UDC 669
DOI: 10.15587/1729-4061.2023.289232

DESIGN AND EVALUATION OF HOLLOW FRAME STRUCTURES FOR THE DEVELOPMENT OF URBAN-CENTRIC TWO-PASSENGER ELECTRIC VEHICLES

Muhammad Hidayat Tullah
Doctoral Candidate of Mechanical Engineering, Assistance Professor*
Danardono Agus Sumarsono
Corresponding author
Professor*
Research Centre for Advanced Vehicles Universitas Indonesia**
E-mail: danardon@eng.ui.ac.id
Iwan Susanto
Associate Professor***
Fuad Zainuri
Doctor of Mechanical Engineering, Assistance Professor***
Sonki Prasetya
Doctor of Mechanical Engineering, Assistance Professor***
Rahmat Noval
Doctoral Candidate of Mechanical Engineering, Assistance Professor*
Sulaksana Permana
Doctor of Engineering in Metallurgy and Materials, Assistance Professor
Department of Mechanical Engineering
Gunadarma University
Margonda Raya str., 100, Depok, West Java, Indonesia, 16424
Laboratory of Prof. Dr. Ir. Johny Wahyuadi S., DEA
Department of Metallurgy and Materials
Universitas Indonesia
Margonda Raya str., Pondok Cina, Kecamatan Beji,
Kota Depok, Jawa Barat, Indonesia, 16424
Bayu Dwi Aprianto
Master of Engineering, Assistance Professor*
*Department of Mechanical Engineering**
**Universitas Indonesia
Prof. DR. Ir Soemantri Brodjonegoro str., Kukusan, Kecamatan Beji,
Depok, Jawa Barat, Indonesia, 16425
***Department of Mechanical Engineering
Politeknik Negeri Jakarta
Prof. DR. G.A. Siwabessy str., Kukusan, Kecamatan Beji,
Kota Depok, Jawa Barat, Indonesia, 16424

This paper focuses on the design and evaluation of hollow frame structures for the development of two-passenger electric vehicles targeted for urban use. The primary problem addressed is the lack of focused research on efficient, lightweight, and safe electric vehicle frame designs, particularly for urban transportation needs. Through 3D simulation and Finite Element Analysis (FEA), this paper successfully develops a hollow frame design with dimensions of 2,148×800×640 mm and a weight of 40.77 kg that meets strength and stiffness criteria. The analysis shows that the design has an adequate safety margin with a safety factor of 2.053e+01. ASTM A36 steel is chosen as the material, balancing strength, stiffness, and cost. The results offer an innovative and practical solution to urban transportation issues, with broad potential applications in the electric vehicle industry. In particular, this study focuses on the specialized needs of urban-centric, two-passenger electric vehicles. The Finite Element Analysis (FEA) used here serves as a robust validation method, effectively reducing the need for extensive physical testing. This accelerates the R&D process and opens possibilities for future studies on alternative materials and dynamic loading conditions. The study's limitations and future research directions are also discussed. Moreover, the study's computational methods offer an eco-friendly alternative to traditional physical prototypes. This aligns with sustainability goals and provides methodologies for future studies. With rising urban populations, the demand for efficient vehicles is increasing. This study paves the way for city-focused, two-passenger electric cars that meet modern urban needs and sustainability goals

Keywords: electric vehicles, hollow frame structures, urban transportation

Received date 08.08.2023
Accepted date 17.10.2023
Published date 30.10.2023

How to Cite: *Tullah, M. H., Sumarsono, D. A., Susanto, I., Zainuri, F., Prasetya, S., Noval, R., Permana, S., Aprianto, B. D. (2023). Design and evaluation of hollow frame structures for the development of urban-centric two-passenger electric vehicles. Eastern-European Journal of Enterprise Technologies, 5 (7 (125)), 80–86. doi: https://doi.org/10.15587/1729-4061.2023.289232*

1. Introduction

The adoption of Electric Vehicles (EVs) is seen as a pivotal strategy in reducing greenhouse gas emissions and mitigating climate change impacts, particularly in the transportation sector, which contributes significantly to global emissions [1, 2]. While the transition to EVs brings environmental advantages, it also presents new challenges in vehicle design and engineering. Among these, the design of the vehicle's frame or chassis emerges as a crucial yet often overlooked aspect [3].

The chassis serves as the backbone of any vehicle, providing structural integrity while affecting key parameters such as strength, safety, and efficiency [4]. In the realm of EVs, the role of the chassis becomes more complex due to the necessity to incorporate various components like batteries, electric motors, and power electronics efficiently [5]. These complexities are magnified in designing EVs for urban settings, where the demand for compactness, efficiency, and short-range operability is high [6, 7].

While most existing electric vehicle designs are optimized for long-range and high passenger capacity, urban transportation primarily consists of short, frequent commutes that could benefit from smaller, more efficient vehicle designs [7]. This highlights an unmet need for a specialized chassis design that caters to a two-passenger electric vehicle ideal for urban utility.

Therefore, studies dedicated to the design and evaluation of hollow frame structures for the development of urban-centric two-passenger electric vehicles are scientifically relevant. Studies involve various aspects such as material selection, structural analysis, safety evaluations, and aerodynamic considerations. Researchers work on optimizing the design to enhance vehicle performance, increase energy efficiency, and ensure passenger safety.

2. Literature review and problem statement

Previous research has extensively focused on various aspects of electric vehicles, such as improving battery life, design, and material selection [8]. There are four primary factors that contribute to vehicle performance and are directly related to vehicular accidents: Brakes, Wheels, Stability, and Worthiness. These factors are intricately linked to the vehicle's chassis [9]. An electric brake booster for the Mekara Electric Vehicle 02 has been developed, successfully reducing electricity consumption by 28.2 % [10]. Studies have also explored optimizing the weight of electric vehicle chassis frames through various methods [6], including the replacement of steel with aluminum alloys [11] and developing robust roll cages capable of withstanding challenging conditions [12]. Direct frequency response analysis has been employed to assess the roll cage's ability to endure vibrations in diverse conditions [13]. Dynamic analysis using ANSYS explicit dynamics has also been performed to evaluate the roll cage's response under various crash scenarios [14]. The investigation focused on reducing weight while considering strength and ergonomics, leading to the conclusion that tube dimensions should be carefully selected to prevent an unnecessary increase in chassis weight [15]. In conclusion, prior research has been dedicated to various facets of electric vehicles, encompassing battery life enhancement, design, and material selection. It highlights the pivotal role of four primary factors – Brakes, Wheels, Stability, and Worthiness, which have direct implications for vehicle performance and safety and are intricately interconnected with the vehicle's chassis. The practical implementation of an electric brake booster, which resulted in a significant 28.2 % reduction in electricity consumption for the Mekara Electric Vehicle 02, exemplifies the tangible impact of previous studies. Furthermore, research has delved into optimizing electric vehicle chassis weight through diverse methodologies, including the adoption of aluminum alloys to replace steel, as well as the development of robust roll cages capable of withstanding challenging conditions. Complex analytical techniques, including direct frequency response analysis and dynamic analysis using ANSYS explicit dynamics, have been employed to evaluate the roll cage's performance across various scenarios. The overarching aim of the investigation was to reduce chassis weight while taking into account strength and ergonomics, concluding that tube dimensions should be thoughtfully selected to prevent undue increases in chassis weight.

The reasons for this gap in research could be objective difficulties such as the need for lightweight yet strong components, operational efficiency, and short-range performance, which make further research costly and perhaps inexpedient [7, 16]. To address these challenges, some studies have suggested that tubular frames offer a promising compromise between weight and structural integrity [12, 16]. However, these studies are limited in scope and do not fully consider the unique needs of urban-centric, two-passenger electric vehicles.

All this allows us to argue that it is appropriate to conduct a study devoted to the development and evaluation of hollow frame structures for urban-centric, two-passenger electric vehicles.

3. The aim and objectives of the study

The aim of the study is to explore and optimize the design of electric vehicle chassis, specifically tailored for urban-centric two-passenger electric vehicles. This investigation aims to address the growing need for sustainable transportation solutions in urban areas by focusing on the chassis design, a critical component in electric vehicles.

To achieve this aim, the following objectives are accomplished:

– to assess the technical feasibility of developing an efficient and lightweight chassis for electric vehicles by utilizing hollow frame structures;

– to evaluate and optimize the electric vehicle's chassis through static load calculations, focusing on performance metrics and rear-wheel traction for enhanced efficiency and safety;

– to conduct a static structural analysis using the Finite Element Analysis (FEA) method to ensure chassis safety and structural reliability under various load conditions.

4. Materials and methods

This research posits a hypothesis: the development of a technically optimized hollow frame structure can enhance the crash safety and structural robustness of two-passenger electric vehicles, leading to safer and more dependable vehicles. The study centers on exploring, developing, and analyzing hollow frame structures tailored for urban-centric electric vehicles designed to accommodate two passengers. Its principal objective is to assess the feasibility, effectiveness, and advantages of implementing hollow frame structures in the context of small, electric vehicles designed for urban use.

Utilizing SolidWorks, a 3D design and simulation software renowned for its accuracy and reliability in engineering applications [17], we modeled and scrutinized the frame structure. SolidWorks' integrated simulation capabilities enable us to conduct load test simulations, replicating real-world forces and various physical conditions under both static and dynamic scenarios. We carefully control the simulation settings to accurately represent the load-bearing conditions of the vehicle's chassis. Our focus is on examining the behavior of hollow frame structures under diverse conditions, thereby enhancing the overall safety and performance of the vehicle. These simulations serve as the foundation of our theoretical approach, allowing us to generate data that would otherwise necessitate extensive physical experimentation. To validate the model's adequacy, we cross-reference our simulation outcomes with existing scholarly literature and theoretical calculations [18]. A deviation of less than 5 % from these benchmarks is deemed acceptable [18, 19]. Moreover, our research methodology and results have undergone peer review to identify and rectify any methodological shortcomings or biases. This multi-tiered validation process bolsters the credibility of the proposed hollow frame structure, specifically designed for urban two-passenger electric vehicles.

5. Research results of evaluating hollow frame in urban two-passenger electric vehicles

5. 1. Chassis design and structures

The design process commences by surveying existing designs and conducting an in-depth review of pertinent literature. Subsequently, the chassis dimensions and material properties are established [20]. Given that the chassis constitutes the fundamental structural element of the vehicle, a comprehensive strength analysis becomes imperative [11, 21]. The results of the strength analysis, having demonstrated a satisfactory safety margin with a minimum safety factor of 1.5, pave the way for the subsequent phases of the engineering process, including detailed design, manufacturing, and assembly [22].

Driver safety is a key aspect of design and is considered through all stages. The entire design process from chassis involves various factors such as material selection, safety, ease of manufacture, passenger and driver comfort, and cost. The selection of the right material increases the reliability, safety, and overall performance of the vehicle.

The chassis adopted features a hollow structure, with main frame dimensions of 40×40×2 mm, supporting frame dimensions of 25×25×1.5 mm, and driver's seat frame dimensions of 25×25×3.2 mm. The design places a strong emphasis on driver ergonomics, focusing on the arrangement and design of driver controls to enhance efficiency and comfort within the driving environment. The holistic chassis design revolves around four key principles: prioritizing driver safety, emphasizing ergonomics, ensuring manufacturability, and enhancing overall structural strength. The image below illustrates the chassis design, which carefully integrates material selection, safety considerations, ease of manufacture, passenger and driver comfort, and cost-effectiveness.

Fig. 1 shows a chassis design with an upper frame and vehicle components installed.

The chassis dimensions are 2,148 mm long, 800 mm wide and 640 mm high, and the weight is 40.77 kg. The design further accommodates components such as the motor, gearbox, and electrical systems, facilitating streamlined assembly processes for these intricate components.

a

b

Fig. 1. Design of chassis: *a* — chassis with upper frame; *b* — main chassis

5. 2. Static load calculations

Static load is a load that occurs when the vehicle is at rest, static load is purely due to the weight of the components on the vehicle, components that can be used as loading are components that have a large enough weight, but later the total amount is equal to the weight of the vehicle. The weight of these components can be seen in Table 1 as follows.

Notably, the chosen load distribution accounts for the load-bearing capacity of the chassis, and components like the electric motor, directly supported by the axle shaft, are not considered in this load analysis.

Fig. 2 shows the determined static load distribution, with specified distances from each load source component.

Assuming the chassis is a cross-sectional rod that receives the load of vehicle components, the Free body is a load distribution diagram described as shown in Fig. 3.

Table 1

Load on the Supported Component

Number	Load Type	Weight
1	Chassis	60 kg
2	Passenger	70 kg
3	Driver	70 kg
4	Battery	20 kg
5	Steering	7 kg
6	Air Conditioning	7 kg

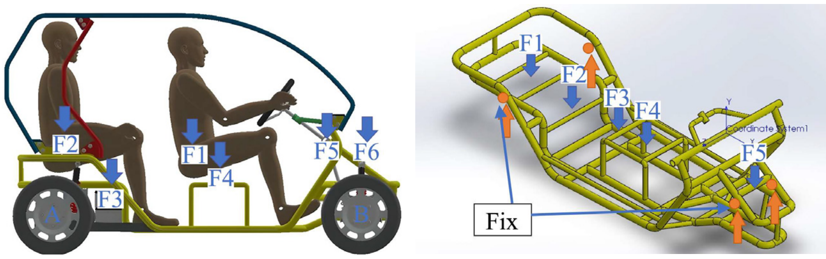

Fig. 2. Load distribution layout on the chassis

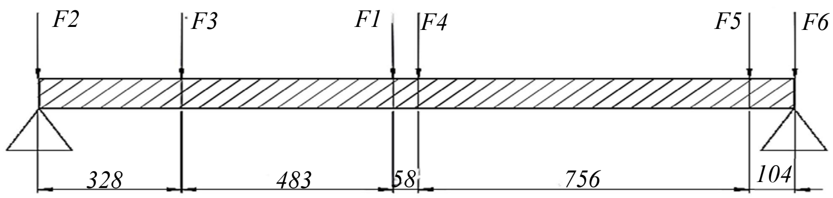

Fig. 3. Free body diagram of the chassis

To find the support reaction load received by each axle at point A and point B, the moment equation is used:

$$\Sigma Mb = \Sigma Ma = 0, \tag{1}$$

where the subareas noted by ΣMb and ΣMa are calculated by:

$$\Sigma Mb = (F6 \times 0) + (F5 \times 104) + (F4 \times 860) + \\ + (F1 \times 918) + (F3 \times 1{,}401) + \\ + (F2 \times 1{,}729) - (Fa \times 1{,}729), \tag{2}$$

$$\Sigma Ma = (F2 \times 0) + (F3 \times 328) + (F1 \times 811) + \\ + (F4 \times 869) + (F5 \times 1{,}625) + (F6 \times 1{,}729) - (Fb \times 1{,}729). \tag{3}$$

In the analysis, *Ma* represents the moment equation for Axle A, and *Mb* denotes the moment equation for Axle B. The forces acting at individual points are labeled as *F*1 through *F*6. Meanwhile, Fa signifies the force at Axle A, and *Fb* indicates the force at Axle B. From the above calculation, it is concluded that Axle A (208.23 kg) receives a greater reaction force than Axle B (137.44 kg), which means that the rear wheels hold a greater load than the front wheels. This is used for higher wheel grip/traction as a rear-wheel drive vehicle. The load distribution is carefully planned to maximize efficiency and safety, ensuring that the vehicle's rear wheels bear a greater load for improved traction.

5. 3. Material selection and static structural analysis

5. 3. 1. Material selection

The selection of materials is a pivotal stage in the design and manufacturing process, exerting a profound influence on vehicle safety, reliability, and performance. Thorough market research is crucial to identify optimal materials through an exhaustive comparison of mechanical and chemical properties. Such an endeavor contributes to the realization of a high-performance chassis.

The chosen materials for the chassis are the result of meticulous evaluation, incorporating factors such as tensile strength, yield strength, flexural strength, stiffness, density, availability, cost, and weldability. Minimizing chassis weight remains paramount to preserve vehicle performance. The weight of the chassis is of paramount importance [23, 24], and thus, ASTM A36 Steel material is selected based on its specified mechanical properties. Mechanical property data for ASTM A36 Steel material can be found in Table 2.

Table 2

ASTM A36 Steel mechanical properties

Mechanical properties	Value
Density (kg/m^3)	7,850
Young's Modulus (GPa)	190–210
Tensile Strength (MPa) (Standard)/(Quenching, Tempering)	400
Yield Strength (MPa) (Standard)/(Quenching, Tempering)	250
Poisson's ratio	0.26

The study shows that the right material selection can significantly impact the vehicle's performance, emphasizing the value of thorough market research.

5. 3. 2. Static structural analysis

From the results of the design, a strength analysis will be carried out using the finite element method. The main function of the chassis is to support all the weight of the vehicle so the chassis must be strong and sturdy in supporting the load. The load given is 70 kg driver load, 70 kg passenger load, 20 kg battery load, 5 kg steering system load, and 5 kg air conditioner load then for the fixed part, which is based on all four wheels. The following is the result of strength analysis using the FEA method.

FEA method process:

1. Selection of simulation type (static).

In this research, the type of simulation carried out is static stimulation. The results of the static simulation will be a picture of the actual situation.

2. Material selection.

Material selection is based on several aspects, such as its availability on the market and the size of the load that will be received.

3. Determining the location of the support.

Determining the fulcrum location is based on the fulcrum point on the free-body diagram.

4. Determining the location and amount of force to be received.

Determining the forces that work is based on the placement of vehicle components, the location of the driver's seat and the location of the passenger seat.

5. Carrying out the meshing process.

The meshing process is the process of forming small elements that build a digital model of an object or product. This technique is used to divide objects into smaller parts thereby enabling more accurate and effective numerical simulations.

6. Carrying out the strength analysis process.

The strength analysis process is a running process to process the entered data.

If the results of the strength analysis have no errors, the output from the strength analysis can be used.

Fig. 4 is the chassis stress analysis.

The results of the stress analysis show that it is still below the yield strength of the material, which is 2.500e+08, which means that the design and chassis material are still safe to use with this load. The biggest stress results are in the steering system, driver's area and some of the passenger areas shown in green and light blue.

The safety factor values are 2.053e+01, which are categorized as very safe for this load. Here are some results of the chassis strength analysis as shown in Fig. 5.

The minimum shear force value is –9.770e+02 and the maximum shear force value is 5.868e+2 as shown in Fig. 6.

Detailed resultant forces data can be found in Table 3.

Fig. 7 shows the beam force that occurs on the electric vehicle chassis by using several variables such as axial force, shear, moment and torque.

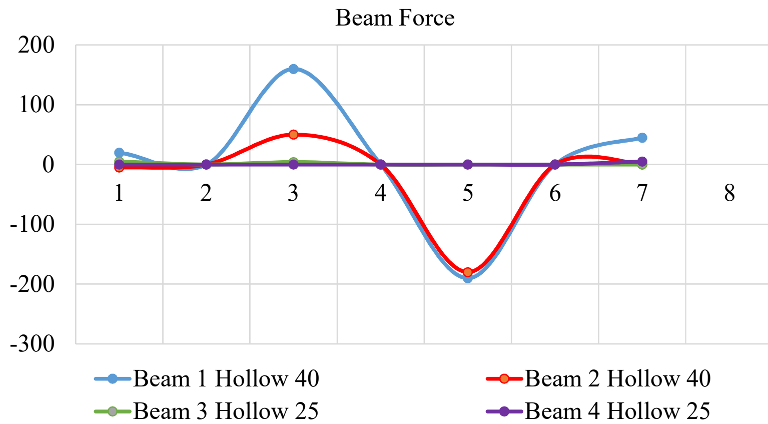

Fig. 7. Beam force

Table 3

Resultant Forces

Data	Units	Sum *X*	Sum *Y*	Sum *Z*	Resultant
Reaction Forces	N	–3.05176e-05	2.076.53	3.8147e-06	2.076.53
Reaction Moments	N·m	–0.154853	0.192526	–9.73124	9.73437
Free body forces	N	0	0	0	0
Free body moments	N·m	0	0	0	0

The section employs the Finite Element Analysis (FEA) method for strength analysis. The results affirm that the stress levels are well below the yield strength of the material, indicating that the design is safe for the specified load. The safety factor values were found to be considerably high, further validating the structural integrity of the chassis.

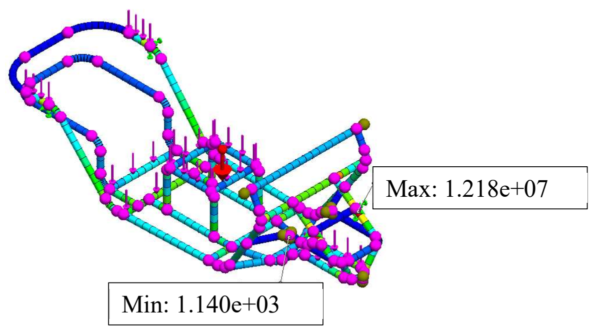

Fig. 4. Stress analysis

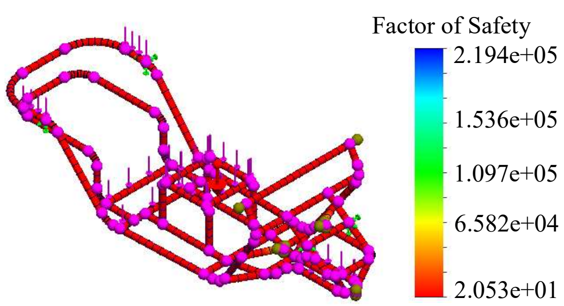

Fig. 5. Factor of Safety

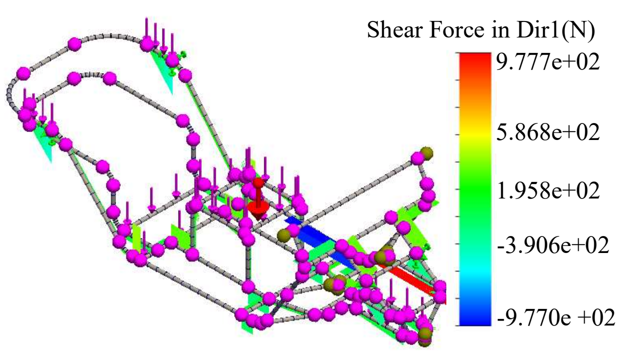

Fig. 6. Shear force

6. Discussion of the results of evaluating urban-centric hollow frame configurations for electric vehicles

The design process commences by surveying existing designs and conducting an in-depth review of pertinent literature. Subsequently, the chassis dimensions and material properties are established [20]. Given that the chassis constitutes the fundamental structural element of the vehicle, a comprehensive strength analysis becomes imperative [11, 21]. The results of the strength analysis, having demonstrated a satisfactory safety margin with a minimum safety factor of 1.5, pave the way for the subsequent phases of the engineering process, including detailed design, manufacturing, and assembly [22].

Driver safety is a key aspect of design and is considered through all stages. The entire design process from chassis involves various factors such as material selection, safety, ease of manufacture, passenger and driver comfort, and cost. The selection of the right material increases the reliability, safety, and overall performance of the vehicle.

The chassis adopted features a hollow structure, with main frame dimensions of 40×40×2 mm, supporting frame dimensions of 25×25×1.5 mm, and driver's seat frame dimensions of 25×25×3.2 mm. The design places a strong emphasis on driver ergonomics, focusing on the arrangement and design of driver controls to enhance efficiency and comfort within the driving environment. The holistic chassis design revolves around four key principles: prioritizing driver safety, emphasizing ergonomics, ensuring manufacturability, and enhancing overall structural strength. The chassis design is illustrated (Fig. 1), which carefully integrates material selection, safety considerations, ease of manufacture, passenger and driver comfort, and cost-effectiveness.

The chassis dimensions are 2,148 mm long, 800 mm wide and 640 mm high, and the weight is 40.77 kg. The design further accommodates components such as the motor, gearbox, and electrical systems, facilitating streamlined assembly processes for these intricate components.

Stress analysis (Fig. 4) indicates that the designed hollow frame structure remains well below the yield strength of the chosen ASTM A36 steel material, confirming its structural integrity under the applied loads. These findings corroborate with the safety factor values (Fig. 5) and shear force calculations (Fig. 6), emphasizing the overall safety and reliability of the designed chassis.

The current design shows a considerable improvement in weight efficiency and safety factors compared to traditional steel frame structures used in electric vehicles. While previous research emphasized the use of tubular frames and roll cages, respectively, our study integrates these concepts into a unified, optimized design [10, 16].

The limitations of this study include the sole reliance on simulation data, which may not capture all real-world variables, such as material imperfections or unexpected load conditions. The study also assumes static load conditions and does not account for fatigue over extended periods.

One drawback of the current study is the absence of physical prototype testing. Future work could include such tests to validate the simulation results further. Additionally, alternative materials like carbon-fiber-reinforced polymers could be explored for potential weight reduction and performance enhancement.

The potential extensions of this research include a more comprehensive evaluation involving dynamic load conditions and fatigue analysis. Challenges may arise in terms of the computational complexity involved in dynamic simulations and the need for more extensive experimental validation.

7. Conclusions

1. The research effectively assessed the possibility of creating a lightweight and efficient chassis for electric vehicles by employing a hollow frame structure with specific dimensions: 2,148 mm in length, 800 mm in width, and 640 mm in height, and a weight of 40.77 kg. The design of the chassis met the necessary criteria for strength and stiffness, ensuring its capability to support various vehicle components.

2. Through a thorough analysis of static loads, the study successfully evaluated and optimized the chassis of the electric vehicle. By concentrating on essential performance indicators and rear-wheel traction, the analysis verified that the chassis design fulfills the requirements for improved efficiency and safety, maintaining an adequate safety margin.

3. The study accomplished its primary goal by conducting 3D simulations to comprehensively assess the electric vehicle's chassis, concentrating on strength and safety parameters. By carefully selecting materials, specifically ASTM A36 Steel for its mechanical properties, the research effectively fine-tuned the design to strike a balance between weight and performance. The final chassis design not only adheres to safety standards, as indicated by a stress analysis result of 2.500e+08 and a safety factor of 2.053e+01, but also enhances efficiency and sustainability, making it ready for practical implementation.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

Sources of funding have been supported by research grants from Universitas Indonesia.

Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

Acknowledgments

The author would like to acknowledge the funding support for this research from the Directorate of Research and Development, Universitas Indonesia.

References

1. Khalili, S., Rantanen, E., Bogdanov, D., Breyer, C. (2019). Global Transportation Demand Development with Impacts on the Energy Demand and Greenhouse Gas Emissions in a Climate-Constrained World. Energies, 12 (20), 3870. doi: https://doi.org/10.3390/en12203870
2. Cunanan, C., Tran, M.-K., Lee, Y., Kwok, S., Leung, V., Fowler, M. (2021). A Review of Heavy-Duty Vehicle Powertrain Technologies: Diesel Engine Vehicles, Battery Electric Vehicles, and Hydrogen Fuel Cell Electric Vehicles. Clean Technologies, 3 (2), 474–489. doi: https://doi.org/10.3390/cleantechnol3020028
3. Liu-Henke, X., Scherler, S., Fritsch, M., Quantmeyer, F. (2016). Holistic development of a full-active electric vehicle by means of a model-based systems engineering. 2016 IEEE International Symposium on Systems Engineering (ISSE). doi: https://doi.org/10.1109/syseng.2016.7753142
4. Sutisna, N. A., Akbar, M. F. A. A. (2019). FEM Simulation of Electric Car Chassis Design with Torsional Bar Technology. Journal of Mechanical Engineering and Mechatronics, 3 (2), 97. doi: https://doi.org/10.33021/jmem.v3i2.542
5. Luque, P., Mántaras, D. A., Maradona, Á., Roces, J., Sánchez, L., Castejón, L., Malón, H. (2020). Multi-Objective Evolutionary Design of an Electric Vehicle Chassis. Sensors, 20 (13), 3633. doi: https://doi.org/10.3390/s20133633
6. Nazaruddin, N., Adhitya, M., Sumarsono, D. A., Siregar, R., Heryana, G., Prasetya, S., Zainuri, F. (2021). Development of electric vehicle (EV)-bus chassis with reverse engineering method using static analysis. Eastern-European Journal of Enterprise Technologies, 2 (7 (110)), 15–22. doi: https://doi.org/10.15587/1729-4061.2021.219928

7. Soon Keey Tiew, H., Wei Lee, M., Shyang Chang, W., Ishak, M. H. H., Ismail, F. (2020). Fluid-Structure Interaction on The Design of Fully Assembled Shell Eco-Marathon (SEM) Prototype Car. CFD Letters, 12 (12), 115–136. doi: https://doi.org/10.37934/cfdl.12.12.115136
8. Patel, D., Jasani, V., Shah, D., Lakdawala, A. (2022). Design and FE analysis of chassis for solar powered vehicle. Materials Today: Proceedings, 62, 1626–1631. doi: https://doi.org/10.1016/j.matpr.2022.04.137
9. Suraji, A., Djakfar, L., Wicaksono, A. (2021). Analysis of bus performance on the risk of traffic accidents in East Java-Indonesia. EUREKA: Physics and Engineering, 3, 111–118. doi: https://doi.org/10.21303/2461-4262.2021.001820
10. Nugraha, A. A., Sumarsono, D. A., Adhitya, M., Prasetya, S. (2021). Development of Brake Booster Design for Electric City Cars. International Journal of Technology, 12 (4), 802. doi: https://doi.org/10.14716/ijtech.v12i4.4636
11. Nandhakumar, S., Seenivasan, S., Mohammed Saalih, A., Saifudheen, M. (2021). Weight optimization and structural analysis of an electric bus chassis frame. Materials Today: Proceedings, 37, 1824–1827. doi: https://doi.org/10.1016/j.matpr.2020.07.404
12. Misra, S. (2017). Static Analysis of the Roll Cage of an All-Terrain Vehicle (SAE BAJA). International Research Journal of Engineering and Technology, 04 (09). Available at: https://www.irjet.net/archives/V4/i9/IRJET-V4I9157.pdf
13. Kasi V Rao, P., Sai Kumar Putsala, K., Muthupandi, M., Mojeswararao, D. (2022). Numerical analysis on space frame chassis of a formula student race car. Materials Today: Proceedings, 66, 754–759. doi: https://doi.org/10.1016/j.matpr.2022.04.077
14. S. Gupta, U., Jain, S., Jain, H., Singh Rathi, S. (2015). Static & Dynamic Analysis of F-SAE Roll cage Vehicle. International Journal of Engineering Trends and Technology, 27 (5), 245–247. doi: https://doi.org/10.14445/22315381/ijett-v27p244
15. Upadhyay, P., Kumar Sharma, S., Kumar, G., Bansal, P., Sharma, P. (2020). Optimization of chassis for a solar powered vehicle. IOP Conference Series: Materials Science and Engineering, 748 (1), 012021. doi: https://doi.org/10.1088/1757-899x/748/1/012021
16. Kumaresan, M., Shanthini, B., Rajesh, S., Raja Guru, R., Rajesh Kannaa, S. V., Prasanth, B. (2018). Design and analysis of a two seater electric car. International Journal of Mechanical Engineering and Technology, 9, 94–100. Available at: https://iaeme.com/MasterAdmin/Journal_uploads/IJMET/VOLUME_9_ISSUE_3/IJMET_09_03_011.pdf
17. Krzikalla, D., Mesicek, J., Petru, J., Sliva, A., Smiraus, J. (2019). Analysis of Torsional Stiffness of the Frame of a Formula Student Vehicle. Journal of Applied Mechanical Engineering, 08 (01). doi: https://doi.org/10.35248/2168-9873.19.8.315
18. Hazimi, H., Ubaidillah, Setiyawan, A. E. P., Ramdhani, H. C., Saputra, M. Z., Imaduddin, F. (2018). Vertical bending strength and torsional rigidity analysis of formula student car chassis. AIP Conference Proceedings. doi: https://doi.org/10.1063/1.5024109
19. Ary, A. K., Prabowo, A. R., Imaduddin, F. (2020). Structural assessment of alternative urban vehicle chassis subjected to loading and internal parameters using finite element analysis. Journal of Engineering Science and Technology, 15 (3), 1999–2022.
20. Nazaruddin, N., Syehan, A., Heryana, G., Adhitya, M., Sumarsono, D. A. (2019). Mode Shape Analysis of EV-Bus Chassis with Reverse Engineering Method. IOP Conference Series: Materials Science and Engineering, 694 (1), 012002. doi: https://doi.org/10.1088/1757-899x/694/1/012002
21. Amale, T., Badwaik, P., Durge, S., Dube, A., Belveker, A. (2021). FEA Approach for Modal Analysis of an Electric Motor in Electric Vehicle Drive. Lecture Notes in Mechanical Engineering, 425–434. doi: https://doi.org/10.1007/978-981-15-9853-1_36
22. Heryana, G., Adhitya, M., Sumarsono, D. A., Nazaruddin, Siregar, R., Prasetya, S., Aprianto, B. D. (2021). Designing an electric motor with 200 KW of power for the needs of large electric vehicles. AIP Conference Proceedings. doi: https://doi.org/10.1063/5.0066917
23. Wei, D., He, H., Cao, J. (2020). Hybrid electric vehicle electric motors for optimum energy efficiency: A computationally efficient design. Energy, 203, 117779. doi: https://doi.org/10.1016/j.energy.2020.117779
24. Eldho Aliasand, A., Josh, F. T. (2020). Selection of Motor foran Electric Vehicle: A Review. Materials Today: Proceedings, 24, 1804–1815. doi: https://doi.org/10.1016/j.matpr.2020.03.605