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Numerical Analysis of Bumper System Performance in Low and Medium Speed Impacts

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Abstract

This study uses Finite Element Analysis (FEA) to analyze the performance of bumper systems in low and medium-speed crashes. The study's goal is to determine how good lightweight materials like aluminum alloy and magnesium alloy absorb impact energy during collisions at speeds of 20 and 40 km/h, respectively. ANSYS was used to simulate frontal impacts on bumpers against a structural steel wall. The findings demonstrate that aluminums alloy performed well at low speed, demonstrating superior energy absorption and structural integrity. The distribution and absorption of energy during the collision are readily visible, with deformation concentrated in the front sections. However, deformation at 40 km/h indicates that material selection or bumper design adjustments may be required to optimize protection at higher collision speeds. This simulation effectively demonstrates how the bumper system absorbs energy and reduces force transmission to the vehicle's structural components while preserving the passenger compartment's integrity.

1. Introduction

Vehicle safety has become one of the most pressing issues in modern automotive engineering. As the automobile industry shifts to lightweight vehicle designs to improve fuel efficiency and reduce environmental impact, safety performance, particularly in crashes, remains an important field of research. Bumper systems serve an important role in ensuring that vehicles can resist collisions and absorb impact energy, thereby protecting the passengers [1]. Traditionally, bumpers have been designed to reduce damage in high-speed collisions. The bumper's primary function acts as a buffer zone[2]. Even low and medium-speed collisions, such as parking lot accidents and minor fender benders, can result in significant vehicle damage and substantial repair costs

This study's major goal is to use Finite Element Analysis (FEA) to assess the performance of bumper systems in low and medium-speed impacts. This numerical approach enables us to simulate and evaluate the behavior of various bumper materials, such as aluminum and magnesium alloys, across a range of crash scenarios. The research focuses on impacts at 20 km/h (low speed) and 40 km/h (medium speed), which are common in daily driving. Understanding how different materials perform under these conditions aims to improve bumper designs and make them more effective in frequent accident scenarios.

2. Material and Method

All figures should be numbered with Arabic numerals (1, 2, 3...). Every figure should have a caption. All photographs, schemas, graphs and diagrams are to be referred to as figures. Line drawings should be good quality scans or true electronic output. Low-quality scans are not acceptable. Figures must be embedded into the text and not supplied separately. In MS word input the figures must be properly coded. Preferred format of figures are PNG, JPEG, GIF etc. Lettering and symbols should be clearly defined either in the caption or in a legend provided as part of the figure. Figures should be placed at the top or bottom of a page wherever possible, as close as possible to the first reference to them in the paper. Please ensure that all the figures are of 300 DPI resolutions as this will facilitate good output.

The figure number and caption should be typed below the illustration in 10pt and left justified [Note: one-line captions of length less than column width (or full typesetting width or oblong) centered]. Artwork has no text along the side of it in the main body of the text. However, if two images fit next to each other, these may be placed next to each other to save space. For example, see Fig. 1.

2.1 Material Selection

The materials for the bumper system and the impact wall were selected for their common use in automotive safety systems. The bumper is modeled using aluminum alloy for its strength-to-weight ratio and energy absorption characteristics, while the impact wall is designed using structural steel to represent a rigid, stationary object in collision scenarios.

Table 1 *Parameters of Car Bumper*

Parameter	Unit
Young's Modulus	70 GPa
Poisson's Ratio	0.33
Tensile Strength	310 MPa
Density	2,455 kg/m
Bumper plate thickness	12 mm

Table 2 *Dimension of steel wall*

Dimensions	*Value*
Density	7850 kg/m^3
Yield Strength	250 - 500 MPa
Elastic Modulus	200 GPa
Poisson's Ratio	0.3
Height	2.0 m
Width	4.0m (coverage of the vehicle's width during impact)
Thickness	0.05 m

2.2 Geometry Model

The geometry for this study was designed to model actual collisions between a sedan-class car and a stationary barrier. To achieve a correct structural depiction, the primary model focuses on the vehicle's front-end assembly, specifically the bumper system and its supporting structure, rather than the entire drivetrain or interior elements. The bumper system was designed with proportions in line with industry norms for a conventional car. The rigid impact wall was built with sufficient height and width to fully engulf the vehicle's frontal profile during a collision, assuring complete engagement of the bumper system in accordance with accepted crash testing methods.

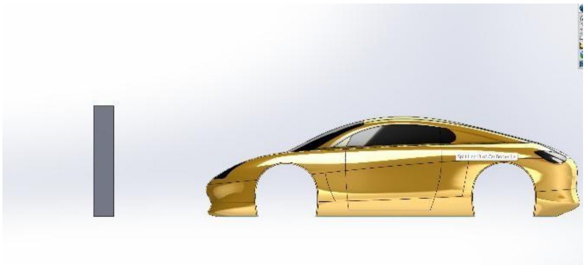


Fig.1 *Geometry model; vehicle, wall*

2.3 Mesh

The meshing process in the finite element simulations is critical in finite element models since it involves breaking down the geometry into discrete elements permitting the approximation of the complex physical systems at the time of impact. In the current case, more mesh density was specifically used in the front-end part of the lightweight sedan model, specifically the crumple zone and the bumper to record the detailed deformation as per the crash conditions. The refinement means that it is more precise in regions most energy is absorbed during the frontal collision.

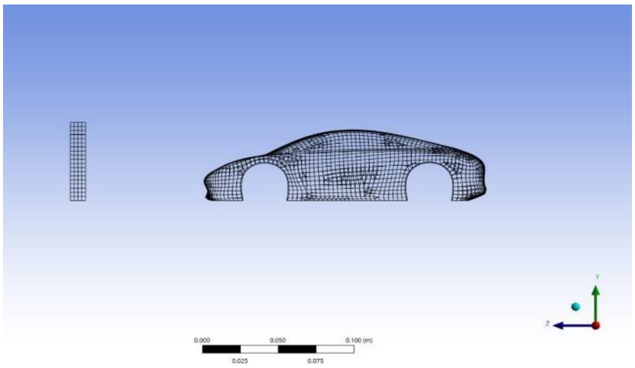


Fig. 2 *Final Mesh of wall and vehicle*

2.4 Simulation

In this work, ANSYS Workbench is used to simulate the collision behavior of a lightweight vehicle during low (20 km/h) and medium-speed (40 km/h) frontal impacts. The simulation process began with the importation of a 3D model of a lightweight automobile created in SolidWorks into ANSYS. The materials were established with precise properties: the car structure was composed of aluminum alloys, and the rigid wall was modelled with steel to simulate real-world impact behavior.

The rigid wall was fixed, and the vehicle body's initial velocities (20 km/h and 40 km/h) were applied to the wall using the Explicit Dynamics module, with appropriate boundary conditions provided. The automobile was simulated to advance towards the wall, mimicking a frontal collision. The bottom of the wall was maintained by permanent restrictions to replicate an immovable barrier in real-world scenarios. The simulation was carried out using an explicit solver, with the time step chosen to meet convergence requirements. Output control was set up to record critical data points like deformation, stress, and strain. The crash energy absorption patterns and structural performance were evaluated using post-processing to determine total deformation, equivalent (von Mises) stress, and equivalent elastic strain.

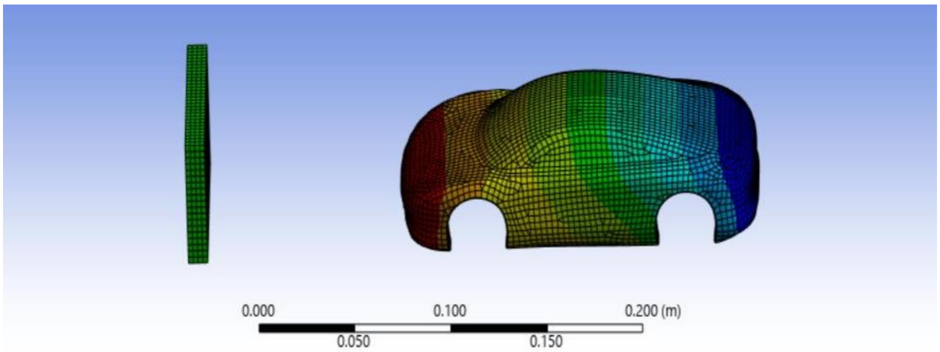
2.5 Numerical Analysis Overview

In the present study, ANSYS was employed to simulate the frontal collision of an aluminum-alloy lightweight sedan body against a rigid steel wall at impact velocities of 20 km/h and 40 km/h. The rigid wall was maintained in a stationary condition to represent a real-world immovable obstacle. The numerical analysis primarily focused on the total deformation of the vehicle structure, particularly at the front-end components such as the crumple zone and bumper system. In addition, deformation along the x-axis was evaluated to investigate the structural response and deformation behavior of the vehicle during impact.

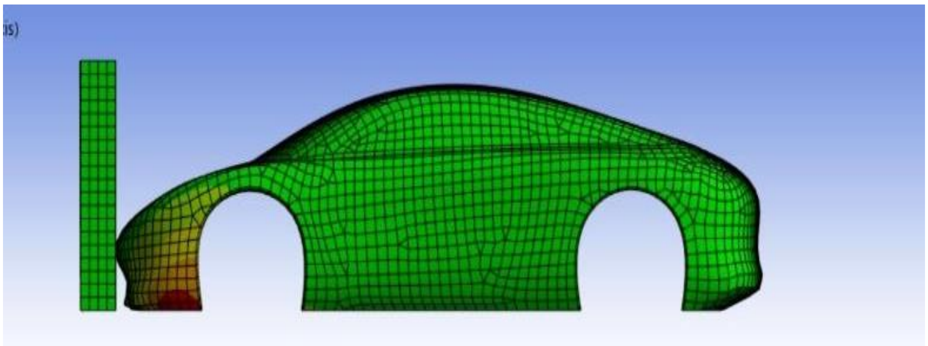
3. Results and Discussion

3.1 Simulation result at 20km/h

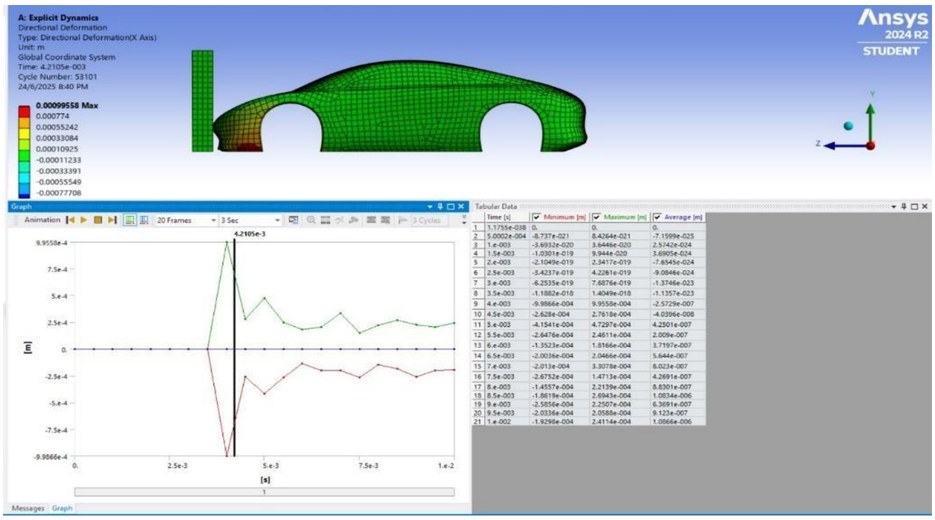
This image depicts the general deformation of a lightweight automobile after a frontal collision with a rigid wall at a speed of 20 km/h. The deformation map shows that, following collision, the vehicle's front-end structure, particularly the bumper and crumple zone, exhibits substantial distortion. The distribution and absorption of energy during the accident are readily visible, with deformation concentrated in the front sections. This simulation effectively demonstrates how the bumper system absorbs energy and reduces force transmission to the vehicle's structural components while preserving the passenger compartment's integrity.



(a)



(b)



(c)

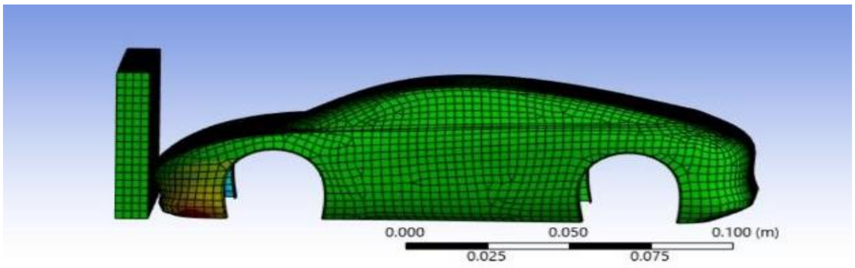
Fig 3 *(a), (b), (c) Simulation impact at 20 km/h,* The images show the simulation results of a car bumper system subjected to a 20 km/h impact, as examined with ANSYS software. The top section of the picture depicts the bumper system's deformation contours, with the colour gradient indicating directional distortion along the X-axis. The car body is shown undergoing plastic deformation, with areas of maximal deformation highlighted in red and yellow to indicate where the most impact energy was absorbed.

The graphs below the deformation contours illustrate the displacement time history for both the bumper and the impact surface, as well as the dynamic reaction across the simulation's duration. The green curve shows the displacement of the bumper, and the red curve represents the collision wall. The graph depicts the highest displacement values at specific time intervals, illustrating the bumper's ability to absorb energy during a collision. The largest deformation of the bumper occurs during the initial impact phase, as seen by the abrupt spike in the displacement graph.

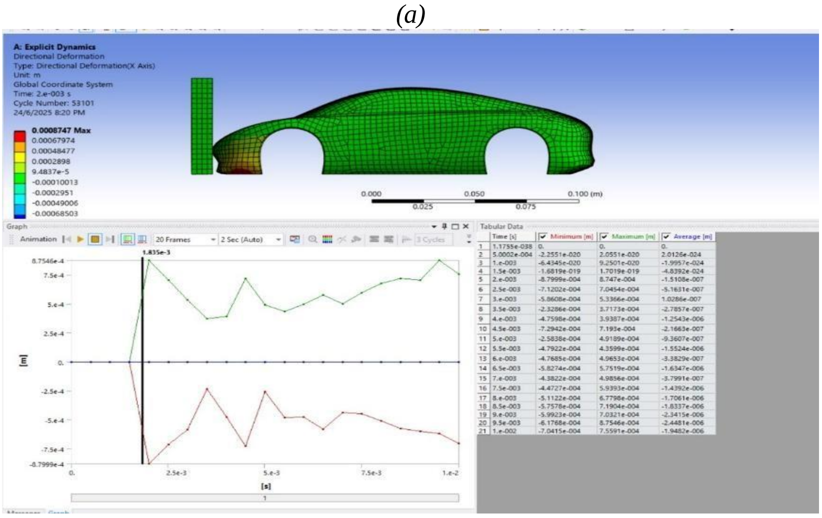
This asymmetric progression resulted from minor geometric imperfections and material inhomogeneities modelled in the simulation, reflecting real-world manufacturing variations [5].These findings shed light on the bumper system's energy distribution and structural behavior, which are important for evaluating its performance in real-world low-speed collisions.

3.2 Simulation result at 40km/hr

The Figure depicts the simulated reaction of a baseline solid aluminum bumper to a 40 km/h (11.11 m/s) frontal impact with a rigid barrier. This velocity is the upper limit of the medium-speed collision scenario proposed in this study. To imitate vehicle motion, the simulation used an initial velocity of 40 km/h for the bumper assembly. The results, shown as total deformation, equivalent (von Mises) stress, and directional displacement contours, characterize the bumper's structural behavior under higher-energy impact situations. The study showed considerable plastic deformation in the central impact zone. The stress distribution reveals important concentrations at the connections of the bumper's front face and vertical webs, where values approach the material's ultimate tensile strength. These zones highlight key structural flaws and potential failure spots in the traditional design. This result offers a performance standard and emphasizes the energy absorption and stress management constraints that the proposed enhanced bumper designs seek to address.



(a)



(b)

Fig 4 *(a),(b) Siulation impact at 40km/h*

3.3 Analysis of deformation profile

At a speed of 20 km/h, the vehicle showed modest deformation, with a peak deformation of about 55 mm. The bumper absorbed a significant amount of impact energy, preserving the vehicle's structural integrity, particularly in the passenger cabin. The displacement at 40 km/h was significantly greater, with a peak deformation of around 105 mm. At this speed, the front end of the vehicle deformed more significantly, yet the bumper still protected essential components including the firewall and the passenger compartment. Overall, the vehicle performed well to moderate-speed impacts; however, increased deformation at 40 km/h indicates that material selection or bumper design adjustments may be required to optimum protection at higher collision speeds.

3.4 Analysis of equivalent stress

At 20 km/h, the equivalent stress in the bumper gradually increased, with the maximum value reaching around 1.5 GPa. The stress was predominantly centered in the front-end components, particularly the bumper and crumple zone, and the car was able to resist the impact without major structural damage. At 40 km/h, the comparable stress was significantly higher, reaching 7.2 GPa. Stress concentrations were found in the front-end components, such as the firewall and A-pillars, indicating a greater risk of material failure and structural damage. These findings indicate that the vehicle performs well in moderate-speed impacts, but stronger materials or additional reinforcements in high-stress regions may be required to prevent failure at higher collision speeds.

3.5 Analysis of equivalent elastic strain

At 20 km/h, the elastic strain was relatively low, peaking at around 0.0055 (unitless), showing that the material underwent elastic deformation and recovered to its former shape without permanent damage. This trend implies that the bumper system was effective in absorbing impact energy while retaining the vehicle's integrity. However, at 40 km/h, the strain increased dramatically, reaching a peak value of 0.0284, suggesting that the material had undergone significant stretching. This increased strain indicates that some components of the bumper may have exceeded their elastic limit, resulting in potential plastic deformation or failure. These findings highlight the necessity of choosing materials with the right flexibility and strength to guarantee that the bumper can withstand higher impact energies without jeopardizing vehicle safety.

4. Conclusion

This study emphasizes the need to examine the performance of bumper systems in low and medium-speed impacts, particularly for lightweight automobiles. Simulations utilizing ANSYS software revealed that materials like aluminum alloys provide significant benefits in terms of vehicle weight reduction and fuel efficiency. However, they pose issues in preserving structural integrity during higher-energy impacts. The calculations showed that at a speed of 20 km/h, the vehicle's bumper absorbed a large amount of impact energy, preventing serious cabin intrusion and limiting deformations. However, above 40 km/h, the bumper's energy absorption capability reduced, with increased stress and deformation at important places such as the firewall and A-pillars, potentially reducing passenger survival space. These findings highlight the need for enhanced design solutions, such as the use of hybrid materials, multi-layer crumple zones, and optimized structural geometry, to increase crashworthiness in lightweight cars. Overall, the study offers significant insights for striking the correct balance between lightweight vehicle design and occupant safety, assisting automotive engineers and manufacturers in designing safer, more efficient vehicles without sacrificing performance.

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Conflict of Interest

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

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** Mohammed Mirza Rais Zaihan, ***data collection:*** Mohammed Mirza Rais Zaihan, Mohd Norihan Ibrahim; ***analysis and interpretation of results:*** Mohammed Mirza Rais Zaihan; ***draft manuscript preparation:*** Mohammed Mirza Rais Zaihan, Mohd Norihan Ibrahim. *All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Khan, F., Hossain, N., Mim, J. J., Rahman, S. M., Iqbal, M. J., Billah, M., & Chowdhury, M. A. (2024). Advances of composite materials in automobile applications – A review. In Journal of Engineering Research (Kuwait). Elsevier B.V. https://doi.org/10.1016/j.jer.2024.02.017

[2] Kumar, S. & Sharma, S. (2017). Impact Analysis of Car Front Bumper to Enhance Crashworthiness. International Journal of Engineering Trends and Technology, 46. http://www.ijettjournal.org

[3] Yeshanew, E. S., Ahmed, G. M. S., Sinha, D. K., Badruddin, I. A., Kamangar, S., Alarifi, I. M., & Hadidi, H. M. (2023a). Experimental investigation and crashworthiness analysis of 3D printed carbon PA automobile bumper to improve energy absorption by using LS- DYNA. Advances in Mechanical Engineering, 15(6). https://doi.org/10.1177/16878132231181058

[4] Du, B., Li, Q., Zheng, C., Wang, S., Gao, C., & Chen, L. (2023). Application of Lightweight Structure in Automobile Bumper Beam: A Review. In Materials (Vol. 16, Issue 3). MDPI. https://doi.org/10.3390/ma16030967

[5] G Keni, L., Singh, V., Singh, N., Thyagi, A., Kalburgi, S., & Chethan, K. N. (2021a). Conceptual design and analysis of a car bumper using finite element method. Cogent Engineering, 8(1). https://doi.org/10.1080/23311916.2021.1976480