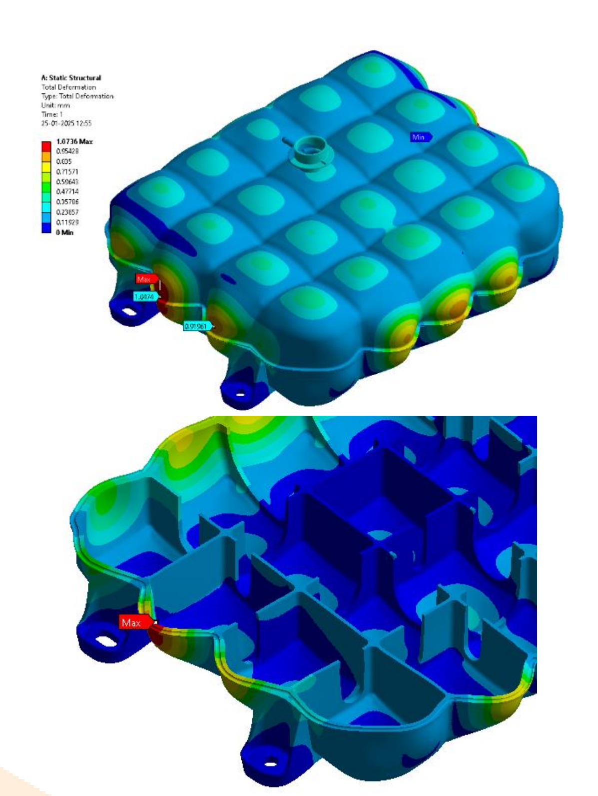
PP	PP-GF-10
	
Maximum displacement: 2.57 mm	Maximum displacement: 1.04 mm

Figure 9. Maximum Displacement Produced

4.2 Stress

Stress analysis determines the internal force distribution within the material when subjected to pressure. The simulation results show that PP experiences slightly higher maximum stress (65.30 MPa) compared to PP GF 10 (62.90 MPa)**.** While the difference in stress values is not highly significant, it indicates that PP is under more internal force per unit area**,** making it slightly more prone to strain and deformation. PP GF 10, due to its reinforced structure and higher Young's modulus, distributes stress more efficiently, reducing localized stress concentration and improving overall strength**.**

The stress distribution pattern reveals that the highest stress concentrations occur near the mounting points, where the structure is constrained and subjected to reaction forces. The areas near the inlet and outlet also show moderate stress concentrations, influenced by fluid pressure and structural discontinuities. PP, due to its lower stiffness, experiences higher localized stress values, leading to increased risk of material fatigue over extended use**.** In contrast, PP GF 10 demonstrates more uniform stress distribution, reducing the likelihood of material failure over time**.** Although both materials remain within their allowable stress limits and do not exhibit immediate failure under the given pressure conditions**,** PP GF 10 provides a greater safety margin**.** This means that under prolonged operational use, PP GF 10 would be more reliable in maintaining structural integrity, particularly in high-stress and high-temperature environments**.** The slightly lower stress values in PP GF 10 suggest that it is better equipped to handle repeated pressure fluctuations without significant material degradation**.**

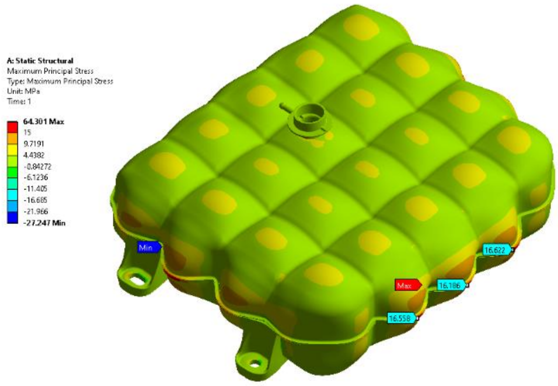
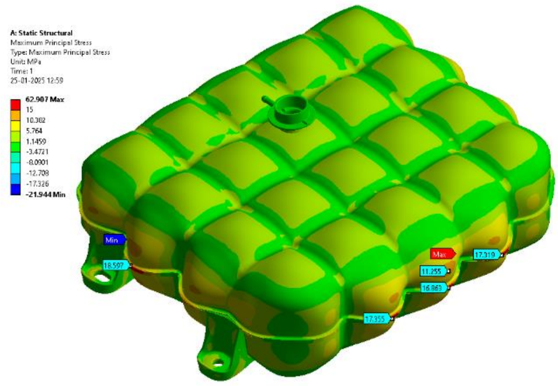
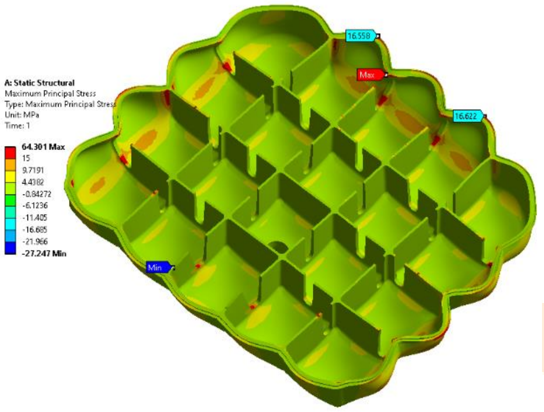
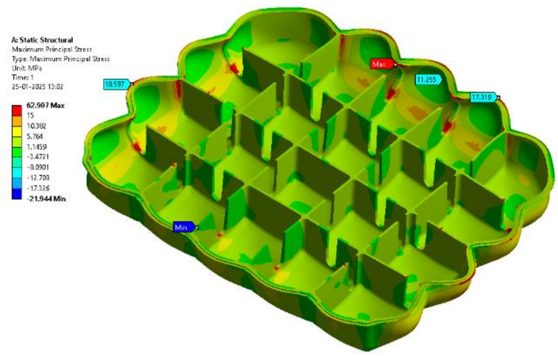
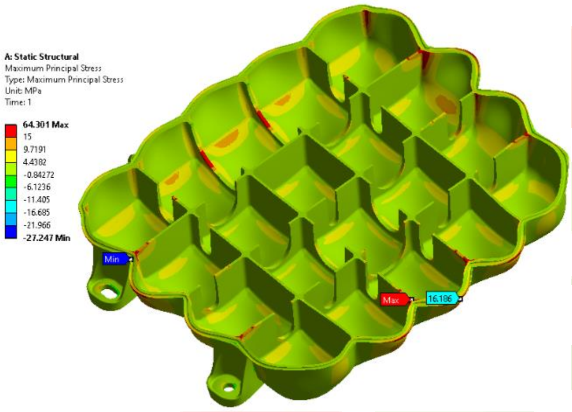
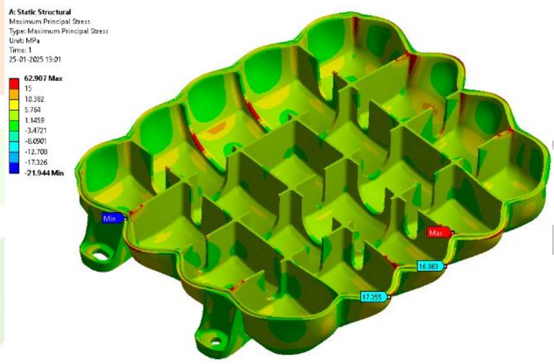
PP	PP-GF-10
	
	
	
PP have bad behavior Several areas don't reach the target specifications	PP-GF-10 has better behaviors than PP Assembly reaches the target specifications

Figure 10. Maximum Stress Produced

- **Overall Discussion and Material Recommendation**

The comparative analysis of displacement and stress clearly demonstrates that PP GF 10 outperforms PP in terms of mechanical strength, lower deformation, and better stress distribution, making it the more suitable material for automotive coolant tanks where structural stability is a priority**.** While PP remains a viable option for lightweight, cost-sensitive applications**,** its higher deformation and slightly elevated stress levels suggest it is more suitable for non-critical automotive components**.** In contrast, PP GF 10, with its lower displacement and improved stress-handling capabilities, offers superior durability and reliability, making it the preferred choice for coolant tanks operating under high pressure and thermal stress conditions.

The increased stiffness and stability of PP GF 10 justify its slightly higher material weight, as the performance benefits outweigh the marginal increase in mass. For applications where long-term reliability, safety, and structural integrity are critical, PP GF 10 is recommended over PP. Future research could explore hybrid materials or further modifications to PP GF 10 to optimize its mechanical properties while reducing weight and cost. Additionally, fatigue and impact analysis under varying temperature and load conditions would provide a deeper understanding of the long-term behavior of these materials in real-world automotive applications.

Table 2. Performance of Coolant tank under various conditions

Property	PP	PP GF 10
Maximum Deformation(mm)	2.57	1.04
Maximum Stress (MPa)	65.30	62.90
Weight (Kg)	3.647	4.408

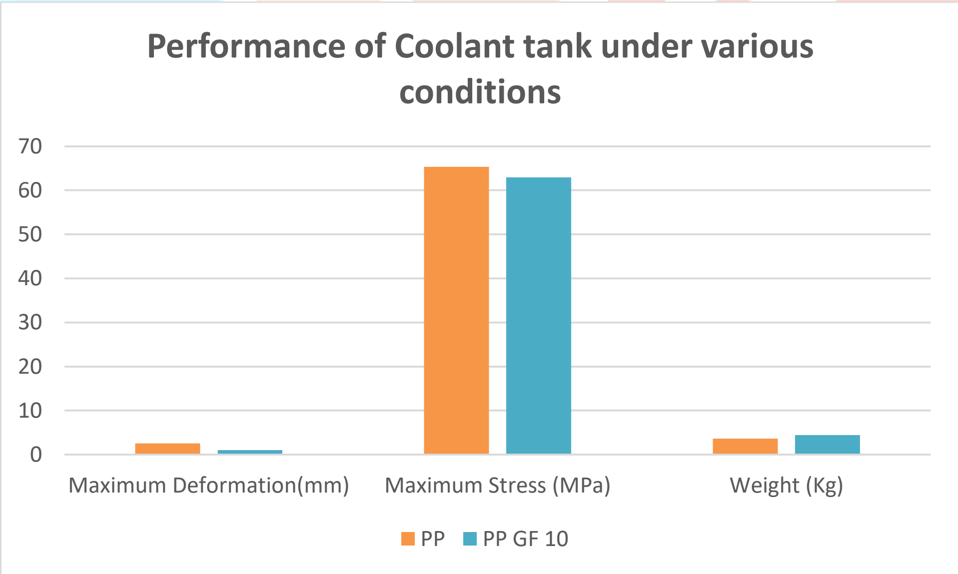


Figure 11. Performance of Coolant tank under various conditions

5. Conclusion

This research investigated the design optimization of an automotive coolant tank using Polypropylene (PP) and Polypropylene Glass Fiber Reinforced (PP GF 10) through Finite Element Method (FEM) analysis. The study focused on evaluating mechanical strength, deformation, and stress distribution under an internal pressure load of 1.25 bar. The findings indicate that PP GF 10 outperforms PP in terms of structural integrity, thermal resistance, and overall durability, making it a superior choice for high-stress automotive applications. The displacement analysis showed that PP exhibited significantly higher deformation (2.57

mm) compared to PP GF 10 (1.04 mm), making it more susceptible to shape distortion under pressure. PP GF 10's reduced deformation ensures better dimensional stability, minimizing the risk of long-term fatigue failure. Similarly, stress analysis demonstrated that PP GF 10 distributes stress more efficiently, experiencing slightly lower peak stress than PP. This indicates higher mechanical strength and improved load-bearing capacity.

While PP remains a cost-effective and lightweight option for non-critical components, PP GF 10's superior mechanical and thermal properties make it the preferred material for coolant tanks in high-performance automotive applications. Future research could explore hybrid composites or further reinforcement techniques **to** optimize weight, cost, and performance balance.

- **Future Scope**

Future research can explore hybrid composite materials that combine the benefits of PP and PP GF 10 while minimizing weight and cost. Investigating advanced reinforcement techniques, such as nano-fillers or fiber orientation optimization, could further enhance mechanical strength and thermal resistance. Additionally, fatigue and impact analysis under cyclic loading and varying temperature conditions would provide deeper insights into long-term durability. Experimental validation of FEM results through prototype testing could refine simulation accuracy. Lastly, the integration of sustainable and recyclable materials in coolant tank manufacturing can contribute to eco-friendly automotive solutions without compromising performance.

- **Recommendations**

  - PP GF 10 should be preferred for coolant tanks in high-stress and high-temperature applications due to its superior mechanical strength, lower deformation, and better stress resistance.
  - Weight optimization should be explored by developing hybrid composites or alternative reinforcement techniques to reduce the weight of PP GF 10 without compromising structural integrity.
  - Prototype testing should be conducted to validate FEM simulation results, ensuring real-world applicability and refining material properties.
  - Structural reinforcements such as optimized rib patterns or variable wall thickness should be considered to enhance performance and durability.
  - Sustainability initiatives should focus on integrating eco-friendly, recyclable, or bio-based polymer composites for lightweight and environmentally responsible automotive solutions.

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