International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1651-1656
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0234

Finite Element Analysis in Automobile

T Balasubramanian[1], U Amirdhavarshini[2], A. Imayavaramban[3]
[1]Associate Professor, Dept. of Mech, St. Joseph's College of Engineering, Chennai, Tamil Nadu, India.
[2,3]UG Scholar, Dept. of Mech, St. Joseph's College of Engineering, Chennai, Tamil Nadu, India.
Emails: *rtbalasubramani@gmail.com[1], amirdhau@gmail.com[2], imayavaramban2414@gmail.com[3]*

Abstract

As the automobile industry is moving towards the production of lightweight materials, improved fuel efficiency and structural characteristics have become more significant. In the present study, aluminium and polymer composite materials are compared for producing automobile bodies according to simulations. Though used conventionally, aluminium is heavy and corrodes easily. In order to overcome the drawbacks mentioned above, polymer composites proved to be a more suitable choice since they are weightless, have satisfactory strength, and can resist corrosion. Simulation output shows the polymer composite is superior in many respects. It deforms much less with deformation reduction 66.2% and less strain, and hence it is stiff and more resistant to stretching on impact. It also withstands impact forces better, with less equivalent stress of 28.8% decreased. All these point towards polymer composites as a potential substitute for aluminium in car body manufacture, with increased durability and performance.

Keywords: *Aluminium; Analysis; Automobile; FEA; Polymer Composites.*

1. Introduction

Automobile safety plays a crucial role in preventing accident-related fatalities and injuries. One of the most critical aspects of car safety is how crash energy absorption zones are engineered to protect passengers as they absorb energy. The special engineering of such zones is for them to crush upon impact in an accident, whose effect is the diffusion of force from the automobile passengers. The impact-absorbing structure concept gained huge popularity in the mid-20th century when engineers began to seek a way to mitigate the destructive effects of crashes. Over time the design, material technology, and manufacturing processes have all combined to improve these safety features step by step. Previously, steel and aluminum were used mainly in car frames because of their high strength and durability. But with more demands for weightlessness, fuel efficiency, and environment-friendliness, polymer composites are also finding growing grounds as a likely solution within the automotive industry. Aluminum ensures high strength-to-weight ratio, resistance to corrosion, and recyclability. But it's dense and thus ruins the fuel efficiency and power. Polymer composites are light, have great energy absorbing characteristics, and are corrosion resistant. What is unique about polymer composites is that when they are struck, they deform but never break into fragments. That makes them the absolute best to use in protecting the occupants within a crash. Here dynamic and modal analysis have been employed for investigation of the performance of various materials under actual conditions. These analyses are used to investigate various parameters like vibration, stress, and deformation, all of which come under the domain of investigating the safety and strength of structure of the vehicle. The results of these analyses will assist in the determination of the most appropriate material to use in a bid to make the vehicle safer. Finally, this study seeks to advance car safety through the exploration of polymer composites and dynamic testing techniques [1-4].

2. Methodology

- Collection of dimensions of the Car Monocoque and selection of Material.
- Design of the monocoque body using CATIA.
- The model is implemented in ANSYS for FE analysis of different parameters such as 'total

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1651-1656
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0234

deformation', 'stress', and 'strain' etc.,

- Comparing the material behavior under different forces.
- Optimization and validation of the results.
- Final results and conclusions.

3. Modelling Methodology

CATIA is a parametric, feature-based product development and 3D design tool. It is a parametric system where parameters determine the model's behavior as well as its geometry. Parameters can be numerical, i.e., dimensions (length, width, diameter), or geometric, i.e., tangency, perpendicularity, concentricity, or symmetry. Parametric constraints in CATIA define relationships between model elements, so that changing one element updates others to keep them consistent. This preserves design intent and facilitates easy adaptation during the product lifecycle. CATIA relations allow dependencies between dimensions or features, making modifications easier and ensuring accurate, error-free modeling [5-9].

3.1. Design of Monocoque Chassis

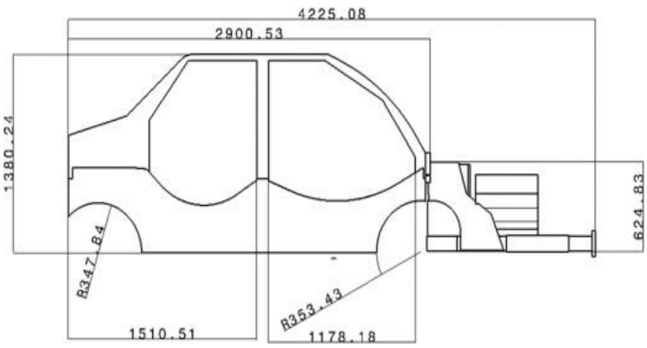

Figure 1 Side View Details

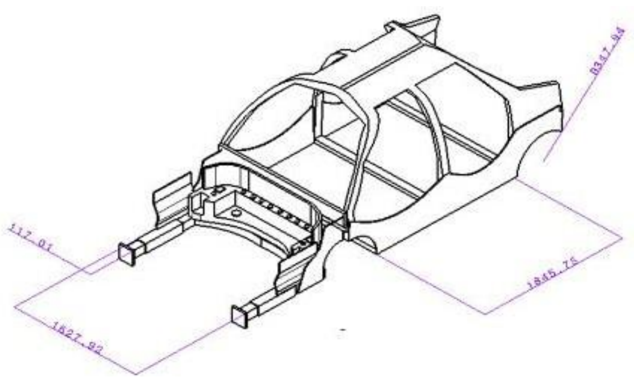

Figure 2 Isometric View Details

Material Selection

3.2. Aluminium

Figure 1 & 2. Aluminium is a corrosion-resistant, strong, light metal that possesses excellent malleability and electrical conductivity and finds excellent application in automotive and aerospace industries. Here Aluminium Alloy 6061-T6 is taken for analysis which is common in automobile industries, shown in Table 1 [10-14].

Table 1 Mechanical Properties of Aluminium Alloy 6061-T6

PROPERTIES	VALUES
Ultimate tensile strength	310 MPa
Density	2700 kg/m³
Modulus of elasticity	68.9 GPa
Shear strength	207 MPa
Yield strength (0.2% offset)	276 MPa
Melting point	660°C
Elongation	12%

3.3. Polymer Composite

Polymer composites such as CFRP and GFRP are light-weight, high-strength materials of high stiffness and excellent impact resistance, and hence are suited for applications in the automobile sector such as crumple zones and structural members, Table 2.

Table 2 Mechanical Properties of Polyethylene Composite

PROPERTIES	VALUES
Ultimate tensile strength	31 MPa
Density	1200 kg/m³
Modulus of elasticity	2.85 GPa
Shear strength	13 MPa
Yield strength (0.2% offset)	25 MPa
Melting point	137°C
Elongation	300%

4. Analysis in Ansys

ANSYS Workbench is a software platform that helps engineers run different types of simulations in one place. It has a simple and easy-to-use interface that makes even complex simulations easier to manage. The software connects well with CAD programs, has

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1651-1656
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0234

automated meshing, and allows users to adjust parameters easily. This helps engineers improve their designs by using simulations to test and optimize, Figure 3 & 4.

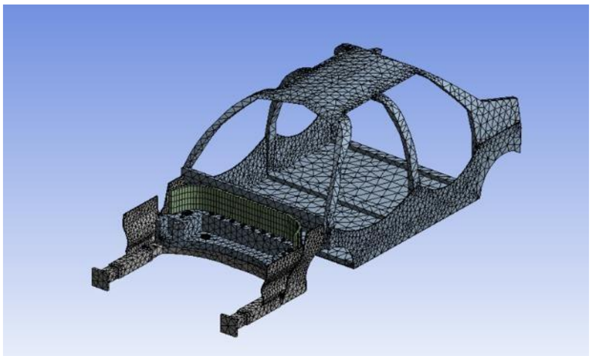

Figure 3 Meshing of Monocoque Chassis

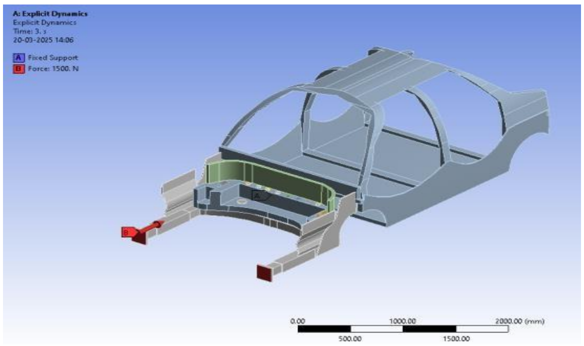

Figure 4 Boundary Conditions

4.1. Dynamic Analysis

Dynamic analysis is conducted to analyze the material and structural response because of time-varying loads like impacts, vibration, or shock loads. Dynamic analysis includes time-varying phenomena like instantaneous deformation and energy dissipation, which are not included in static analysis.

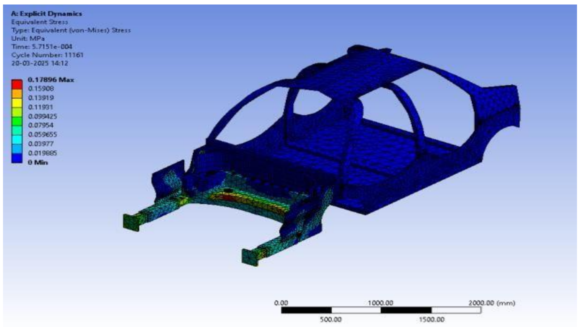

Figure 5. Equivalent Stress for Aluminum Material

It is very much involved in actual applications like vehicle crashes or machinery operation where the loads become dynamic and cause immense material deformation or failure. So, here dynamic Analysis is done to understand the material behavior on a particular load with a fixed support [15] (Refer Figures 5 to 17).

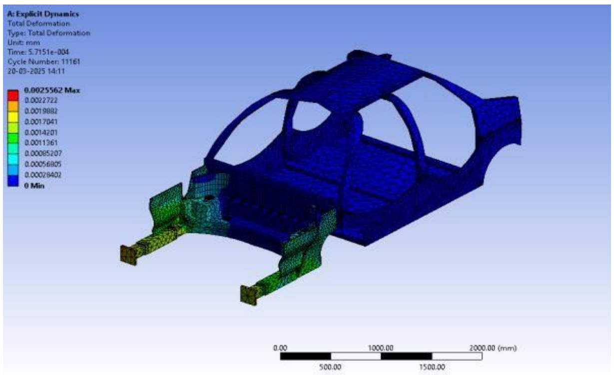

Figure 6 Total Deformation for Aluminium Material

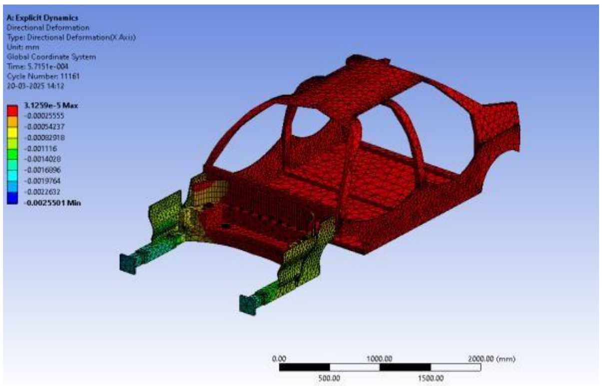

Figure 7 Directional Deformation for Aluminium Material

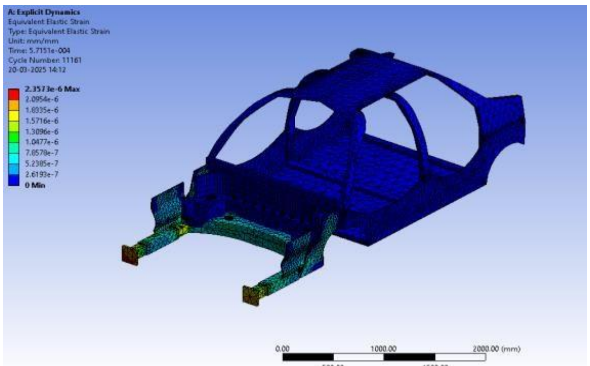

Figure 8 Equivalent Elastic Strain for Aluminium Material

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1651-1656
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0234

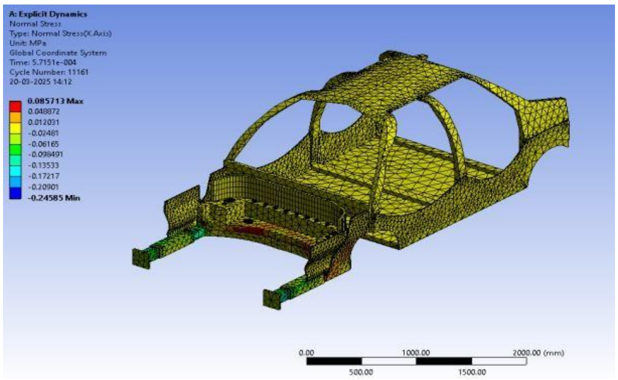

Figure 9 Normal Stress for Aluminium Material

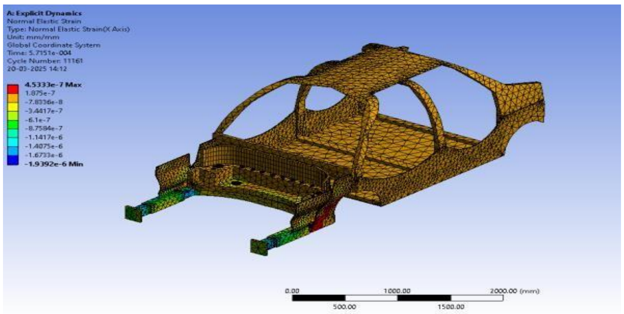

Figure 10 Normal Elastic Strain for Aluminium Material

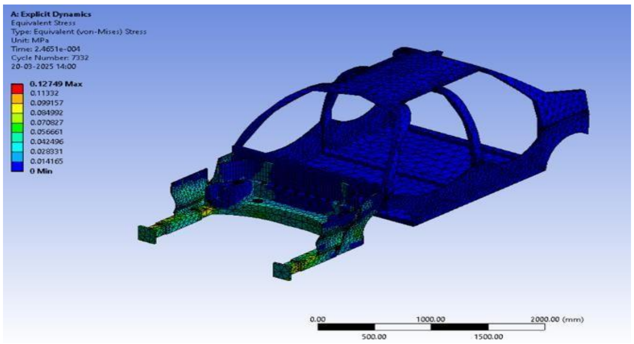

Figure 11 Equivalent Stress for Polyethelene based Composite

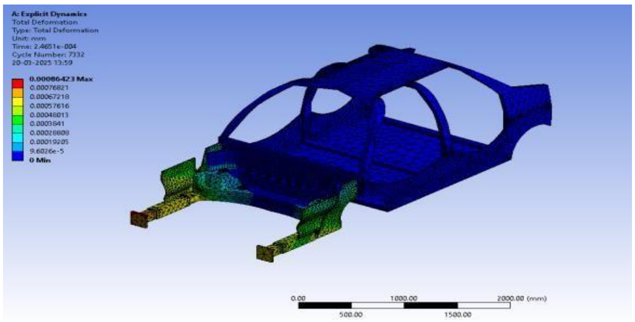

Figure 12 Total Deformation for Polyethelene based Composite

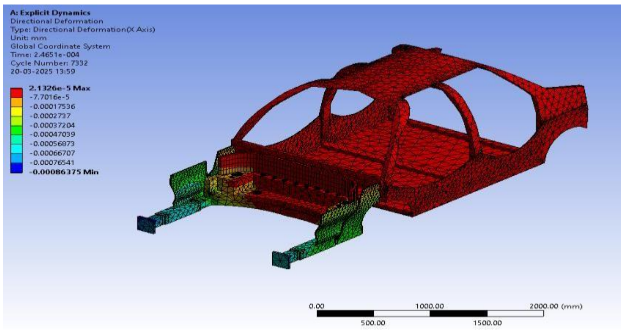

Figure 13 Directional Deformation for Polyethelene based Composite

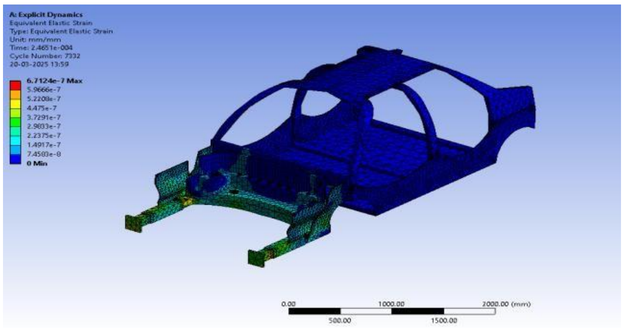

Figure 14 Equivalent Elastic Strain for Polyethelene based Composite

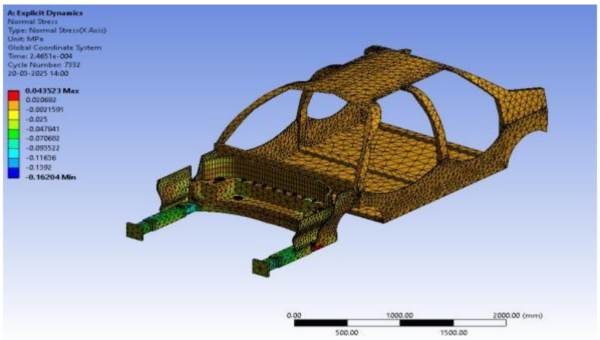

Figure 15 Normal Stress for Polyethelene based Composite

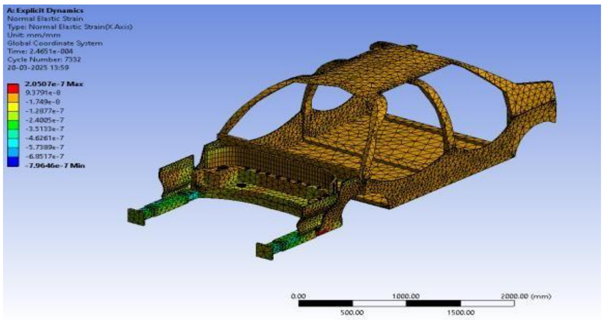

Figure 16 Normal Elastic Strain for Polyethelene based Composite

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1651-1656
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0234

Results and Discussion

4.2. Results

Aluminum and polymer composite material crumple zone returns outstanding differences in deformation, strain, and stress responses. Aluminum deformation is 0.0025562 m, whereas the polymer composite deformation is 0.00086423 m. Directional deformation results are 3.13e04 and 2.13e-05 for aluminum and the polymer composite, respectively. Equivalent elastic strain of aluminum is 2.36e-06, which is extremely larger than 6.71e-07 of the polymer composite. Normal elastic strain is also in the same but with very large values, that of aluminum being 4.53e07, while polymer composite is 2.05e-07, which is a very small value. Equivalent stress in aluminum presents a larger value of 0.17896 MPa, while that of polymer composite is 0.12749 MPa. Similarly, normal stress in aluminum (0.085713 MPa) is greater than that of the polymer composite (0.043523 MPa). This implies that even though the aluminum is stronger, it deforms and holds more stress than the polymer composite material under identical conditions, Table 3.

Table 3 Analysis Result

	Aluminum	Polymer Composite
Total Deformation	0.0025562 m	0.00086423m
Directional Deformation	3.13e04	2.13e-05
Equivalent Elastic Strain	2.36e06	6.71e-07
Normal Elastic Strain	4.53e07	2.05e-07
Equivalent Stress	0.17896 MPa	0.12749 Mpa
Normal Stress	0.085713 MPa	0.043523Mpa

4.3. Discussion

The research illustrates a clear variation in aluminum and polymer composite materials' response to mechanical effects due to impact loading in the case of a crumple zone. A metal material such as aluminum produces higher stress and deformation values that are due to its relatively larger stiffness and limited energy absorption feature. It can be said that aluminum is strong against impact but transmits larger force to the rest of the structure.

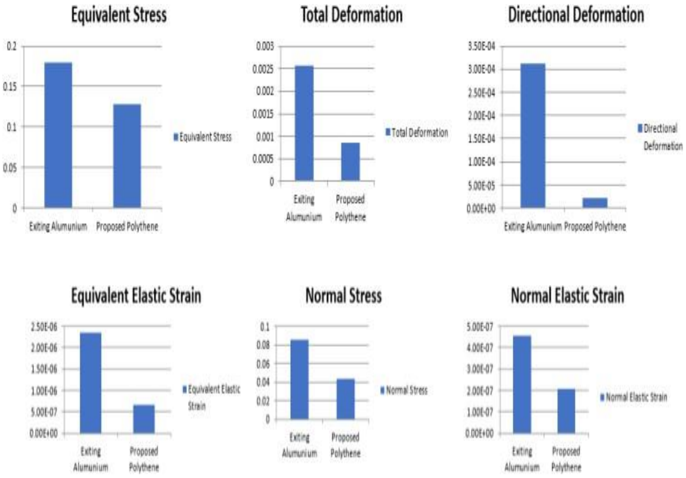

Figure 17 Graphical Representation by Comparison of Analysis Results

On the other hand, polymer composite has lower deformation and stress levels, which reflect a greater ability to absorb impact energy as well as disperse forces. Smaller normal and equivalent elastic strain values also reflect that polymer composites are able to realize controlled deformation without extreme stress concentration and thus avoid potential damage on adjacent components. From a safety perspective, polymer composites employed in crumple zones are able to offer better protection through enhanced energy absorption of impacts, with hopefully fewer injuries as a result of automobile crashes. But again, there is always the alternative route of aluminum based on its strength properties and its long history of use in the construction of automobiles. The choice between the two would be a matter of balance between structural integrity, energy absorption efficiency, and cost. Overall, the current research is aimed at optimizing materials in crumple zones for maximum energy absorption and structural strength. Future studies can investigate hybrid materials that leverage the advantages of both aluminum as well as polymer composites to enhance safety and durability for crash- intensive use.

Conclusion

The comparative analysis of aluminum and polymer composite materials for use in crumple zones has been discussed through this study. The study verifies that although aluminum possesses higher stress and deformation capacity, polymer composites possess better energy absorption characteristics. The compromise between structural stiffness and impact absorption is an important factor in the material selection utilized in crumple zones. Polymer composites appear to be a promising candidate for improving passenger safety as it possesses superior impact energy absorption and dissipation capabilities. These features can be further improved by future material science breakthroughs, potentially leading to hybrid solutions that increase performance and safety in automotive and structural applications.

Acknowledgements

I personally believe in the mentorship and advice of my professors and mentors whose inputs formulated my thoughts and process. I am grateful to my family and friends for their support and researchers and open-source community whose work allowed me to build this project upon a good ground. My problem-solving and technical skills have tremendously been developed because of this experience, and thus this project is essentially an example of teamwork and collective knowledge.

References

[1]. Ali, M., & Kumar, R. (2023). Design and crash analysis of automotive crumple zones. International Journal of Automotive Engineering, Vol. 10(2), pp. 45-52.

[2]. Bansal, S., & Sharma, P. (2023). Comparative analysis of aluminum and composite materials in vehicle crumple zones. Journal of Mechanical Research, Vol. 15(1), pp. 22-30.

[3]. Chen, X., & Liu, H. (2022). Energy absorption characteristics of polymer composite materials in crumple zones. Materials Today: Proceedings, Vol. 56, pp. 78-85.

[4]. Das, P., & Roy, S. (2023). Finite element modeling of impact forces in crumple zones using ANSYS. International Journal of Impact Engineering, Vol. 112, pp. 301-310.

[5]. Evans, T., & Patel, M. (2022). Optimization of crumple zone structures using lightweight materials. SAE International Journal of Transportation Safety, Vol. 9(3), pp. 89-97.

[6]. Feng, J., & Zhao, Y. (2023). Modal analysis of crash impact on different vehicle frame materials. Computational Mechanics Journal, Vol. 18(4), pp. 110-120.

[7]. Gupta, A., & Singh, R. (2022). Structural analysis of crumple zones with aluminum and hybrid composites. Journal of Vehicle Safety Engineering, Vol. 20(2), pp. 55-65.

[8]. Harris, J., & Wright, L. (2023). Experimental and numerical studies on automotive crashworthiness. International Journal of Crashworthiness, Vol. 29(1), pp. 120-130.

[9]. Ibrahim, A., & Noor, M. (2023). Frontal crash simulation of composite materials in vehicles. Advances in Mechanical Engineering, Vol. 17(2), pp. 210-220.

[10]. Jones, K., & Adams, B. (2022). Dynamic response of crumple zones under varying impact velocities. Journal of Computational Structural Analysis, Vol. 14(3), pp. 95-105.

[11]. Kumar, S., & Verma, D. (2023). Design optimization of energy-absorbing structures in automobiles. International Journal of Advanced Mechanical Design, Vol. 8(1), pp. 200-210.

[12]. Lee, T., & Park, J. (2022). Simulation- based assessment of crumple zones in electric vehicles. Energy Absorption Journal, Vol. 19(3), pp.150-160.

[13]. Mohan, R., & Rajesh, P. (2023). Crashworthiness analysis of aluminum and carbon fiber composites. Journal of Automotive Structural Engineering, Vol. 27(2), pp. 85-95.

[14]. Nguyen, H., & Tran, L. (2022). Vehicle safety enhancement using innovative crumple zone materials. Journal of Materials Science and Engineering, Vol. 32(4), pp. 400-410.

[15]. O'Connor, M., & Phillips, D. (2023). Multi-material integration in vehicle safety structures. Proceedings of the International Automotive Engineering Conference, pp. 320-330.