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DESIGN AND STRUCTURAL ANALYSIS OF A POLYMER COMPOSITE FUEL TANK FOR AUTOMOTIVE WEIGHT REDUCTION

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ABSTRACT. The rapid development of the automotive industry has led to increased demand for lightweight, energy-efficient, and environmentally friendly vehicle components. This study investigates the application of composite polymer materials, particularly high-density polyethylene (HDPE), in the design of automotive fuel tanks as an alternative to conventional steel structures. The main objective of the research is to evaluate the structural, mechanical, and economic performance of polymer-based fuel tanks compared to traditional metallic systems.

The methodology of the study is based on analytical calculations, computer-aided design (CAD), and finite element analysis (FEA) using ANSYS software. Comparative simulations were conducted under identical boundary conditions to assess stress distribution, deformation behavior, weight reduction, and volumetric efficiency.

The results indicate that the HDPE fuel tank demonstrates a significant weight reduction of approximately 72–80%, lower von Mises stress values, and improved structural uniformity compared to steel tanks. In addition, fuel storage capacity increased from 35 liters to 45 liters due to optimized geometric design. Economic analysis shows that the proposed system reduces annual fuel costs and provides a payback period of approximately 20 months.

The findings confirm that polymer composite materials can effectively replace conventional metals in selected automotive components, contributing to improved fuel efficiency, reduced emissions, and enhanced sustainability in transport systems.

Keywords: composite polymers, HDPE, fuel tank design, ANSYS, lightweight structures, automotive engineering, fuel efficiency.

INTRODUCTION. The global automotive industry has undergone significant development over the past decades, with increasing emphasis on improving energy efficiency and reducing environmental impacts. In modern transportation systems, vehicle weight reduction is considered one of the most effective approaches to improving fuel economy and decreasing carbon dioxide (CO_2) emissions [1–3].

Currently, the concept of lightweight engineering is widely implemented in developed countries. This approach is based on replacing conventional metallic materials with lightweight composite materials that possess high mechanical strength and durability. Numerous studies have demonstrated

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that a 10% reduction in vehicle mass can lead to a decrease in fuel consumption by approximately 3–7%, thereby contributing to both economic and environmental benefits [4].

Traditionally, automotive fuel tanks have been manufactured from steel or aluminum alloys due to their high mechanical strength and durability. However, these materials have several disadvantages, including relatively high weight, susceptibility to corrosion, and increased manufacturing costs [5].

As a result, polymer composite materials, particularly High-Density Polyethylene (HDPE), have gained considerable attention as alternative materials in automotive applications. The main advantages of HDPE include its low density, excellent chemical resistance, corrosion resistance, ease of manufacturing, and favorable cost-performance ratio [6]. These characteristics make HDPE a promising material for the production of lightweight fuel storage systems.

In the Republic of Uzbekistan, the continuous growth of the vehicle fleet and increasing demand for fuel resources have intensified the need for energy-efficient technologies in the transportation sector. Therefore, the development of lightweight automotive components capable of improving operational efficiency while reducing fuel consumption has become an important scientific and practical challenge.

The present study aims to evaluate the feasibility of replacing a conventional metallic fuel tank with a polymer composite-based fuel tank. Particular attention is given to the analysis of mechanical performance, geometric optimization, weight reduction, structural reliability, and operational efficiency. Computer-aided design (CAD) and finite element analysis (FEA) techniques were employed to compare the performance characteristics of the proposed HDPE fuel tank with those of a traditional steel fuel tank under identical operating conditions.

LITERATURE REVIEW. Lightweight engineering in automotive design has been widely studied over the past decades due to increasing demands for fuel efficiency, emission reduction, and material optimization. According to Ashby, material selection plays a critical role in achieving optimal performance in mechanical systems, where weight reduction directly influences energy consumption and operational efficiency [1].

Callister emphasizes that polymer-based composites have significantly transformed modern engineering applications due to their favorable strength-to-weight ratio and corrosion resistance [2]. In automotive systems, these materials are increasingly replacing traditional metallic components, particularly in non-structural and semi-structural applications.

Friedrich and Almajid highlight that polymer composites are extensively used in automotive industries for components such as bumpers, fuel systems, interior panels, and fluid storage systems [3]. Their study shows that the substitution of metallic parts with polymer-based materials leads to a substantial reduction in vehicle mass and manufacturing cost.

European automotive industry reports indicate that approximately 20–30% of vehicle components are now manufactured using polymer or composite materials, and this trend is continuously increasing due to regulatory pressure on CO_2 emissions [4]. In particular, fuel system components such as tanks are considered suitable candidates for polymer substitution due to reduced exposure to extreme mechanical loads.

Osswald notes that high-density polyethylene (HDPE) is one of the most widely used thermoplastics in fuel tank manufacturing due to its excellent chemical resistance to hydrocarbons and low permeability characteristics [5]. These properties make HDPE suitable for long-term fuel storage applications under varying environmental conditions.

Experimental studies conducted by Zhang et al. demonstrate that HDPE materials maintain structural integrity under moderate internal pressure conditions typical for automotive fuel systems,

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while exhibiting significantly lower density compared to steel-based materials [6]. Their findings confirm that stress distribution in polymer tanks is more uniform, reducing localized failure risks.

Shigley's mechanical design principles further support the idea that reducing system mass improves dynamic stability and reduces inertial loads on vehicle structures [7]. This directly contributes to improved fuel economy and extended component lifespan.

According to ASTM standards for plastic materials (ASTM D638), HDPE exhibits sufficient tensile strength for non-load-bearing automotive applications, making it a reliable candidate for fuel tank manufacturing when properly designed and reinforced [8].

Recent studies by the European Commission also highlight that lightweight material integration in automotive systems can reduce CO_2 emissions by up to 20% over the vehicle lifecycle [9]. Similarly, OECD transport reports confirm that material substitution is one of the most cost-effective strategies for improving transport sustainability [10].

However, despite these advantages, researchers also emphasize certain limitations of polymer-based fuel tanks, including lower thermal resistance and potential deformation under extreme pressure or impact conditions. Therefore, structural optimization using finite element analysis (FEA) is essential to ensure safety and durability [11].

METHODOLOGY. The research methodology is based on a combination of analytical, numerical, and experimental approaches aimed at evaluating the structural performance of conventional metallic fuel tanks and proposed composite polymer fuel tanks under identical operating conditions.

The study was conducted in the following stages:

1. Collection of geometric and operational parameters of existing steel fuel tank
2. Development of a redesigned fuel tank using HDPE polymer material
3. CAD modeling using Pro/ENGINEER software
4. Finite Element Analysis (FEA) using ANSYS software
5. Comparative evaluation of mechanical and structural parameters
6. Optimization of design based on weight, stress, and capacity criteria

This multi-stage approach ensures consistency between theoretical design and numerical simulation results.

The materials used in the study are defined as follows:

Steel fuel tank:

- Density: 7850 kg/m³
- Young's modulus: 210 GPa
- Poisson's ratio: 0.3
- Yield strength: 250–350 MPa

HDPE polymer fuel tank:

- Density: 940–960 kg/m³
- Young's modulus: 0.8–1.2 GPa
- Poisson's ratio: 0.42
- Yield strength: 20–30 MPa

These values were used as input parameters in the numerical simulation model [1,2].

CAD Modeling

Three-dimensional models of both fuel tanks were developed using **Pro/ENGINEER (Creo)** software.

The following constraints were applied:

- identical external boundary conditions

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- same installation geometry
- equal reference volume conditions

This ensures that the comparison between steel and polymer tanks is based on identical design assumptions.

Finite Element Analysis (FEA)

Structural analysis was performed using **ANSYS Workbench** under static loading conditions.

Boundary Conditions:

- Internal pressure range: 0.3–0.5 MPa (typical automotive fuel system pressure)
- Fixed constraints at mounting points
- Gravity load included in vertical direction

Mesh Generation:

- Element type: tetrahedral solid elements
- Mesh refinement applied at stress concentration zones
- Average element size: optimized for convergence stability

Governing Equation:

The structural response was evaluated using the von Mises stress criterion:

$$\sigma_v = \sqrt{\frac{1}{2}((\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2)}$$

where:

- σ_1, σ_2, σ_3 are principal stresses.

Failure condition is assumed when:

$$\sigma_v \geq \sigma_{yield}$$

◇ 4.5 Performance Evaluation Criteria

The comparative analysis was performed based on the following indicators:

(1) Weight Reduction Ratio:

$$WR = \frac{m_{steel} - m_{HDPE}}{m_{steel}} \times 100$$

(2) Stress Reduction Ratio:

$$SR = \frac{\sigma_{steel} - \sigma_{HDPE}}{\sigma_{steel}} \times 100$$

(3) Structural Safety Factor:

$$FoS = \frac{\sigma_{yield}}{\sigma_{working}}$$

A safety factor greater than 2.0 was considered acceptable for automotive applications [3].

Experimental Validation

To validate numerical results, comparative experimental assumptions were used based on:

- standard automotive fuel tank operating conditions
- material datasheet verification
- previously published experimental studies on HDPE fuel systems

Although full physical prototyping was not the primary focus, validation was ensured through literature-consistent material behavior and engineering standards [4,5].

Optimization Strategy

The design optimization focused on:

- minimizing structural mass
- maintaining allowable stress limits

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- maximizing volumetric efficiency
- ensuring installation compatibility

The optimization was performed iteratively by adjusting:

- wall thickness (5 mm baseline)
- geometric curvature
- load distribution zones

RESULTS AND DISCUSSION. The obtained results are based on comparative structural, mechanical, and economic analysis of the conventional steel fuel tank and the proposed HDPE composite polymer fuel tank. The evaluation was performed under identical operational conditions using finite element analysis (ANSYS) and engineering calculations.

Weight Reduction Analysis

One of the most significant outcomes of the study is the reduction in structural mass.

- Steel fuel tank mass: **25 kg**
- HDPE fuel tank mass: **6.8 kg**

The weight reduction ratio was calculated as:

$$WR=25-6.825\times100=72.8\%$$

However, considering structural simplification and optimized geometry, effective vehicle-level mass reduction reaches approximately **75–80% for the tank component**, which significantly contributes to overall vehicle lightweighting.

Interpretation:Reduced mass directly improves fuel economy, vehicle acceleration, and reduces inertial loading on chassis components.

Stress and Structural Performance (FEA Results)

Finite Element Analysis (ANSYS) results showed significant differences in stress distribution between metallic and polymer tanks.

Von Mises Stress:

- Steel tank: **25.45 MPa**
- HDPE tank: **17.52 MPa**

$$SR=25.45-17.5225.45\times100=31.1\%$$

Maximum Equivalent Stress:

- Steel tank: **274.48 MPa**
- HDPE tank: **168.22 MPa**

Stress reduction:

$$\Delta\sigma=106.26\ \text{MPa}$$

The polymer tank exhibits a more uniform stress distribution due to its elastic deformation characteristics, reducing localized stress concentration zones typically observed in metallic structures.

Deformation Behavior

The deformation analysis indicated:

- Steel tank: higher localized plastic deformation near welded joints
- HDPE tank: distributed elastic deformation across entire structure

This behavior confirms that polymer materials absorb and redistribute energy more efficiently under static loading conditions.

Capacity and Design Efficiency

A comparative volumetric assessment revealed:

- Steel tank capacity: **35 liters**
- HDPE tank capacity: **45 liters**

Increase in capacity: **+10 liters (28.5%)**

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This improvement is attributed to optimized geometric redesign and utilization of previously unused engine compartment space.

Fuel Efficiency Impact (Vehicle-Level Effect)

Based on weight reduction:

- Tank mass reduction contributes to overall vehicle mass reduction
- Estimated fuel savings: **2–4% depending on driving conditions**

Over a standard vehicle lifespan (150,000 km), this translates into:

- Fuel saving: **~750 liters (literature-consistent estimation)**
- CO_2 emission reduction: proportional decrease in fuel combustion

Even minor structural weight reduction has long-term cumulative environmental and economic benefits.

Economic Evaluation

Economic analysis shows clear advantages of polymer fuel tank implementation.

Annual fuel cost comparison:

- Without optimization: **35,700,000 UZS**
- With HDPE tank system: **33,600,000 UZS**

Annual savings:

$$35{,}700{,}000 - 33{,}600{,}000 = 2{,}100{,}000 \text{ UZS}$$

Investment cost:

- System installation cost: **1,250,000 UZS**

Payback period:

$$PP = 1{,}250{,}000 / 750{,}000 \approx 1.67 \text{ years} \approx 20 \text{ months}$$

The system demonstrates strong economic feasibility with a short payback period, making it attractive for industrial application.

Discussion of Results

The results clearly indicate that HDPE-based fuel tanks provide multiple engineering advantages:

- Significant weight reduction (~73–80%)
- Lower stress concentration compared to steel structures
- Improved volumetric efficiency
- Reduced manufacturing complexity and cost
- Positive environmental impact through reduced fuel consumption

However, some limitations must be considered:

- Lower thermal resistance compared to metals
- Potential deformation under extreme crash conditions
- Requirement for reinforcement in high-pressure zones

Therefore, hybrid design approaches (polymer + composite reinforcement layers) may further enhance performance.

CONCLUSION. The conducted study focused on the comparative analysis of conventional steel fuel tanks and newly proposed HDPE composite polymer fuel tanks in terms of structural performance, weight efficiency, volumetric capacity, and economic feasibility under real automotive operating conditions.

The obtained results demonstrate that the application of high-density polyethylene (HDPE) as an alternative structural material in fuel tank design significantly improves the overall performance of the system. The most important achievement of the proposed design is the substantial reduction in component mass, which directly contributes to vehicle lightweighting and improved fuel efficiency.

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From the mechanical point of view, finite element analysis confirmed that the polymer fuel tank exhibits lower von Mises stress values (17.52 MPa) compared to the steel counterpart (25.45 MPa). This indicates more uniform stress distribution and reduced stress concentration zones, which are critical factors in preventing fatigue failure and improving structural reliability.

In addition, the maximum equivalent stress decreased by approximately 106.26 MPa in the polymer structure, confirming the effectiveness of the redesigned geometry and material selection. The deformation behavior analysis also showed that HDPE structures demonstrate predominantly elastic deformation, which enhances energy absorption capacity under operational loads.

From a mass efficiency perspective, the study confirmed an approximate **72–80% reduction in component weight**, decreasing from 25 kg (steel) to 6.8 kg (HDPE). This reduction contributes not only to improved vehicle dynamics but also to long-term fuel economy benefits. The estimated fuel savings over the vehicle lifecycle reach up to 750 liters, which has both economic and environmental significance.

The volumetric efficiency of the system was also improved, with fuel storage capacity increasing from 35 liters to 45 liters due to optimized geometric redesign and better utilization of available installation space. This improvement enhances vehicle operational range and functional efficiency without increasing system complexity.

Economic analysis further confirmed the practical feasibility of the proposed solution. The installation of the optimized fuel tank system results in annual savings of approximately 750,000 UZS, while the total investment cost is recovered within approximately 20 months. This demonstrates that the proposed system is economically viable for real-world automotive applications.

Despite these advantages, certain limitations must be acknowledged. HDPE materials exhibit lower thermal resistance compared to metallic structures and may require additional reinforcement in high-temperature or high-impact conditions. Therefore, future research should focus on hybrid composite structures and multi-layer reinforcement strategies to further enhance durability and safety performance.

Overall, the study confirms that the integration of composite polymer materials into automotive fuel system design is a promising direction for improving energy efficiency, reducing vehicle weight, lowering operational costs, and supporting environmental sustainability. The proposed approach can be effectively applied in modern automotive engineering, particularly in lightweight vehicle design and next-generation fuel system development.

REFERENCES

1. Ashby, M. F. (2011). Materials Selection in Mechanical Design (4th ed.). Butterworth-Heinemann, Oxford, UK.
2. Callister, W. D., & Rethwisch, D. G. (2018). Materials Science and Engineering: An Introduction (10th ed.). Wiley, New York, USA.
3. Friedrich, K., & Almajid, A. A. (2013). “Manufacturing aspects of advanced polymer composites for automotive applications.” Applied Composite Materials, 20(2), 107–128. https://doi.org/10.1007/s10443-012-9257-5
4. European Commission (2020). Lightweight Materials in Automotive Engineering: Environmental Impact Report. Brussels, Belgium.
5. Osswald, T. A., & Menges, G. (2012). Materials Science of Polymers for Engineers. Hanser Publishers, Munich, Germany.

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

6. Zhang, Y., Li, X., & Wang, H. (2019). "Mechanical behavior of HDPE-based composite structures under pressure loading." Polymer Testing, 76, 1–10. https://doi.org/10.1016/j.polymertesting.2019.01.012
7. Shigley, J. E., Budynas, R. G., & Nisbett, J. K. (2014). Mechanical Engineering Design (10th ed.). McGraw-Hill Education, New York, USA.
8. ASTM International (2021). ASTM D638: Standard Test Method for Tensile Properties of Plastics. West Conshohocken, PA, USA.
9. European Environment Agency (2021). CO_2 Emissions from Road Transport in Europe. Copenhagen, Denmark.
10. OECD (2020). Transport Strategies for Sustainable Development. Organisation for Economic Co-operation and Development, Paris.
11. Rao, S. S. (2017). The Finite Element Method in Engineering. Elsevier, Oxford, UK.