COMPARATIVE STATIC STRUCTURAL PERFORMANCE OF ALUMINUM 6061 PROTOTYPE ELECTRIC VEHICLE CHASSIS WITH H, X, AND Y REINFORCEMENT CONFIGURATIONS USING FINITE ELEMENT ANALYSIS

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ABSTRACT

This study aims to analyze the effect of variations in the chassis configuration of an electric vehicle prototype on structural performance using the Finite Element Analysis (FEA) method. The chassis was designed using 6061 aluminum with a C-channel profile in three configuration variations: H, X, and Y. Three-dimensional modeling and simulation were performed using Autodesk Inventor 2025 software based on a total static load of approximately 1,668 N, derived from an assumed mass budget of 170 kg for a single-seat prototype, was applied at the driver's feet, seat, and backrest, and at the motor and battery mounts, representing the weight of the driver and vehicle components. The analyzed parameters included the distribution of von Mises stress, displacement, and the safety factor to determine the most optimal chassis configuration. The simulation results showed that all variations met the safety criteria, as they had a safety factor of 15. The H-pattern configuration produced a maximum von Mises stress of 18.13 MPa with a displacement of 0.70 mm; the X-pattern produced a stress of 17.17 MPa with a displacement of 0.57 mm; while the Y-pattern produced the lowest stress of 16.48 MPa with a displacement of 0.59 mm. Based on a comparison of these three parameters, the Y-pattern configuration provides a more even load distribution, resulting in the best structural performance compared to the H and X patterns. The research findings indicate that variations in chassis geometry affect stress and strain characteristics, and can therefore serve as a reference in the development of prototype electric vehicle chassis designs that are lightweight, safe, and have good structural strength.

Keywords: 6061 Aluminum, Autodesk Inventor, Chassis, Finite Element Analysis, Electric Car, von Mises Stress.

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1. INTRODUCTION

The development of electric vehicles (EVs) has seen significant growth as part of efforts to reduce dependence on fossil fuels and greenhouse gas emissions. In addition to being supported by advancements in battery technology, the use of electric vehicles has also become a key strategy for improving energy efficiency in the transportation sector (Ardiyanti et al., 2023). In Indonesia, the development of electric vehicles is being further driven by various government policies and improvements in the national manufacturing industry's capacity to produce electric vehicle components. Therefore, the development of vehicle designs that are lightweight, strong, and safe is a key aspect in supporting the performance of electric vehicles (Akshay et al., 2018).

One of the key components that determines a vehicle's performance is the chassis (Efendi, 2020). The chassis serves as the primary structure that supports all vehicle components, such as the powertrain, suspension, steering system, battery, and the driver. In addition to withstanding static loads, the chassis must also have sufficient stiffness to handle dynamic loads while the vehicle is in operation (Budiman, 2021). A suboptimal chassis design can lead to increased deformation, uneven stress distribution, and even structural failure when subjected to loads. Therefore, analyzing the structural strength of the chassis is a critical step before the manufacturing process begins (Kareem et al., 2021).

Previous FEA studies on lightweight vehicle chassis have mainly examined material selection or a single frame layout (Faizin 2023; UNESA 2023). For example, Faizin et al. [ref] evaluated a prototype electric car chassis made of 7075 aluminum under a 1,000 N load, while [LACCEI 2026] reported that aluminum chassis may require geometric reinforcement to compensate for lower stiffness. In our earlier work, H, X, and Y patterns were compared using hollow 6061 aluminum profiles under a 900 N load (Bahasyim 2023). However, [what these studies did not address, to be verified: e.g., C-channel profiles, load derived from a mass budget, equivalent stiffness or stiffness-to-mass comparison]. This leaves open the question of how reinforcement geometry affects stress and stiffness of a C-channel Aluminum 6061 chassis under a defined load case

Material selection is also a key factor in the design of electric vehicle chassis (Kusuma et al., 2025). Aluminum 6061 is one of the most widely used materials because it has low density, good corrosion resistance, and relatively high mechanical strength compared to other aluminum alloys. The use of this material allows for a reduction in vehicle mass without compromising the structure's load-bearing capacity, thereby contributing to improved energy efficiency in electric vehicles (Muhajrin et al., 2023).

Advances in Computer-Aided Engineering (CAE)-based software have made it possible to perform structural analysis numerically using the Finite Element Analysis (FEA) method (Mulyaningtyas et al., 2023). This method can predict the distribution of stress, deformation, and the safety factor of a structure prior to fabrication, thereby reducing product development costs and time. Autodesk Inventor 2025 provides FEA-based simulation capabilities that can be used to evaluate chassis performance using parameters such as von Mises stress, displacement, and safety factor (Pranoto et al., 2021).

Several previous studies have utilized the FEA method to evaluate the structural strength of vehicle chassis (Purnawan and Mufarida, 2025). However, most of these studies analyzed only a single frame configuration or used different materials, and thus have not provided information on the effect of configuration variations on the distribution of stress and strain in a chassis made of 6061 aluminum (Rafi et al., 2023). Furthermore, studies comparing various reinforcement patterns in prototype electric vehicle chassis are still relatively limited, so further research is needed to determine the most optimal structural configuration (Rahardian et al., 2021).

Based on these conditions, this study analyzed three chassis configuration variations—namely, the H, X, and Y patterns—using 6061 aluminum with a C-channel profile (Prabakaran and G, 2014). The analysis was performed using Autodesk Inventor 2025 based on Finite Element Analysis with a static load of 1,668 N. The parameters analyzed included the distribution of von Mises stress, displacement,

and the safety factor to determine the chassis configuration that provides the best structural performance (Sahu et al., 2018).

This study is expected to provide information on the effect of variations in chassis configuration on stress and strain characteristics, while also serving as a reference for the development of prototype electric vehicle chassis designs that are lightweight, safe, and have optimal structural strength. Unlike previous studies that primarily evaluated a single chassis configuration or focused on material substitution, this study investigates the influence of reinforcement geometry while maintaining identical material properties, profile dimensions, and loading conditions. The novelty of this work lies in the systematic comparison of three reinforcement configurations (H, X, and Y) using Aluminum 6061 under identical static loading conditions, allowing the effect of reinforcement geometry on stress distribution, displacement, and structural efficiency to be evaluated independently. Furthermore, the study introduces a structural performance evaluation based on the combined assessment of von Mises stress, displacement, and structural stiffness to identify the most efficient reinforcement layout for lightweight prototype electric vehicle chassis.

Therefore, this study aims to evaluate the structural performance of H-, X-, and Y-pattern chassis configurations using Finite Element Analysis (FEA) in Autodesk Inventor Professional 2025. The evaluation is based on the combined analysis of von Mises stress, displacement, safety factor, and equivalent structural stiffness under identical loading conditions. The findings are expected to provide design recommendations for selecting an efficient reinforcement configuration for lightweight prototype electric vehicle chassis.

2. METHODS

This study employs a quantitative method using a numerical simulation approach based on Finite Element Analysis (FEA) to evaluate the structural performance of a prototype electric vehicle chassis. The simulations were conducted using Autodesk Inventor Professional 2025 software. The objective of the analysis is to compare the mechanical characteristics of three chassis configurations H, X, and Y based on stress distribution, deformation, and safety factors.

The research process began with a literature review on the construction of electric vehicle chassis, the characteristics of 6061 aluminum, and the application of the Finite Element Analysis method to vehicle structural analysis. The chassis material is Aluminum 6061-T6, with density 2,700 kg/m³, Young's modulus 68.9 GPa, Poisson's ratio 0.33, yield strength 276 MPa, and ultimate tensile strength 310 MPa (typical values for the T6 temper, consistent with the Inventor material library). This information served as the basis for determining design parameters, materials, and loading conditions. Next, a three-dimensional chassis model was designed using Autodesk Inventor 2025 with overall dimensions of 2,160 mm × 750 mm × 500 mm. All three models used the same material, Aluminum 6061 with a C-channel profile conforming to DIN 1026-1 standard, measuring 30 mm × 33 mm × 5 mm—so that differences in simulation results were influenced solely by variations in structural configuration.

After the modeling process was completed, the material properties were determined, including density, modulus of elasticity, Poisson's ratio, yield strength, and ultimate tensile strength, based on the data for 6061 aluminum available in the software. The next step was to apply boundary conditions in the form of fixed constraints at the points representing the connection between the chassis and the suspension system, while loads were applied at several points representing the weight of the driver and vehicle components, with a total load of 1,668 N. These loads are distributed across the driver's feet, waist, and back, as well as the engine mount, to closely approximate actual operating conditions.

The structural analysis was performed using the Stress Analysis module in Autodesk Inventor 2025. Prior to the computational process, the model was divided into small elements through a meshing process to obtain a numerical representation capable of depicting the stress distribution throughout the structure. Next, a static analysis was performed to determine the structure's response to the applied loads.

The main parameters analyzed include Von Mises stress, displacement, and safety factor. The Von Mises stress value is used to evaluate the distribution of equivalent stress in the chassis structure. The displacement value indicates the magnitude of the maximum deformation caused by loading, while the safety factor is used to determine the structure's safety level based on a comparison between the material's yield stress and the applied working stress. The simulation results from the three chassis configurations were then compared to determine the design with the most uniform stress distribution, the smallest deformation, and the best safety level.

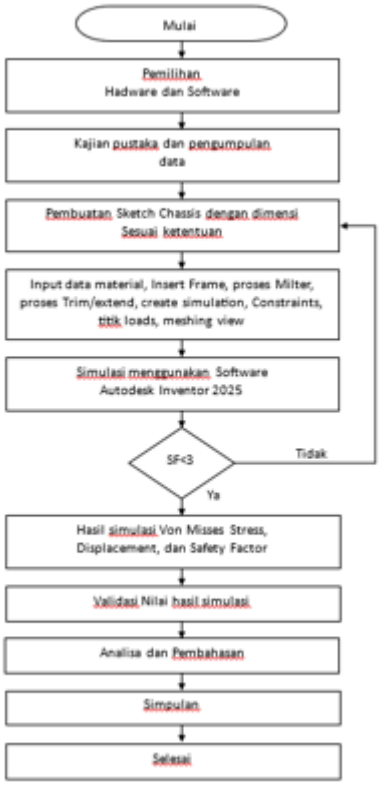
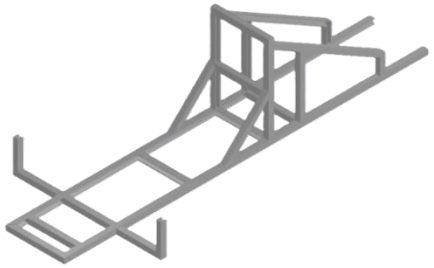


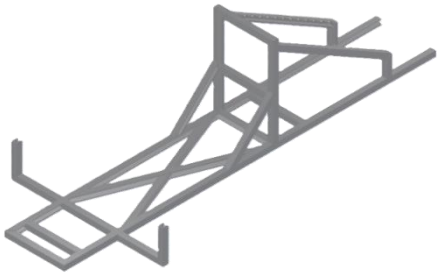
Figure 1 Research Methodology Diagram

Table 1 Simulation Specifications

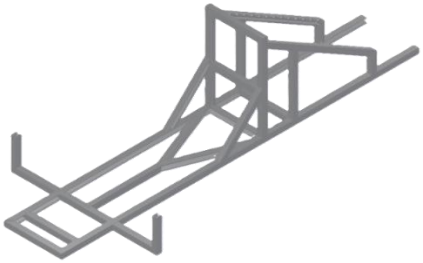
Parameters	Value
Software	Autodesk Inventor Professional 2025
Methods of Analysis	Static Finite Element Analysis
Materials	Aluminium 6061
Profil	Kanal C
Standart Profil	DIN 1026-1
Chassis Dimensions	2160 × 750 × 500 mm
Variations	H, X, Y
Total Load	1,668N
Output	Von Mises Stress, Displacement, Safety Facto0072



(H)



(X)



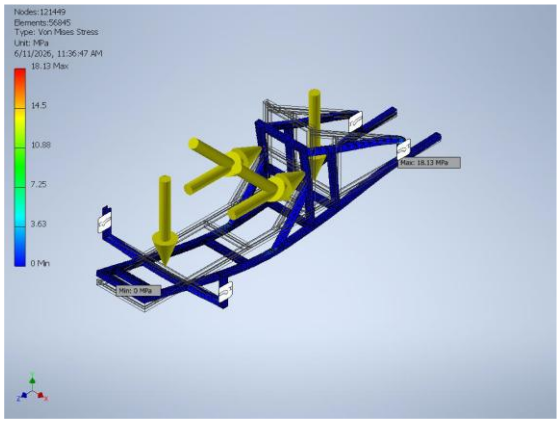
(Y)

Figure 2. H, X, Y Pattern Chassis Design

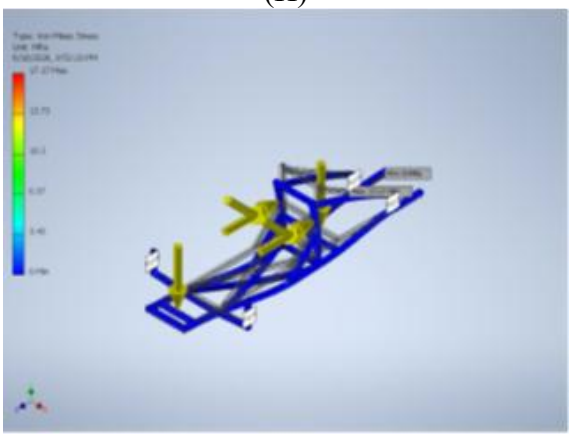
3. RESULTS AND DISCUSSION

3.1. Results of the Finite Element Analysis Simulation

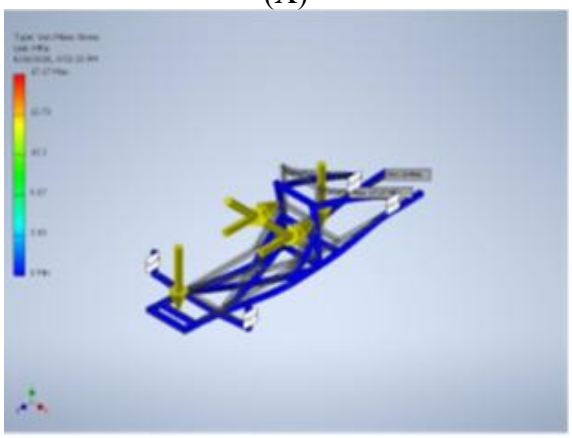
Structural simulations were performed using Autodesk Inventor Professional 2025 on three chassis configurations: H, X, and Y. All three models used 6061 aluminum with a C-channel profile and had the same dimensions and loading conditions; therefore, any differences in the results were entirely due to variations in the structural configurations (Toteles, 2021). The analysis was performed using the Static Finite Element Analysis method with a total load of 1,668 N, representing the weight of the driver and vehicle components.



(H)

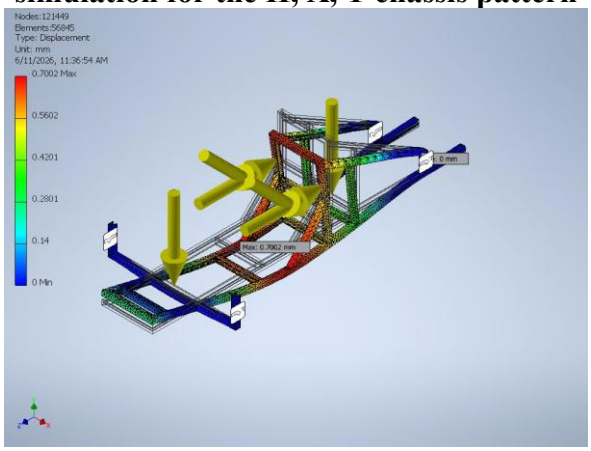


(X)

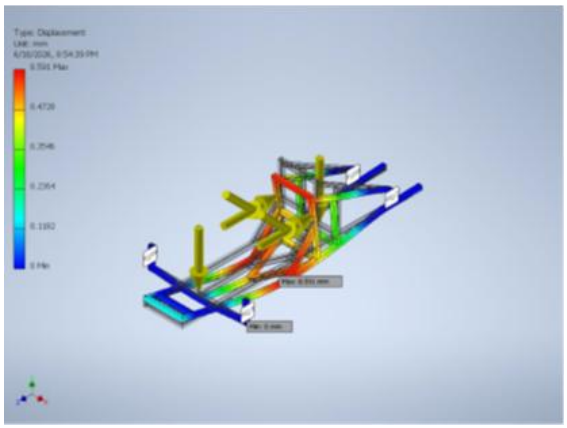


(Y)

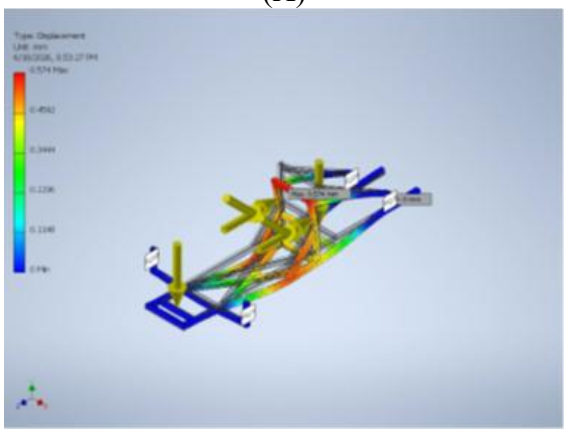
Figure 3 Results of the von Mises stress simulation for the H, X, Y chassis pattern



(H)

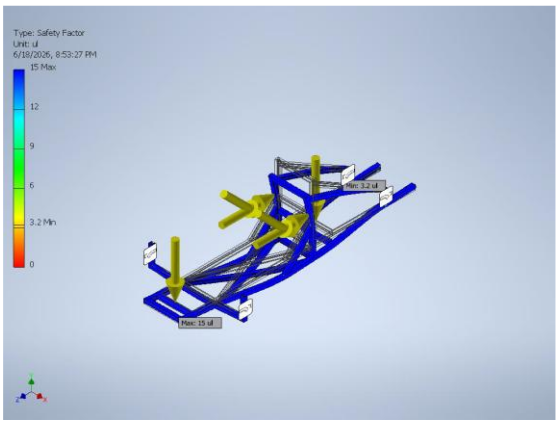


(X)

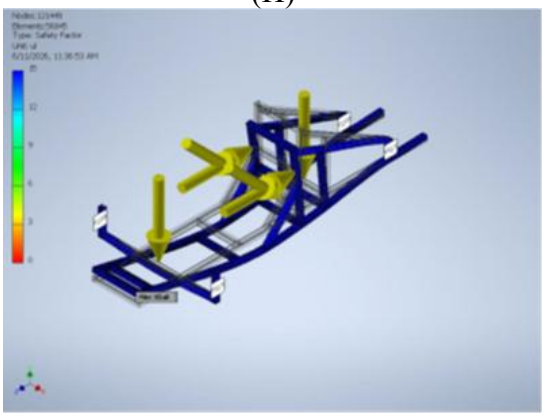


(Y)

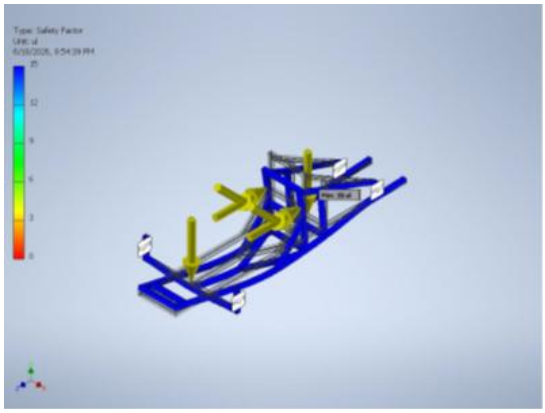
Figure 4 Simulation Results for Chassis Displacement in the H, X, Y Patterns



(H)



(X)



(Y)

Figure 5 Simulation Results for the Safety Factor of the H, X, Y Chassis Configuration

The simulation results show that all chassis configurations remain within safe limits, as the maximum stress values observed are still well below the yield strength of 6061 aluminum. Differences in structural configuration affect the stress distribution, deformation, and safety factor of each model.

The simulation results presented in Figures 3–5 indicate that the structural response of the three chassis configurations is primarily influenced by the arrangement of reinforcement members rather than differences in material properties or loading conditions. Since all models were analyzed using identical dimensions, Aluminum 6061 material, and a static load of 1,668 N, the observed differences in stress distribution and deformation are attributed to the reinforcement geometry.

Based on the stress contours shown in Figure 3, regions experiencing relatively higher stress are generally located around the intersections between the longitudinal members, transverse members, and reinforcement structures. These locations represent changes in structural geometry where the applied load is transferred from one member to another. Consequently, the internal force flow becomes concentrated at these joints, resulting in localized increases in equivalent stress. Such behavior is commonly observed in frame structures subjected to bending and compressive loading.

Although all three configurations remain within the allowable stress limit of Aluminum 6061, the reinforcement pattern influences the ability of the structure to distribute external loads. The H-pattern tends to transfer loads primarily through the longitudinal members, whereas the X and Y configurations provide additional diagonal load paths that contribute to a more uniform force distribution throughout the chassis. This structural characteristic explains why the X and Y configurations exhibit lower maximum stress values than the H configuration.

3.2 Von Mises Stress Analysis

The Von Mises stress value is used to evaluate a structure's ability to withstand loading Saputra, 2024). The maximum equivalent stress from the simulation is shown in Table 2.

Table 1 Comparison of Simulation Results

Model	Von Mises Stress (MPa)	Displacement (mm)	Safety Factor
H	18,13	0,70	15
X	17,17	0,57	15
Y	16,48	0,59	15

Based on the simulation results, configuration H produced a maximum stress of 18.13 MPa, while configuration X showed a decrease to 17.17 MPa. The lowest stress was obtained in configuration Y, at 16.48 MPa.

The decrease in stress in configuration Y indicates that the addition of bracing elements improves load distribution within the structure, thereby reducing stress concentration. The load borne by the chassis is no longer concentrated in a single area but is distributed more evenly throughout the frame.

From a mechanical standpoint, a more even load distribution reduces stress concentrations, which typically occur at joints or changes in geometry. This reduces the potential for permanent deformation or structural failure when the vehicle is under load. Furthermore, the reduction of the maximum von Mises stress from 18.13 MPa in the H configuration to 16.48 MPa in the Y configuration represents an improvement of approximately 9.1%. Although the numerical difference appears relatively small, it indicates that modifying the reinforcement geometry alone can improve structural performance without increasing material usage or changing the chassis dimensions. This finding demonstrates that reinforcement configuration optimization is an effective approach for improving lightweight vehicle structures.

From an engineering perspective, lower equivalent stress is beneficial because it

decreases the possibility of localized yielding and reduces stress concentration around welded joints. Consequently, the chassis is expected to maintain better structural integrity under service loading conditions. It should be noted that this study only evaluates static loading conditions; therefore, the results describe the structural behavior under static loads and do not represent fatigue or impact performance.

3.3 Displacement Analysis

In addition to stress, another important parameter is displacement, which indicates the magnitude of the maximum deformation caused by loading (Widiyanto et al., 2021). The simulation results show that configuration H experienced the largest displacement of 0.70 mm, while configuration X produced the smallest displacement of 0.57 mm. In configuration Y, the displacement was 0.59 mm, slightly larger than that of configuration X but still smaller than that of configuration H.

The relatively small displacement values in all three configurations indicate that the chassis structure has good stiffness. Although the X pattern produced the smallest deformation, the Y configuration still provided a better balance between deformation and stress distribution. Thus, the structural evaluation is not based solely on displacement values but also takes into account the stress distribution across the entire frame.

The displacement results also indicate that all configurations possess relatively high structural stiffness because the maximum deformation remains below 1 mm under the applied load. This suggests that the selected C-channel profile and Aluminum 6061 material provide sufficient rigidity for a prototype electric vehicle chassis. Although the X configuration exhibits the lowest displacement, the difference between the X and Y configurations is only 0.02 mm, indicating that both reinforcement layouts provide comparable structural stiffness. Therefore, displacement should be interpreted together with the stress distribution to obtain a comprehensive assessment of structural performance.

3.4 Safety Factor Analysis

The safety factor is an indicator of a structure's safety under loading (Wahab et al., 2022). The simulation results show that all configurations have a safety factor of 15, indicating that the working stresses are still well below the yield strength of 6061 aluminum.
This value indicates that all chassis variations have a high level of safety against a static load of 1,668 N. However, even though all three configurations have the same safety factor value, the distribution of stress and deformation remains a key consideration in determining the most optimal design.

The identical safety factor obtained for all configurations indicates that the selected material possesses a considerably higher yield strength than the maximum stress generated during simulation. Therefore, the differences among the three chassis configurations are not related to structural safety but rather to the efficiency of stress distribution and structural stiffness. Under these conditions, the reinforcement geometry becomes the primary design parameter for improving structural performance while maintaining the same material specifications.

3.5 Discussion

Differences in the bracing configuration of the chassis have a direct effect on the distribution of forces along the structure. The H configuration has a relatively simple load distribution path, so stress concentration tends to occur in the center of the chassis. The addition of diagonal elements in the X configuration increases the structural stiffness, thereby reducing deformation.

Meanwhile, the Y configuration produces the most even stress distribution. This pattern allows the load to be transmitted through multiple paths simultaneously, thereby minimizing stress concentration at the joints. Although the displacement value is slightly greater than that of the X configuration, the lower maximum stress indicates that the Y configuration has better structural efficiency.

The results of this study show that optimizing the chassis geometry has a significant effect on the mechanical characteristics of the structure. The use of 6061 aluminum, combined with the appropriate bracing configuration, produces a lightweight chassis that still possesses sufficient strength for a prototype electric vehicle.

Overall, the Y configuration was selected as the best design because it produced the lowest Von Mises stress value while maintaining a high

safety factor. These results indicate that the load distribution in the Y configuration is more effective than in the H or X configurations, making this design the most recommended for the development of prototype electric vehicle chassis.

The findings of this study are consistent with previous investigations reporting that reinforcement members significantly improve the mechanical performance of vehicle frame structures by reducing stress concentration and increasing stiffness. In comparison with conventional frame configurations, the incorporation of diagonal reinforcement enables the applied load to be distributed through multiple structural paths, thereby reducing localized loading. This study further demonstrates that different reinforcement layouts produce different structural responses even when the material properties, chassis dimensions, and loading conditions remain unchanged.

From the design perspective, these results provide practical guidance for the development of lightweight electric vehicle chassis. Instead of increasing material thickness or selecting stronger materials, designers may improve structural performance through optimization of reinforcement geometry. Such an approach is advantageous because it can enhance structural efficiency while minimizing additional manufacturing costs and vehicle weight.

3.6 Structural Performance Evaluation and Engineering Implications

The simulation results demonstrate that the structural performance of the prototype electric vehicle chassis is strongly influenced by the reinforcement configuration. Since all chassis models were analyzed using identical material properties, dimensions, profile specifications, and loading conditions, the observed differences in von Mises stress and displacement are attributed solely to the variation in reinforcement geometry. This indicates that geometric optimization plays an important role in improving structural performance without increasing material consumption.

From the structural mechanics perspective, the addition of reinforcement members changes the internal load transfer mechanism within the chassis. The H-pattern provides relatively simple load paths, causing a larger portion of the applied load to be transferred through the main longitudinal members. As a consequence, stress tends to accumulate around the central frame where the bending moment reaches its maximum value. This condition explains why the H configuration produces the highest equivalent stress and the largest displacement among the three investigated models.

The introduction of diagonal reinforcement in the X-pattern improves the structural stiffness by allowing a portion of the bending load to be transformed into axial tensile and compressive forces. Because structural members generally possess higher resistance to axial loading than bending, the overall deformation of the chassis becomes smaller. This mechanism is reflected by the lowest displacement value obtained in the X configuration. Nevertheless, the intersection between diagonal members also creates localized stress concentration, preventing the maximum von Mises stress from becoming the lowest among the evaluated configurations.

Unlike the H and X configurations, the Y-pattern provides a more efficient load distribution by directing external forces through multiple structural paths before reaching the support points. Consequently, the applied load is distributed more uniformly throughout the frame, reducing stress concentration in critical structural regions. Although the displacement of the Y configuration is slightly higher than that of the X configuration, the lower equivalent stress indicates that the reinforcement layout provides better structural efficiency. This balance between stiffness and stress reduction is desirable in lightweight vehicle structures because it minimizes the possibility of excessive local loading while maintaining sufficient rigidity.

Another important finding is that all chassis configurations exhibit a safety factor of 15, indicating that the maximum working stress remains significantly below the yield strength of Aluminum 6061. Therefore, the differences among the three configurations should not be interpreted as differences in structural safety but rather as differences in structural efficiency. Under identical safety conditions, the

reinforcement configuration becomes the primary parameter for selecting the optimum chassis design.

The present study also confirms that structural optimization can be achieved without modifying the material type or increasing the cross-sectional dimensions of the frame members. Instead, improving the arrangement of reinforcement members provides a practical approach to reducing stress concentration while maintaining lightweight construction. Such an approach is particularly beneficial in prototype electric vehicles, where minimizing structural weight contributes directly to improved energy efficiency and driving range.

The findings obtained in this research are consistent with previous studies reporting that the addition of reinforcement members improves the load distribution capability of vehicle frame structures. Previous researchers have shown that diagonal reinforcement increases structural rigidity while reducing localized stress concentration. The present study complements these findings by comparing three different reinforcement layouts under identical simulation conditions, thereby providing a clearer understanding of how reinforcement geometry influences structural behavior.

Overall, the Y-pattern configuration demonstrates the best compromise between low von Mises stress, acceptable displacement, and a high safety factor. Based on these results, the proposed reinforcement configuration can be considered an effective alternative for the development of lightweight electric vehicle chassis that require both structural strength and material efficiency.

4. CONCLUSION

Based on the results of the Finite Element Analysis (FEA) simulation using Autodesk Inventor Professional 2025, it can be concluded that variations in chassis configuration affect the mechanical characteristics of the prototype electric vehicle structure made of 6061 aluminum with a C-channel profile. All three chassis configurations—H, X, and Y—demonstrate a good level of safety with a safety factor of 15, meaning all designs still meet safety criteria for a static load of 1,668 N. The simulation results show that the H-pattern configuration produces a maximum von Mises stress of 18.13 MPa with a displacement of 0.70 mm, the X-pattern produces 17.17 MPa with a displacement of 0.57 mm, while the Y-pattern produces the lowest stress of 16.48 MPa with a displacement of 0.59 mm. Although the X pattern has the smallest displacement value, the Y pattern configuration provides a more even stress distribution with the lowest von Mises stress value; therefore, it can be considered the most optimal chassis design for application in a prototype electric vehicle because it provides the best balance between structural strength, stiffness, and safety levels.

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