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Analyzing Graphene based composites on the Performance of Household Vehicle

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***Abstract*— The demand for advanced materials in the automotive industry has driven focus into graphene-based composites due to their exceptional mechanical, thermal, and lightweight properties. But comprehensive study for a particular area could not be achieved yet. By applying detailed finite element simulations, this study assesses the performance of aluminum reinforced with graphene nanoplatelets (Al + G) in vehicle components, particularly a front bumper and an automobile door. To evaluate deformation, stress distribution, impact resistance, and thermal conductivity, ANSYS Workbench was used for static structural, transient dynamic, and thermal analyses. Significant performance gains were confirmed by load testing; under the same load conditions, the Al + G composite reduced deformation by more than 30% when compared to traditional aluminum. Improved heat dissipation, which is essential for high-performance automotive systems and electric vehicles, was validated by thermal analysis. These findings pave the way for next-generation automotive material solutions by confirming the feasibility of graphene-based composites in the production of lightweight, robust, and energy-efficient vehicle components. Still more tests and analysis need to be done to ascertain the use of graphene-based components in automobiles.**

Keywords*—*Graphene composites, automotive materials, lightweight structures, finite element analysis, aluminum-graphene, thermal management, impact resistance

I. INTRODUCTION

The global automotive industry has entered a transformative era driven by growing demands for fuel efficiency, reduced emissions, enhanced performance, and safety. One of the most effective strategies to achieve these objectives is reducing the weight of vehicle components without compromising structural integrity. Traditionally, materials such as steel and aluminum alloys have dominated the construction of automotive parts due to their established mechanical properties and manufacturability. However, these materials exhibit a trade-off between strength and weight. Steel offers high strength but contributes significantly to vehicle mass, while aluminum reduces weight but falls short in terms of fatigue resistance and thermal management in some high-stress environments.

In contrast graphene which is a two-dimensional monolayer of carbon atoms arranged in a hexagonal lattice has emerged as a revolutionary material with the potential to redefine the landscape of automotive material science.

Discovered in 2004, graphene exhibits a remarkable set of properties including ultra-high tensile strength (~130 GPa), high Young's modulus (~1 TPa), superior thermal conductivity (up to 5300 W/m·K), and excellent electrical conductivity. These characteristics make graphene an ideal reinforcement agent when incorporated into metal or polymer matrices to form graphene-based composites. In automotive applications, graphene-based composites hold promise across several domains:

Mechanical enhancement: The inclusion of graphene can significantly improve the tensile strength, impact resistance, and fatigue life of structural components.

Weight reduction: Due to its high strength-to-weight ratio, graphene allows for thinner, lighter parts without sacrificing performance.

Thermal management: The exceptional thermal conductivity of graphene makes it ideal for components exposed to high temperatures, such as engine parts or electric vehicle (EV) battery enclosures.

Electrical properties: Graphene's conductivity opens up possibilities for multifunctional components with integrated sensing, self-monitoring, or EMI shielding capabilities.

Graphene's practical application in automotive systems remains unresolved despite its scientific advantages. This is mainly because of issues with dispersion uniformity, large-scale production costs, and long-term material behavior under changing load and environmental conditions. But new developments in material processing, like chemical vapor deposition (CVD), solution mixing, and powder metallurgy, have made it more and more possible to create graphene-aluminum (Al + G) composites, which combine the reinforcement properties of graphene with the lightweight benefit of aluminum.

This study focuses on evaluating the practical application of Al + G composites in two representative automotive components: a **car door panel** and a **front bumper**. Through a combination of finite element analysis (FEA) and comparative performance testing, the study aims to:

- Quantify improvements in mechanical strength, deformation behavior, and impact resistance
- Analyze thermal performance under operational heat gradients
- Compare results against traditional aluminum counterparts under equivalent load conditions

The research employs ANSYS Workbench to simulate static structural loads, transient impacts, and thermal conductivity across both materials. The findings not only demonstrate the substantial benefits of integrating graphene into automotive designs but also underscore the potential for future adoption of such composites in large-scale manufacturing, particularly in EVs and high-performance vehicles where lightweight efficiency is critical.

II. LITRETURE REVIEW

In recognition of its exceptional mechanical, thermal, and electrical properties, graphene has drawn a lot of interest in materials science. Numerous studies have looked into how adding graphene to metal matrices can improve performance in automotive applications. Because aluminum alloys are already widely used in the automotive industry, the use of graphene in vehicle components focuses primarily on strengthening them.

Composites reinforced with graphene have shown significant improvements in impact absorption, fatigue resistance, and tensile strength. According to studies like Rafiee et al. [1], adding as little as 0.1–0.5 weight percent graphene to epoxy or aluminum matrices could increase their tensile strength by as much as 40%. In a similar vein, Zhou et al. [2] noted that graphene composites show decreased stress concentrations and improved crack resistance under impact loading.

Because of its high thermal conductivity (~5300 W/m·K), graphene can be used to improve heat dissipation in EV battery enclosures, brake systems, and engine parts from the standpoint of thermal management. According to Wang et al. [3], adding graphene to thermal interface materials increased heat dissipation efficiency by over 50%.

Graphene composites are also showing advantages in reducing component weight without losing safety in the context of structural components like doors and bumpers. According to Kim et al. [4], graphene-aluminum composites have a higher specific strength but a lower density, which reduces vehicle weight overall and improves fuel efficiency. By lowering CO_2 emissions over the course of the vehicle's lifecycle, the use of such materials can also help achieve sustainability goals.

III. METHODOLOGY

This study adopts a simulation-based approach to evaluate and compare the performance of graphene-reinforced aluminum (Al + G) composites and regular aluminum in automotive parts. For this analysis, a car door panel and a front bumper were chosen as two representative components. The methodology is divided into four main stages: defining the baseline material, estimating weight, simulating finite elements in ANSYS, and comparing the outcomes under thermal and mechanical loads.

A. Material Selection and CAD Modeling

Two materials were chosen:

- **Aluminum Alloy (baseline)**
- **Graphene + Aluminum Composite (reinforced)**

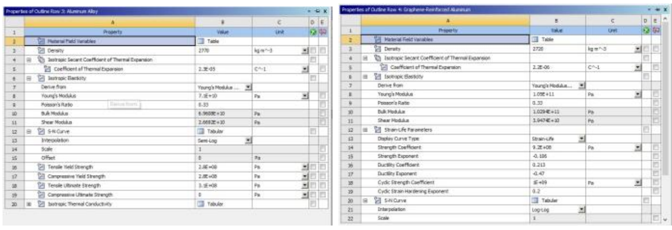

Fig. 1. Material Properties of Al & Graphene based Aluminium

Mechanical properties such as density, Young's modulus, and thermal conductivity were collected from the literature and implemented in **SolidWorks** and **ANSYS**. CAD models for the **car door** and **front bumper** were developed in SolidWorks with geometry simplification to optimize simulation performance.

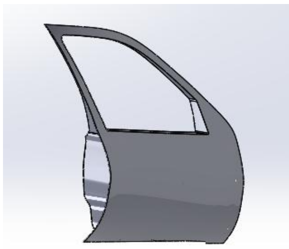

Fig. 2. Solidworks Modeling of a Car Door Panel

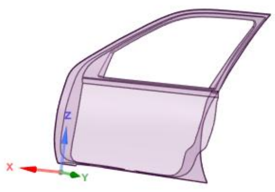

Fig. 3. Simplified Model of the Car Door Panel

Fig. 4. ANSYS Model used

B. *Weight Estimation using SolidWorks*

Material substitution was tested using SolidWorks mass properties analysis. The same CAD geometry was used to compare weights.

TABLE I. WEIGHT COMPARISON

Component	Volume (cm³)	Weight(Al, g)	Weight(Al+ G, g)
Door Panel	2,608,996.07	7305.19	7096.47
Front Bumper	6,752,022.67	18905.66	18365.60

C. *Simulation Tests in ANSYS*

All simulations were performed using **ANSYS** Workbench with tetrahedral mesh elements. Mesh independence was verified by performing sensitivity analysis on mesh sizes (30mm down to 10mm) and comparing maximum stress values. Boundary conditions were applied according to real-world operational scenarios.

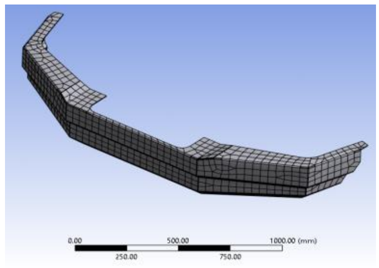

Fig. 5. Mesh and skewness

Simulations performed:

1. **Static Load Deflection Test**

   - Uniform load up to 2000N applied to door and bumper.
   - Results included deformation, stress, and strain.

2. **Impact Analysis**

   - Impact velocity of 5 m/s applied to bumper.
   - Force estimated: ~200kN (based on a 3200 kg vehicle at 40 km/h).
   - Time-dependent analysis captured the dynamic response and energy absorption behavior.

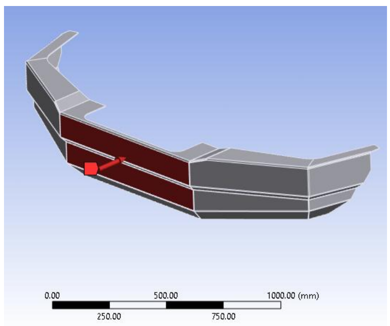

Fig. 6. Boundry condtions - Force

3. **Steady-State Thermal Analysis**

   - 100°C temperature gradient applied to external surfaces.
   - Heat flux evaluated for both materials.

D. Data Analysis and Evaluation

The simulation results were post-processed in ANSYS to extract numerical values for each metric. Comparisons were made between the Al and Al + G materials under identical boundary and loading conditions. Specific attention was given to:

- Reduction in total deformation
- Stress concentration zones
- Heat flow paths and gradients
- Strain and displacement distributions during impact

These outputs were used to verify the performance benefits of using graphene-based composites in vehicle components.

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TABLE II. LOAD TEST COMPARISON AT 2000N

Component	Material	Deformation (mm)	Stress (MPa)	Strain
Door Panel	Aluminum	0.8448	79.36	1.2966×10^{-3}
Door Panel	Graphene + Al	0.5713	79.36	8.767×10^{-4}
Bumper	Aluminum	0.8384	95.13	1.3732×10^{-3}
Bumper	Graphene + Al	0.5672	95.13	9.286×10^{-4}

IV. RESULTS AND DISCUSSION

The results of simulation analyses of graphene-reinforced aluminum (Al + G) and regular aluminum in two important automotive components, the front bumper and the door panel are shown in this section. Deformation, stress, strain, impact resistance, and thermal behavior are among the performance metrics evaluated.

A. Static Load Analysis

Under static loading conditions (up to 2000N), the graphene-reinforced aluminum consistently showed lower deformation and strain values compared to standard aluminum, despite having similar maximum stress. This indicates that Al + G composites are more resistant to shape change under the same loading conditions.

For the car door panel, deformation was reduced by approximately 32% when using graphene-reinforced aluminum. A similar reduction (~32.3%) was observed for the front bumper.

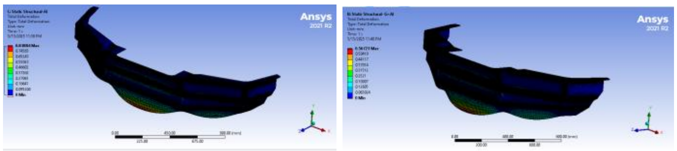

Fig. 7. Deformation of Bumper under 2000N

B. Impact Simulation

Explicit dynamics were used the impulse-momentum principle to calculate an impact force of about 200 kN based on a 3200 kg vehicle, simulating a frontal collision at 5 m/s.

Better energy absorption was demonstrated by graphene composites, as evidenced by reduced peak stress and more evenly distributed strain throughout affected areas. Particularly, the front bumper showed less concentrated stress, improving crashworthiness.

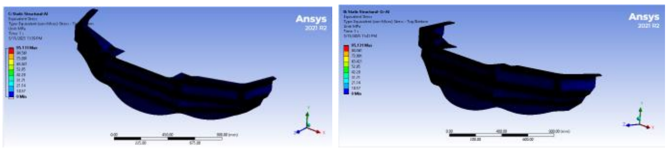

Fig. 8. Stress Contour plots from 2000N impact case

C. Thermal Analysis

A 100°C temperature gradient was applied to the external surfaces in a steady-state thermal simulation. The Al + G composite demonstrated enhanced heat dissipation and more uniform temperature distribution, reducing hotspots.

This behavior is vital in automotive systems, especially for EV battery enclosures, engine compartments, and braking systems, where thermal buildup can lead to degradation and safety risks.

V. CONCLUSION AND FUTUREWORK

With a focus on structural elements like the front bumper and door panel, this study investigated the use of graphene-reinforced aluminum composites in automotive applications. Significant benefits of graphene integration were shown by the ANSYS simulations and SolidWorks modeling in terms of weight reduction, mechanical performance, and thermal efficiency.

The Al + G composites showed a steady reduction in deformation in the static load simulations, by more than 30% when compared to standard aluminum, without sacrificing their ability to handle stress. It means improved dimensional stability and stiffness under operating loads. Better strain distribution and energy absorption were shown by graphene composites during impact simulations, confirming their suitability for safety-critical parts such as bumpers. Additionally, thermal analysis conducted under a gradient of 100°C revealed that the

Al + G composites allow for more uniform heat dispersion, which is crucial for electric vehicles and high-heat areas of internal combustion systems.

According to the weight estimation analysis, there was a noticeable decrease in component mass when aluminum was replaced with graphene-aluminum composite. This supports contemporary automotive sustainability objectives by lowering emissions and increasing fuel efficiency.

Even with these encouraging results, there are still some restrictions and difficulties. Since uneven distribution may lower the impact of the composite, uniform graphene dispersion in the aluminum matrix is still a technical challenge. Furthermore, the viability of producing graphene on a large scale and fabricating composites is still being determined.

The following approaches are suggested in order to build on the results of this investigation and confirm the industrial suitability of graphene composites:

- **Experimental Validation**: Physical prototyping and laboratory testing should be conducted to confirm the simulated results under real-world conditions.
- **Fatigue and Durability Analysis**: Long-term behavior under cyclic loading should be studied to understand the fatigue life of graphene composites in automotive environments.
- **Optimization of Dispersion Techniques**: Further research into scalable dispersion methods—such as chemical functionalization or extrusion-based mixing—can help overcome agglomeration issues and enhance composite uniformity.
- **Cost and Lifecycle Assessment**: Economic and environmental lifecycle analysis should be performed to evaluate the cost-benefit ratio of graphene composite integration at production scale.
- **Application Expansion**: Beyond structural parts, future work could explore graphene's use in battery enclosures, engine mounts, and even smart sensing components within vehicles due to its electrical conductivity.

By addressing these areas, the automotive industry can unlock the full potential of graphene-based materials and move toward a future of lighter, stronger, and more sustainable vehicle design.

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Vinura Costa, Kaushika Kalutarage, and Dylan Perera worked together on this project; each author made an equal contribution to the study and writing of this work.

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