COMPARISON OF SIDE COLLISION ANALYZES OF ELECTRIC VEHICLE AND CONVENTIONAL VEHICLE CHASSIS

by

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Conventional vehicles use fossil fuels, which leads to the emission of CO, causing environmental harm. Due to the damage caused by this gas to the environment and human health, the interest in hybrid or electric cars that can use RES has increased. Parts like powertrains, which are found in conventional vehicles but not in electric ones, have caused design disparities in their respective chassis. This study aims to investigate the load distribution on the chassis of electric and conventional vehicles in the event of a side collision. After conducting a literature review and engineering calculations, a chassis was designed for both types of vehicles using the SOLIDWORKS program. The completed chassis was analyzed at a speed of 40 km/h, taking the average of the speed limits determined in the side impact test and polar impact test in the EXPLICIT module of the ANSYS WORKBENCH program. Due to the load generated during the collision, a deformation of 150.72 mm occurred in the electric vehicle chassis and 403.78 mm in the conventional vehicle chassis. As a result of the deformations, stress of 1228.2 MPa occurred in the electric vehicle chassis base and 1000.2 MPa occurred in the conventional vehicle chassis base. These stresses exceeded the yield limit on the designed chassis bases, causing a permanent shape change in both vehicles, but no rupture occurred.

Key words: *crash analysis, side crash test, electric vehicles*

Introduction

In recent years, vehicle safety and fuel economy have become even more important considerations for automobile buyers. As a result, during the chassis design phase of cars, the objective is to achieve both vehicle safety and economical fuel consumption. Studies have been carried out to develop a durable yet lightweight chassis system. Moreover, research into hybrid and electric vehicles that are able to utilise RES has been increasing. Although fuel economy is the first priority in these studies, special importance has been given to engineering studies on the chassis to ensure the durability of the vehicle in the event of an accident. Although the exterior design is similar to conventional vehicles, the chassis and powertrain are significantly different. As a result, the most damaged parts of electric vehicles during accidents have been taken into consideration, and work has also been done on the design and material structure. In the study, the same type of electric and conventional vehicle chassis were designed to measure deformation. The design techniques and battery positions used in electric

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vehicles were determined based on passenger safety. According to the study, it was examined that the batteries positioned had a positive effect on the living space in side collisions.

It was determined in the literature review that studies were conducted on the design and material optimization of the B-pillar in vehicle chassis for side crash tests in order to improve passenger safety and fuel economy.

It was reported that the front bumper and shock absorber system played a positive role in damping the energy of vehicles involved in 100% and 40% offset collisions [1]. Therefore, the minimum weight to reduce fuel consumption was selected as the optimization objective. Using the experimental design method, approximate design functions were created, and the size optimization problem defined to minimize the total weight.

An electric racing car was designed with a space-framed chassis, which aimed to protect the driver from the batteries and increase the chassis rigidity [2]. The research concluded that the stressed battery boxes cause undesirable results due to their weight and provide torsional rigidity to the chassis.

During a frontal collision accident, the effects of the load of the batteries on electric vehicles were investigated, and the advantages of electric vehicles over conventional vehicles were determined [3].

Guven and Rende [4] have found that the range of electric vehicles is short, the battery charging time is long, and the sales price is high. Therefore, they aimed to lighten the vehicle by using materials with a lower density to increase the range. Within the scope of this study, they examined the materials used to mitigate electric vehicles and the issues that need to be considered when selecting these materials.

Ikpe *et al.* [5] conducted finite element analysis of Column B using HYPERMESH and CATIA V5 software and optimized it according to design goals. When an initial force of 140 kN was applied to column B, a Von-Mises stress of 1646 MPa and a deviation of 5.9 mm were observed. However, with the reinforced B-pillar lighter weight, the design analysis yielded a maximum Von-Mises stress of 673 MPa and a maximum displacement value of 2.39 mm.

Islam *et al.* [6] used a 3-D optical scanner to transfer an existing B-pillar fragment to the CATIA V5 environment, where the existing B-column was divided into five parts with different thicknesses. A cold forming process was then applied, and the optimum thicknesses of the parts making up the B-column were determined through finite element analysis, ultimately leading to a weight reduction.

In the study conducted by Ozturk [7], the B-pillar material structure reducing the vehicle collapse speed and absorbing impact energy from side impacts was determined through the falling weight impact test. The finite element simulation of the same test was then used to verify the results obtained. Consequently, a weight reduction of 17.6% was achieved in the single-material-single-purpose optimization study, while 20% weight reduction was recorded in the two-material-single-purpose optimization study. Ultimately, the two-material-multi-purpose optimization study identified a pareto boundary curve that presented a broad range of design alternatives for the B-column.

Meanwhile, Askar [8] utilized different sheet thicknesses to design a simple vehicle body cage at one-to-one scale in the front bumper system. The front impact of the system against a rigid wall at 64 km/h was analyzed using computer support, and the reaction force transmitted to the passenger cabin was examined.

Koca *et al.* [9] created various designs of chassis with different types. The analysis of the designs with FEM software resulted in the selection of a space roof frame type made of aluminum material 5042-H19, weighing 28163 kg. The maximum Von-Mises stress of the design is 15465 MPa, and the torsional resistance of the chassis was calculated from a maximum torsional deformation of 2495 mm, which is 1828.289 Nm/°.

Hangul [10] conducted a study to evaluate a new chassis design for weight reduction, including correct material selection, design of a battery module that could be easily inserted and removed from the battery module compartment of the chassis, and analysis of the chassis deformation of the entire structure based on static analysis. Necessary arrangements were also made. During the study, AL6061, ST-37, and carbon fiber materials were preferred to lighten the chassis.

Baskara and Cimendag [11] conducted a research on the equipment and technology required for crash testing as part of their undergraduate thesis study. They used SOLIDWORKS and CATIA programs to create 3-D models of the vehicle chassis and body parts that needed to be analyzed, and examined deformation, stress, and damage analyzes by analyzing them in the ANSYS program. After carrying out the analyses, they made the necessary optimizations, repeated the tests, and presented them with tables and graphs.

Liu *et al.* [12] designed a basic electric vehicle which had a battery pack and other components that use new energy sources inducing high voltage. These components contributed to an increase in vehicle weight and occupied a large part of the structural space. After conducting analyses and optimizing the force transfer path, the B-column deformation shape, and the threshold support structure, the hazards that may appear in the living space under IIHS side impact conditions have been minimized.

Isilak [13] analyzed the design variations between electric and conventional vehicles in terms of chassis, body, and interior trim. Moreover, the environmental and fuel economy benefits of electric vehicles are described.

Baskara *et al.* [14] simulated two different B-column designs using finite element analysis method and selected 140 kN as the impact force. In the first analysis, the B-column selected for tensile strength exceeded 1100 MPa and there was a fracture in the material. However, in the design made with DP1000, it was determined that the B-column did not exceed 1100 MPa and the living area was not damaged.

In the literature review, it was determined that studies had been carried out on the design and material optimization of the B-pillar in vehicle chassis for side crash tests, with changes aimed at improving passenger safety and fuel economy. In this study, two chassis designs were developed for electric and conventional vehicles, using engineering calculations. Both chassis were analyzed using the finite element method. The aim of this study is to contribute to the literature by comparing side collision deformations with incoming impact.

Material and method

Finite elements

Due to the fact that the processes that take place in nature depend on many variables and their complexity, they are mostly tried to be solved by expressing them with mathematical models. With these mathematical expressions, it is aimed to simplify various processes and distributions in areas such as economics as well as positive sciences such as physics, chemistry and biology. In engineering problems, the FEM is taken as a basis to solve a process. Finite element analysis has become widespread in parallel with the development of software tools used.

Finite element analysis is applied in three basic stages:

- Finite element network creation *(mesh generation)*: After the mathematical model is established, the structure formed by the sub-elements and connection points is in the appearance of a network. Increasing the network density correctly gives better results.
- Determination of acting forces *(load application)*: The forces acting on the system, especially the mass forces, singular and diffuse forces, are determined.
- Determination of boundary conditions *(boundary conditions)*: A system has naturally occurring or artificially created boundary conditions. In structural analysis, for example, elastic displacements can be calculated with reference to boundary conditions.

The analysis stages are completed by following the steps specified in fig. 1. With the evaluation of the results of the analysis, the desired product can be produced by making improvements on the model when necessary.

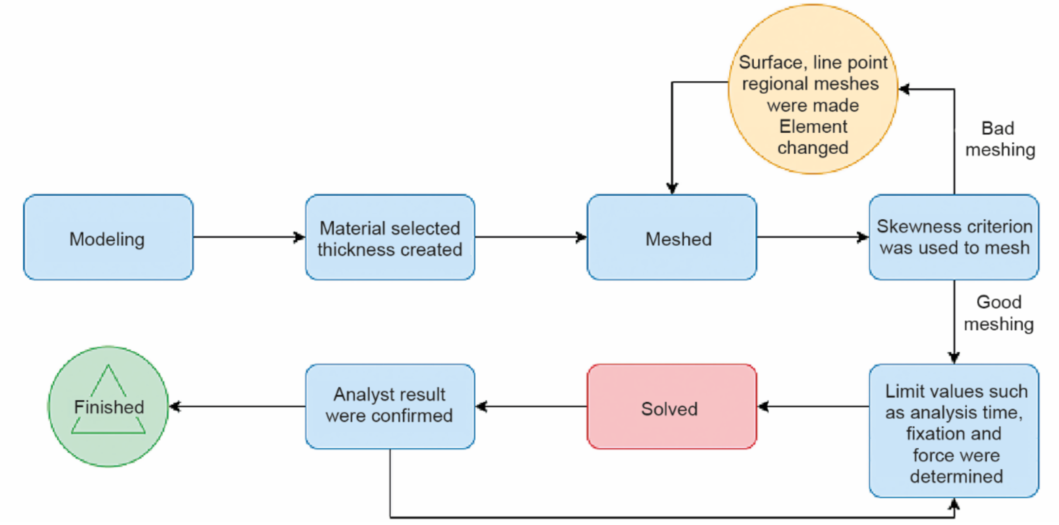


Figure 1. Steps for analysis by finite element method

Chassis design process

This work involves designing the chassis and analyzing it using the finite element method. The designed model took its shape in figs. 2 and 3 after the testing and development stages. In the chassis design, the design process, which can absorb more energy, minimizes the collision forces, and does not damage the living space. The entire process, from draft drawings to the final model, has been completed with tests, analysis, and research.

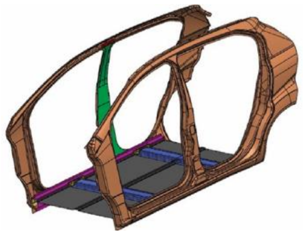


Figure 2. Conventional vehicle chassis design

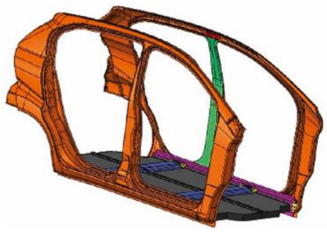


Figure 3. Electric vehicle chassis design

The design of conventional and electric vehicle chassis has been carried out in accordance with TSE standards, considering the MARTOY Regulation (The Regulation on Approval and Market Surveillance of Motor Vehicles and their Trailers) [15]. In compliance with the regulation, the Class M1 is designed as a hatchback 5-door car chassis with AB body type. To prevent major accident effects from the side of conventional vehicles, three different impact-dampening parts have been incorporated, as shown in fig. 4. The chassis design of the conventional vehicle has been completed, using simpler parts instead of structures with more complex surfaces to be manufactured.

The conventional vehicle chassis, the design of which has been completed, underwent a transformation into the electric vehicle chassis shown in fig. 5 by incorporating the design considerations presented in figs. 6 and 7. The electric vehicle chassis has been designed by placing the batteries on the base of the vehicle and distributing the front load, which is typical of conventional vehicles, to the vehicle base. These design decisions improve the road holding and stability of electric vehicles when compared to conventional 4-wheel vehicles.

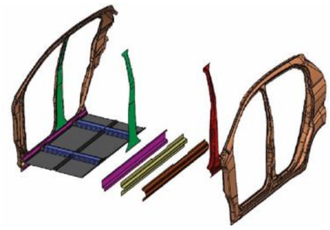


Figure 4. Expansion of conventional vehicle chassis

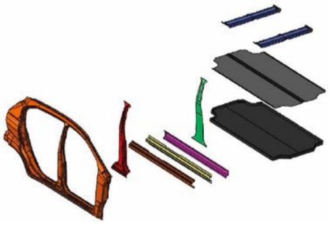


Figure 5. Expansion of electric vehicle chassis

Figure 6. Chassis designs of different electric vehicle brands [16]

Figure 7. Electric vehicle's battery slot structure [17]

In completed vehicle frames, attention should be given to the production, use, maintenance, and recycling stages of the materials used to minimize emissions. The choice of materials is also crucial in electric vehicles due to the weight of batteries. During material selection, priority is given to lightness, environmentally friendly production processes, recyclability after the end of their lifespan, and short deformation distance. Taking these factors into account, the shock-absorbing parts and battery compartments prefer AISI 4150, as seen in tab. 1, while other parts prefer Al 7075-T6, as seen in tab. 2.

Table 1. The AISI 4150 material properties [18]

Density	7.9 e^3 kg/m^3
Possion ratio	0.295
Elasticity module	212 GPa
Tensile force	1.27 e^3 kg/m^3
Yield strength	810 MPa

Table 2. The Al 7075-T6 material properties [18]

Density	2.83 e^3 kg/m^3
Possion ratio	0.335
Elasticity module	76 GPa
Tensile force	580 MPa
Yield strength	530 MPa

Results and discussion

The purpose of finite element analysis is to reduce the sought solution in the universal set to a smaller subset. The finite element interface of the Explicit module in the designed model can be seen in fig. 8. In this section, side collision analyses were performed for two different chassis types, and the obtained results were examined and compared.

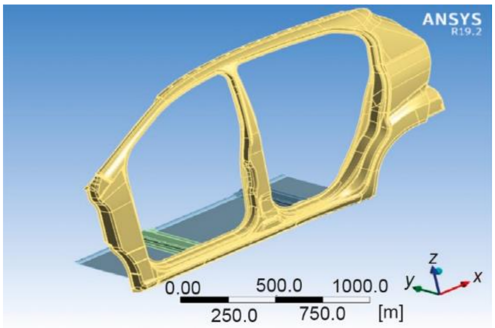


Figure 8. Finite element interface

The basic working logic of the finite element method is to simplify a complex problem in order to reach a solution. The model is divided into basic elements, which consist of small parts, and nodal points at the corners of these elements give stress levels occurring during analysis. Results of the analysis are the values above these points. Mesh types can be chosen differently according to the designed chassis and modeling method, with the finite element model available in the form of a line, plane, or solid model so that the analysis is fast and produces results. As seen in figs. 9 and 10, areas where the vehicle will be hit have been meshed more intensively than the rigid wall. Therefore, any mesh error will either prevent the simulation from running or provide erroneous results.

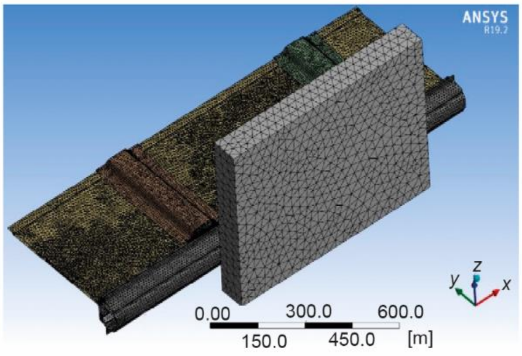


Figure 9. Mesh process of conventional vehicle chassics

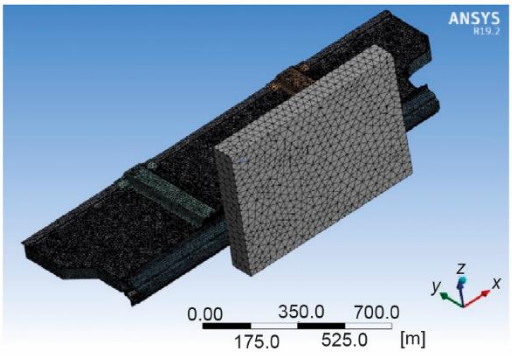


Figure 10. Mesh process of electric vehicle chassics

When creating finite element models, the Tetrahedron method was preferred as the mesh method due to its desired accuracy and analysis time required for obtaining results. In addition, to achieve a high quality mesh, the first meshing process involved applying point, line, and local mesh processes, tailored to the structure of the part. By using the Skewness criterion, the mesh quality close to perfection was achieved, as shown in fig. 11, validating the accuracy and quality of the process.

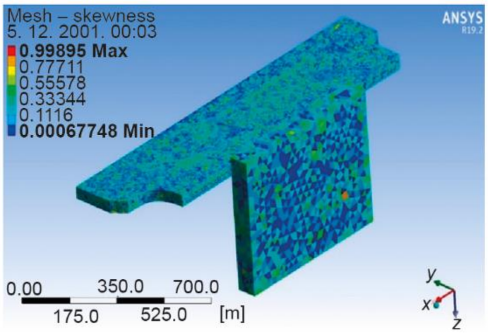


Figure 11. Evaluation of mesh quality by skewness criterion

After the meshing process, loads and boundary conditions, including force, momentum, contact zones, and gravitational acceleration, are determined to match the actual working conditions of the structure. The vehicle chassis must be strong enough to withstand these stresses. These conditions are determined based on the loading conditions outlined in the Euro NCAP standard. Additionally, the vehicle chassis must be capable of cushioning the impacts that occur during an accident without compromising the occupants safety.

To reduce the analysis time of the designed frames, half of the design is symmetrically taken into consideration before the analysis begins. The materials used in the structure will be determined as flexible and the deformation situations that may occur in the chassis will be revealed in the analysis results. The sub-parts that make up the model will be fixed with the Fixed Support module and welded with the Contacts module as defined in the models. The impact of a rigid wall weighing 1000 kg on the vehicle chassis was analyzed at a speed of 40 km/h, which was determined by averaging the speed limits specified in the Side Impact Test and Polar Impact Test.

In this part of the study, the reaction of the vehicle to impact and the parts that absorb it were determined. As shown in figs. 12 and 13, the bumper zone of the vehicle sustains the most damage from the impact.

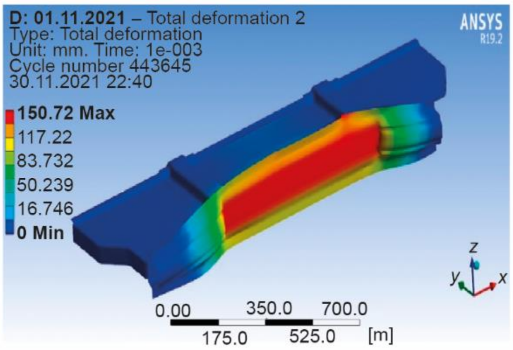


Figure 12. Electric vehicle chassis 40 km/h collision analysis

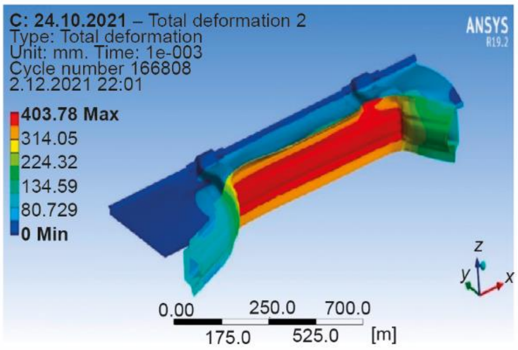


Figure 13. Conventional vehicle chassis 40 km/h collision analysis

Figures 14 and 15 demonstrate that the traditional vehicle chassis experienced a 403.78 mm deformation, while the electric vehicle chassis experienced a much lower

150.72 mm deformation. This substantial difference is attributed to the inclusion of batteries in the base of electric vehicles, which provides exceptional performance.

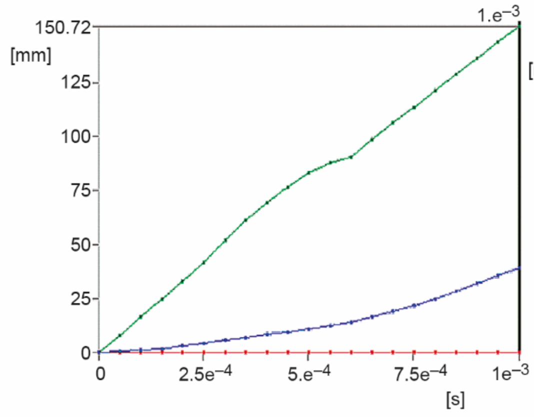


Figure 14. Electric vehicle chassis deformation time

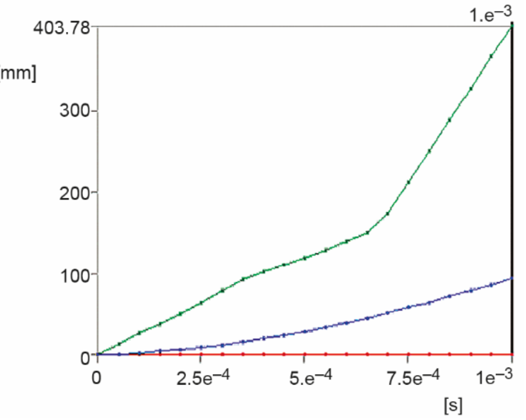
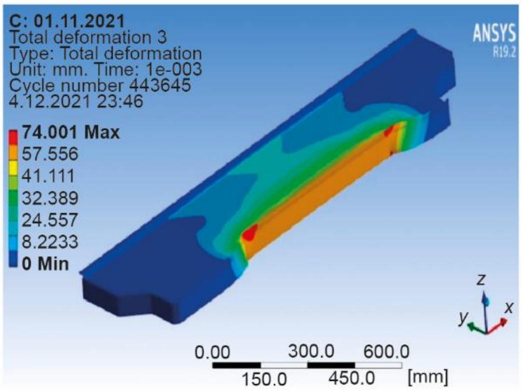


Figure 15. Conventional vehicle chassis deformation time

Battery compartments are equipped with robust structures to prevent negative events that may arise due to potential impacts. This structure safeguards not only the batteries of electric vehicles but also minimizes impact from the side of the vehicle during a collision, as evident in figs. 16-19. The impact was significantly reduced by 250.06 mm, while it was found that the conventional vehicle chassis was unnervingly deformed.

When examining the distortion graphs, it becomes clear that the deformation in the vehicle increases continuously over time. While this increase in deformation may seem like a negative result, it actually serves the main intended purpose – dampening the loads placed on the vehicle during deformation. The analysis reveals that the shock-absorbing parts of the bumper were able to dampen a portion of the load, while the battery compartment withstood minimal deformation to dampen the remaining load. In contrast, the conventional vehicle chassis put the lives of passengers in danger by failing to dampen the loads.



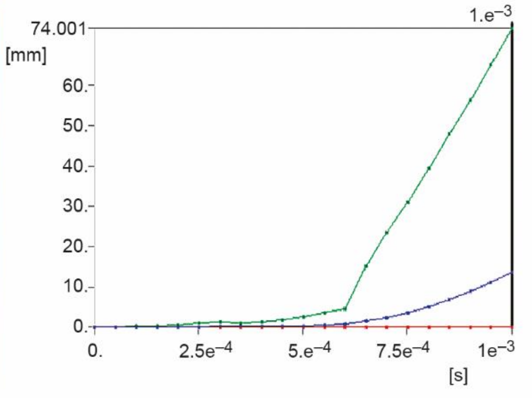


Figure 16. Electric vehicle battery slot deformation

Figure 17. Battery bay deformation chart

The Von-Mises stress and their corresponding graphics can be observed in figs. 20-23. The yield limit was successfully reached by both vehicle chassis, causing the structures to deform and absorb energy before any ruptures occurred. Consequently, it can be observed from the graphics that the electric vehicle chassis experienced a higher level of tension. Upon evaluating the stress graphs of both chassis, it was concluded that no ruptures or tears occurred during the collision.

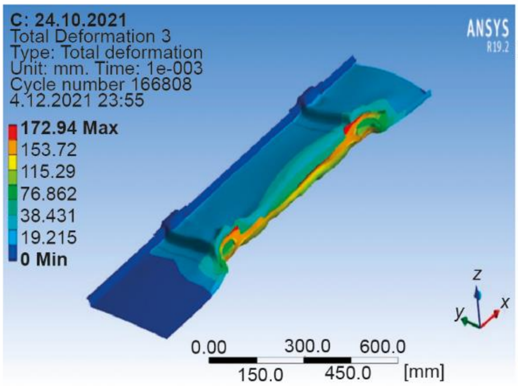


Figure 18. Conventional vehicle chassis base sheet deformation

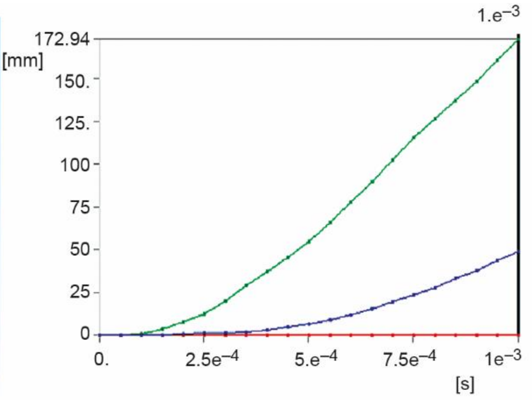


Figure 19. Conventional vehicle chassis base sheet deformation chart

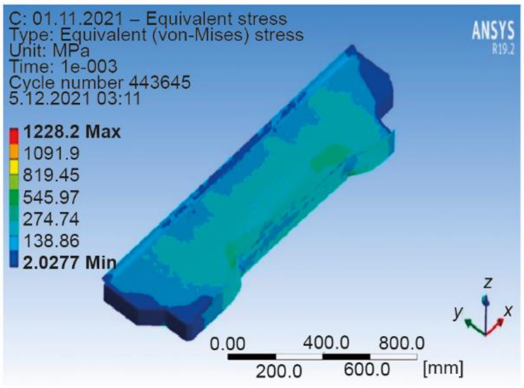


Figure 20. Electric vehicle chassis Von-Mises stress

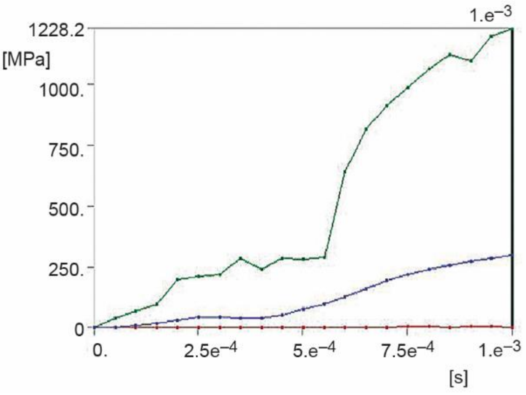


Figure 21. Von-Mises stress graphic of electric vehicle chassis

From the Von-Mises graphics, it is evident that the speed of the rigid wall reduced at the same acceleration until it reached the running board shock absorbing parts section. However, upon reaching the battery compartment in electric vehicles, the acceleration of the reduction in speed increased significantly, resulting in stopping the rigid wall faster than in a conventional vehicle chassis, as seen in fig. 24. The main contributing factor in the breakage showcased in fig. 25 is the placement of the battery compartment on the vehicle base. The battery compartment is solid due to the weight and the preferred material used in the battery system.

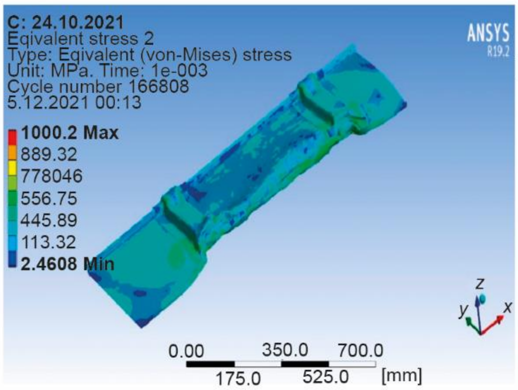


Figure 22. Conventional vehicle chassis Von-Mises stress

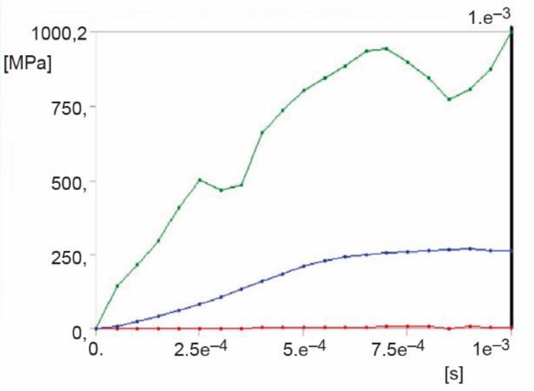


Figure 23. Von-Mises stress graphic of conventional vehicle chassis

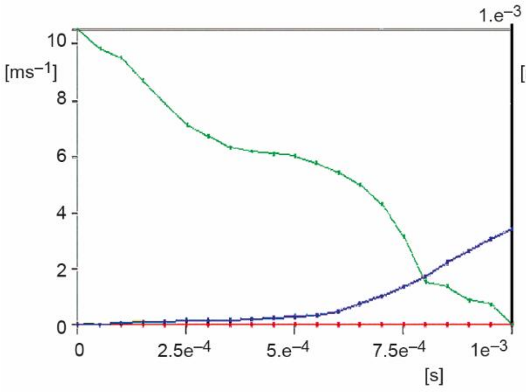


Figure 24. Conventional vehicle collision analysis rigid wall speed-time graph

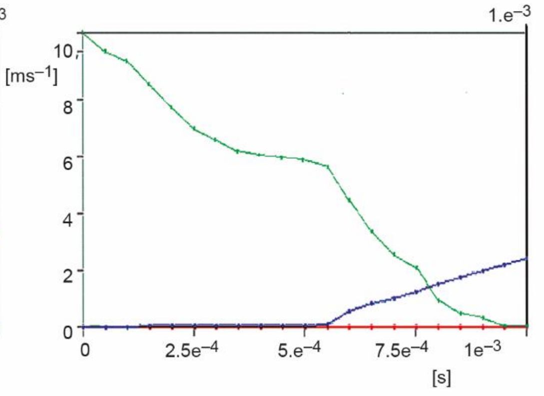


Figure 25. Electric vehicle collision analysis rigid wall speed-time graph

Conclusions

Within the scope of the study, we examined the positive and negative structural features of electric vehicle chassis and conventional vehicle chassis in traffic accidents by using finite element software. The literature primarily covers studies on collision tests in conventional and electric vehicles. Finite element software is crucial in identifying and eliminating errors in studies that have not yet entered the production stage. This approach helps us develop remedies to mitigate potential issues that may arise during the production process.

When conducting collision analyses, the parts comprising the chassis should exhibit the following characteristics.

- The ability to dampen impacts during collisions.
- The ability to distribute incoming impacts to other parts to minimize the impact effect.
- The capacity to absorb maximum impact with minimal deformation.
- A low rate of collapse.
- Capability to minimize the impact on the passengers living space in the vehicle.
- The ability to prevent parts from breaking off and absorbing incoming impacts.

The analyses were conducted on both the conventional vehicle chassis and the electric vehicle chassis, revealing that the battery compartment in the latter was the most significant difference between the two. Despite the added weight, the battery compartment has a positive impact on driving dynamics and vehicle safety. In conventional vehicles, the distribution of load towards the front due to the engine and powertrain makes them more susceptible to somersaulting during large side impacts. On the other hand, the battery slot located in the center of the electric vehicle chassis results in a lower risk of somersaulting, as shown by the tests and analyzes. Additionally, the battery compartment position at the base absorbs side impacts at a shorter distance and minimizes their effects on the living space, unlike conventional vehicles. However, it cannot be said for the latter. When evaluating the stresses exerted on both vehicle frames, there was a flow in the parts exposed to the load on the chassis, but no rupture or breakage occurred.

It has been observed that literature reviews, research, and engineering calculations were conducted to obtain the most accurate data in the design and analysis stages of our study, thus supporting our analysis. The results of our analysis show that placing batteries at the center of the vehicle plays a critical role in balancing as well as in damping the impact of collisions. During the tests, the conventional vehicle chassis was deformed by 403.78 mm, while electric vehicle chassis suffered deformation of 150.72 mm. This indicates that while the shock damping distance of 403.78 mm in conventional vehicle chassis poses a severe threat to passenger safety, the electric vehicle chassis dampens incoming impact by 150.72 mm, ensuring passenger safety without causing harm to their living space. The chassis parts were found to have altered the shape permanently, but no breakage occurred as a result of stress in the chassis. In conclusion, the research conducted at Euro NCAP confirms that electric vehicles equipped with batteries placed at the chassis base are safer and more reliable than conventional vehicles that have received a 5-star rating from side impact tests.

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