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Structural Strength Analysis of Floor Pan Battery Electric Vehicle Class Medium MPV Using Finite Element Method

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Abstract
This study aims to analyze the strength of the floor pan structure on the Battery Electric Vehicle medium MPV class using the finite element method. Simulations were carried out with Ansys 2020 software through static loading that was adjusted to the actual conditions of the vehicle. Floor pan design variations were studied based on the type of material, namely JIS G3101 SS400 (M1) and ASTM A1011 Grade 45 (M2), as well as material thicknesses of 1.2 mm (T1), 1.4 mm (T2), and 1.6 mm (T3). The simulation results show that increasing the material thickness decreases the von mises stress and displacement values, and increases the safety factor. ASTM A1011 Grade 45 material shows better structural performance than JIS G3101 SS400, with smaller displacement and higher safety factor at the same thickness. However, the increase in thickness also results in an increase in the mass of the floor pan. Based on the analysis, the M2T1 model is the best configuration because it produces a von mises stress of 161.68 MPa, displacement of 6.6796 mm, safety factor of 1.9174, and mass of 138.25 kg. This model meets the safety limit and mass efficiency, so it is recommended to be applied to the BEV medium MPV.

1 Introduction

Transportation is the main means that plays an important role in supporting smooth mobility at this time. The transportation sector continues to develop in line with the improvement of the regional and national economy. With the growth and development in the transportation sector that supports the national economy, there are great challenges that can become national and global problems, especially in terms of energy consumption and environmental impacts.

According to the Ministry of Energy and Mineral Resources (2024), national fuel consumption in 2023 reached 505 million barrels, with the transportation sector accounting for the largest portion, at 51%. This sector's dependence on fuel cannot be separated from the increasing number of motorized vehicles [1]. Data from the Central Bureau of Statistics (2024) recorded that Indonesia had 157.08 million units of motorized vehicles in 2023, with the dominance of private vehicles in total covering 95.9% of all motorized vehicles [2]. This high dominance of private vehicles indicates low dependence on public transportation, which has a direct impact on increasing fuel consumption and greenhouse gas emissions. The Central Bureau of Statistics (2024) noted that Indonesia's total greenhouse gas (GHG) emissions in 2022 reached 887,232 Gg CO2e, with CO2 as the main contributor at 77%, followed by CH4 (19%) and N2O (4%). The transportation sector contributes 81,082 Gg CO2e (9.14%) of total national emissions, dominated by CO2 emissions at 97.66%. These emissions come from fuel combustion in conventional engines, making the transportation sector a significant contributor to GHG emissions in Indonesia.

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In response to rising greenhouse gas emissions, the Indonesian government issued Presidential Regulation (Perpres) Number 79 of 2023 concerning the Acceleration of the Battery-Based Electric Motor Vehicle Program. This policy is a form of commitment to encourage the adoption of electric vehicles as an effort to reduce emissions from conventional fossil fuel vehicles, while supporting climate change control [3].

Electric cars are one of the technological solutions to reduce carbon emissions in the transportation sector. Unlike conventional vehicles, electric cars do not produce exhaust emissions such as CO2 because they do not use internal combustion engines [4]. In addition, electric cars support the development of sustainable transportation through long-term strategic planning oriented towards environmental sustainability [5]. As the adoption of electric vehicles increases, the Medium MPV segment becomes a strategic opportunity to develop. GAIKINDO data recorded a surge in electric vehicle sales from around 17,000 units in 2023 to more than 43,000 units in 2024, or a growth of around 152.9%. As of April 2025, Battery Electric Vehicles (BEVs) have also accounted for 8.1% of total four-wheeled vehicle sales, reflecting increasing consumer interest in full electric vehicles.

In the development of Battery Electric Vehicle (BEV) in the Medium MPV category, floor pan design plays an important role as the main structure supporting the vehicle body and components. An optimal design can improve space efficiency, load distribution, and passenger safety without sacrificing comfort and performance. Some previous studies have discussed floor pan, but there are still gaps. Wibisono (2024) examined the lower body structure of a ladder frame-based commercial electric car, without considering a semi-skateboard chassis [6]. Chandru et al. (2018) and Kumar G R (2017) focused on vibration characteristics, not structural strength or material variations [7][8]. Shojaeefard et al. (2016) discussed geometry optimization in conventional cars without modeling the loading, while Lee & Park (2021) focused on sandwich composite materials [9][10]. Thus, there is no study that specifically discusses the structural strength analysis of the floor pan for the BEV class Medium MPV based on a semi-skateboard chassis, using material and thickness variations under static loading.

This research is focused on analyzing the structural strength of the floor pan on the Battery Electric Vehicle (BEV) class Medium MPV, by considering material and thickness variations, where in this study using JIS G3101 SS400 and ASTM A1011 Grade 45 materials, and material thickness variations of 1.2 mm, 1.4 mm, and 1.6 mm respectively. The scope of the research is limited to evaluating the structural response of the floor pan to static loads that represent the operational conditions of the vehicle. The main objective is to ensure that the floor pan has sufficient capacity and durability to withstand static forces and stresses, so as to ensure the safety and structural integrity of the vehicle. The floor pan design analyzed in this study is part of the Medium MPV class BEV design, with geometry adapted to the semi-skateboard chassis configuration [11]. The semi-skateboard platform was chosen because it has generally become the basis for efficient and modular design of modern electric vehicles. With this approach, the floor pan is designed to be structurally compatible while being able to optimally accommodate passenger and freight loads. Therefore, this research is expected to contribute to understanding the mechanical performance of the floor pan, taking into account the aspects of safety, weight efficiency, and structural durability that are prioritized in the development of BEVs in the Medium MPV category.

2 Research Methods

This research uses a quantitative approach because it allows objective analysis of numerical data, such as von Mises stress, displacement, and safety factor, in response to static loads. The type of research applied is numerical simulation-based experimentation using the finite element method (FEM). This method was chosen because it is capable of analyzing the structural strength of floor pans efficiently, accurately, and cost-effectively compared to physical testing, and allows for more flexible explorations of design and material variations as shown in Figure 1.

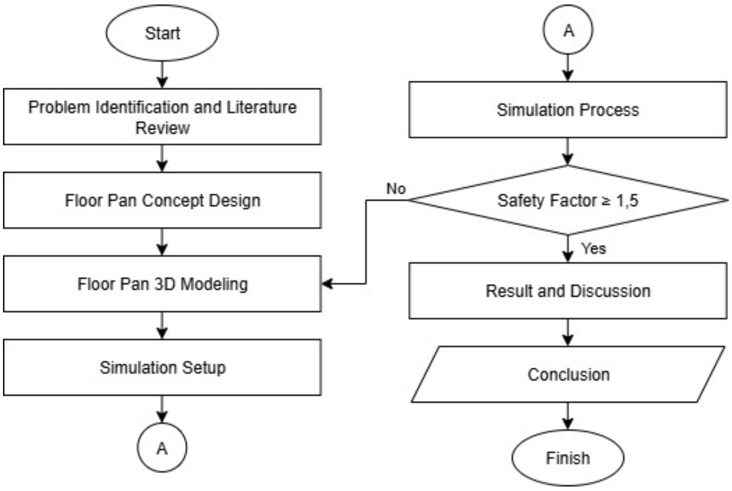


Figure 1. Research Flow Chart

2.1 Equipment and Materials

2.1.1 Laptop

Figure 2. Laptop

2.1.2 Software

Figure 3. Design and Simulation Software

Tools of the design (See Figure 2 and 3) of the floor pan concept that has been made, then modelled with 3 dimensions using SolidWorks 2021 software. Furthermore, the 3D model that has been made is then used for structural strength analysis testing using Ansys 2020 software, using the static structural analysis method.

2.1.3 Design Model Floor Pan

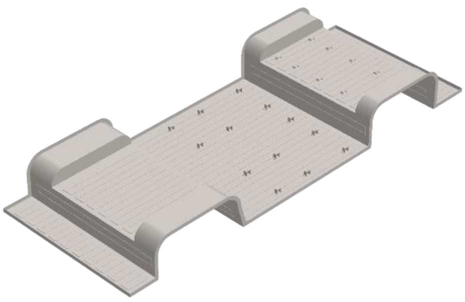


Figure 4. 3D Floor Pan

In Figure 4, the simulation on the structural strength of the floor pan, two types of materials commonly applied in vehicle components are used, namely JIS G3101 SS400 and ASTM A1011 Grade 45. These two materials were chosen because they have mechanical characteristics suitable for lightweight and strong structural applications, such as on electric vehicle platforms. The thickness variations used are 1.2 mm, 1.4 mm, and 1.6 mm, aiming to evaluate the effect of thickness on structural strength and mass efficiency as seen in Table 1.

Table 1. Mechanical Properties of the Material

Properties	Value on the Material	
	JIS G3101 SS400	ASTM A1011 Grade 45
Density (kg/m3)	7860	7870
Ultimate Strength (MPa)	400	410
Yield Strength (MPa)	245	310
Modulus of Elasticity (Gpa)	190-210	200
Poisson Ratio	0,26	0,29
Elongation (%)	21	19

For the loading scenarios, simulations were conducted with static loads that represent the actual conditions of the vehicle when carrying passengers and goods. This load was divided according to the actual load application on the floor pan parts, with the total load adjusted based on the estimated maximum weight of the vehicle when fully loaded. The loading was performed vertically downward to represent the gravitational force received by the floor pan during vehicle operation as shown in Table 2.

Table 2. Load Values on Floor Pan

Load Description	Load Value (kg)	Quantity	Total Load (kg)
Passenger	70	7	490
Single Chair	20	2	40
Set Chair	50	2	100
Small Item	50	2	100
Large Item	100	1	100
Body and Interior	500	1	500
Total Amount of Load			1330

3 Result and Discussion

The floor pan design in this study involves two main variables, namely material type and material thickness. The material types used consist of JIS G3101 SS400 and ASTM A1011 Grade 45, while the material thicknesses applied are 1.2 mm, 1.4 mm, and 1.6 mm. The combination of the two variables resulted in six simulation variations. To simplify identification and interpretation of the results, each combination is systematically coded with the format Mx_1Tx_2, where M1 represents JIS G3101 SS400 and M2 for ASTM A1011 Grade 45, while T1, T2, and T3 indicate thicknesses of 1.2 mm, 1.4 mm, and 1.6 mm, respectively. Thus, the variations used are M1T1, M1T2, M1T3, M2T1, M2T2, and M2T3. This coding system is applied consistently to facilitate tracking of simulation data, preparation of tables, comparison graphs, and narration of discussion of results.

3.1 Mesh Convergence Test

Mesh convergence tests are conducted to ensure that the simulation results have reached numerical stability. In this study, the test is carried out by comparing the von Mises stress values of several simulations using different mesh sizes. The results are considered convergent if two consecutive simulations show a value difference of less than 5%. This test ensures that the quality of the mesh used does not significantly affect the final simulation results. The convergence test data is presented in Figure 5.

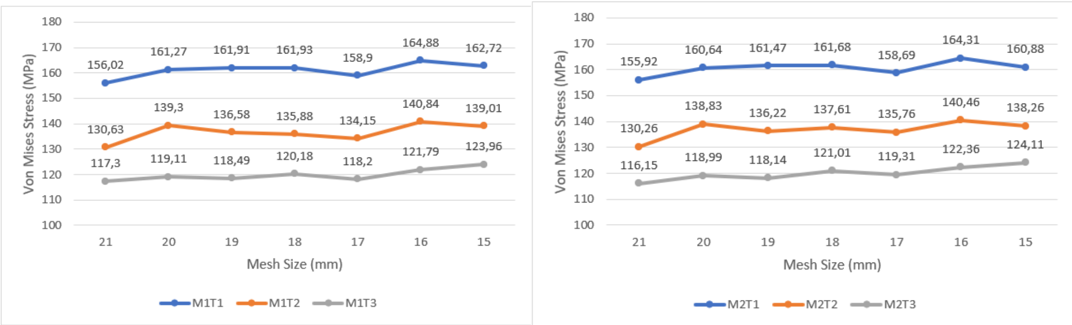


Figure 5. Mesh Convergence Test

Based on the convergence test results, all models show error values below the 5% threshold, indicating that the simulation results have stabilized. Models M1T1, M1T2, M2T1 and M2T2 use a mesh size of 18 mm with percentage errors of 0.01%, 0.51%, 0.13%, and 1.02%, respectively. Meanwhile, models M1T3 and M2T3 use a mesh size of 19 mm with errors of 0.52%, and 0.71%. This mesh size is then used in each model in the simulation process.

3.2 Software Validation Test

The software validation test was carried out to assess the accuracy of the simulation results produced by Ansys 2020, by comparing them to the results from SolidWorks 2021 as a reference. The purpose of this validation is to ensure that the simulation results from Ansys are reliable and suitable for use in research. The case study used is the connecting bracket component between the main chassis and the front of the vehicle. In the simulation, a static force of 20 kg was applied to the top of the bracket, while restraint (fixed support) was applied to the two main holes as well as the bottom area of the bracket in contact with the damper, in order to represent the actual condition when the component was installed as shown in Figure 6.

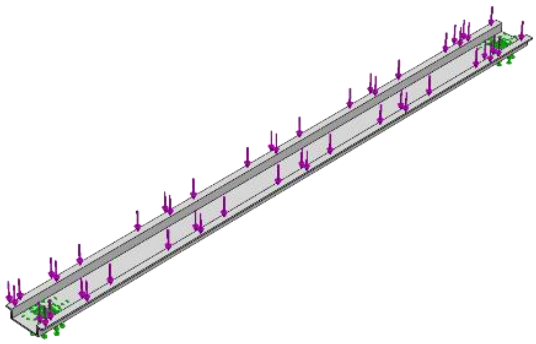


Figure 6. Application of Boundary Conditions on Geometry

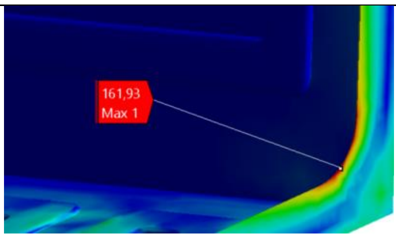
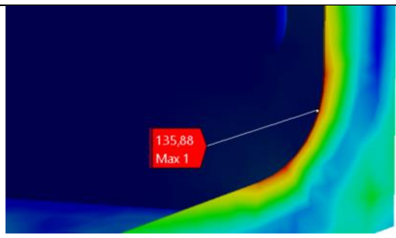
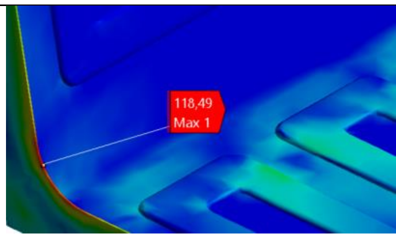
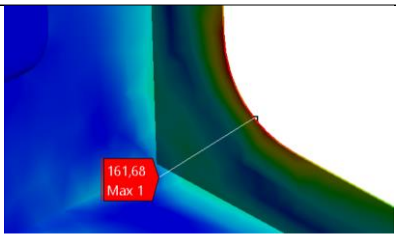
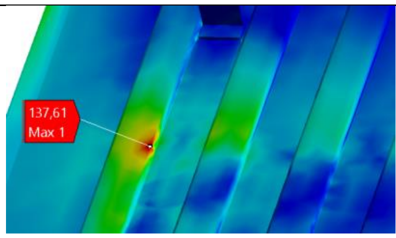
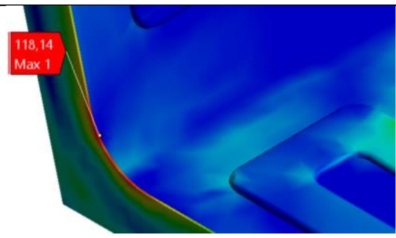
Simulations were performed using the two types of materials used in this study, and the results are summarized in the following Table 3.

Table 3. Software Validation Test Results

Parameter	Software	Result (MPa)	Difference (%)
Von Mises Stress – JIS G3101 SS400	Ansys 2020	14,702	1,24
	Solidworks 2021	14,52	
Von Mises Stress – ASTM A1011 Grade 45	Ansys 2020	14,8	0,54
	Solidworks 2021	14,72	

3.3 Von Mises Stress Result

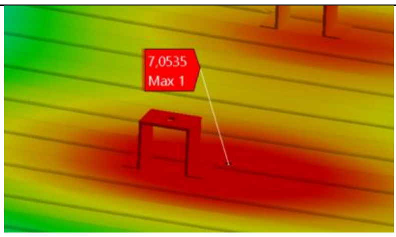
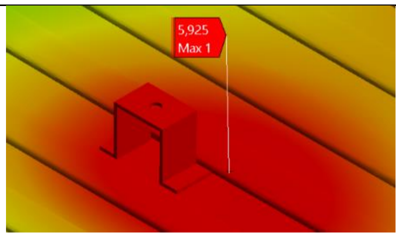
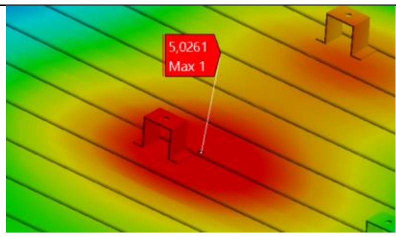
Table 4. Von Mises Stress Result

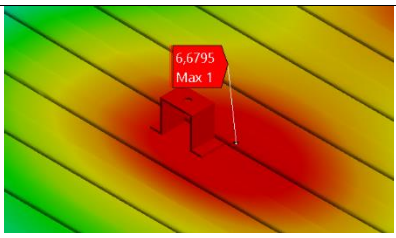
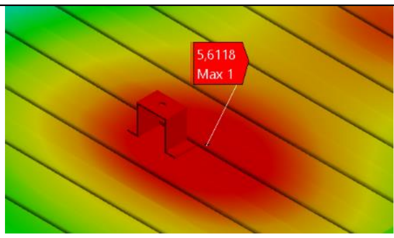
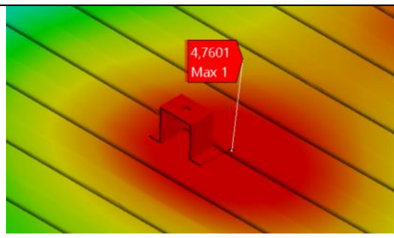
Von Mises Stress Result (MPa)		
Model Code		
M1T1	M1T2	M1T3
		
161,93 MPa	135,88 MPa	118,49 MPa
Model Code		
M2T1	M2T2	M2T3
		
161,68 MPa	137,61 MPa	118,14 MPa

Based on the von Mises stress result data in Table 4, all models show the maximum stress location which is generally located in the front center area of the floor pan. Model M1T1 recorded a maximum value of 161.93 MPa on the right side of the front center section, followed by M1T2 at 135.88 MPa and M1T3 at 118.49 MPa, each also located in the front center area. Then the M2T1 model showed a maximum stress of 161.68 MPa on the right side of the front center section, M2T2 at 137.61 MPa behind the left side front seat bracket, and M2T3 at 118.14 MPa on the left side of the front center section.

3.4 Displacement Result

Table 5. Displacement Result

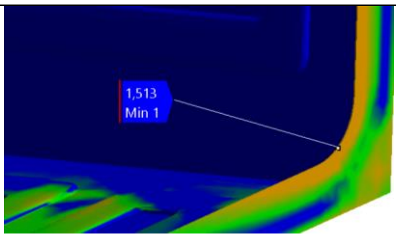
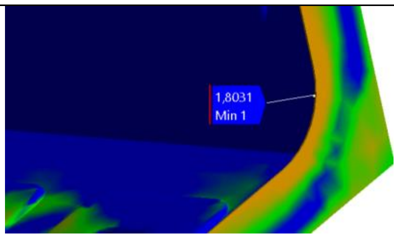
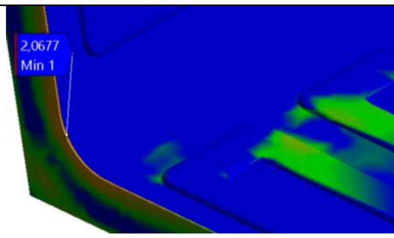
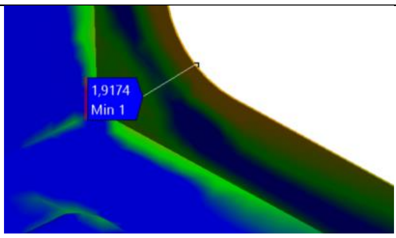
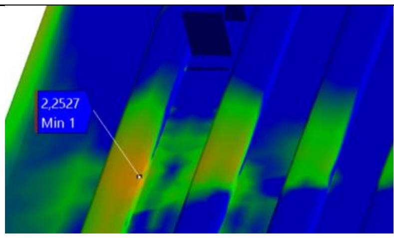
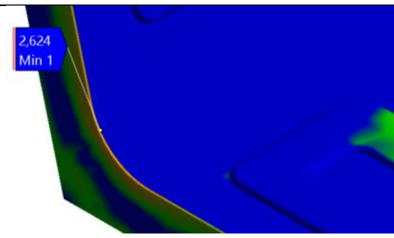
Displacement Result (mm)		
Model Code		
M1T1	M1T2	M1T3
		
7,0535 mm	5,925 mm	5,0261 mm
Model Code		
M2T1	M2T2	M2T3

		
6,6795 mm	5,6118 mm	4,7601 mm

Based on the displacement data in Table 5, all models show the maximum displacement value that occurs in the right front seat bracket area. Model M1T1 recorded the highest displacement of 7.0535 mm, followed by M1T2 of 5.925 mm, and M1T3 of 5.0261 mm. Meanwhile, the M2T1 model showed a maximum displacement of 6.6795 mm, M2T2 of 5.6118 mm, and M2T3 of 4.7061 mm.

3.5 Safety Factor Result

Table 6. Safety Factor Result

Safety Factor Result		
Model Code		
M1T1	M1T2	M1T3
		
1,513	1,8031	2,0677
Model Code		
M2T1	M2T2	M2T3
		
1,9174	2,2527	2,624

Based on the data in Table 6, Model M1T1 has a minimum value of 1.513, M1T2 of 1.8031, and M1T3 of 2.0677. Meanwhile, the M2T1 model has a minimum value of 1.9174, M2T2 of 2.2527, and M2T3 of 2.624. The data shows that the safety factor obtained is ≥1.5, so these results are declared safe and can be continued to the discussion in Table 6.

3.6 Von Mises Stress Value Analysis Result

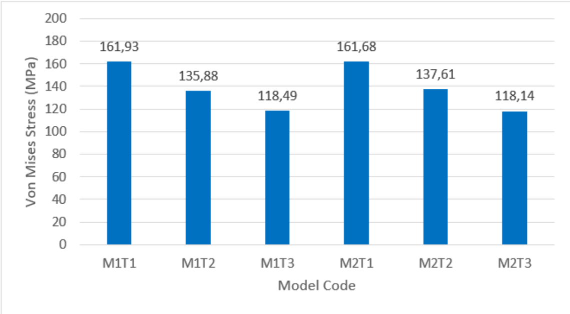


Figure 7. Von Mises Stress Value Graph

Based on Figure 7, the highest von Mises stress value was recorded in the M1T1 model at 161.93 MPa, and decreased gradually in M1T2 (135.88 MPa) and M1T3 (118.49 MPa). A similar pattern is also seen in the M2 model, where M2T1 reaches 161.68 MPa, and then decreases in M2T2 (137.61 MPa) and M2T3 (118.14 MPa). The average decrease in von Mises stress due to the increase in thickness reached 14.48%, while the difference in material types with the same thickness only resulted in an average difference of 0.27%. These results indicate that increasing the material thickness significantly lowers the maximum stress, as the structure becomes more rigid and is able to distribute the load more evenly, thereby reducing stress concentration at critical areas.

3.7 Displacement Value Analysis Result

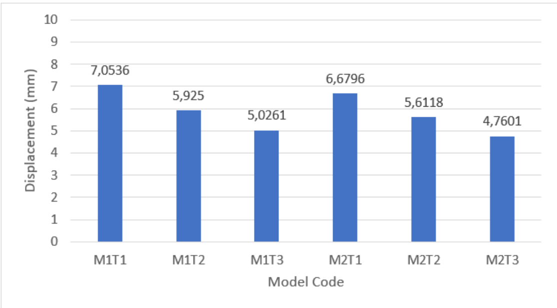


Figure 8. Displacement Value Graph

Figure 8 shows that the highest displacement occurs in the M1T1 model at 7.0536 mm, which then decreases in M1T2 (5.925 mm) and M1T3 (5.0261 mm). A similar pattern is also seen in the M2 model, with M2T1 amounting to 6.6796 mm, then decreasing in M2T2 (5.6118 mm) and M2T3 (4.7601 mm). The average decrease in displacement due to the increase in thickness reaches 15.58%, while the difference in material types with the same thickness gives an average difference of 5.29%. This shows that greater material thickness results in lower displacement, reflecting better structural strength under load.

3.8 Safety Factor Value Analysis Result

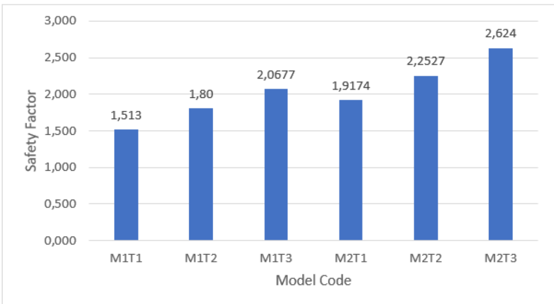


Figure 9. Safety Factor Value Result

Figure 9 shows that the lowest safety factor is found in the M1T1 model at 1.513, then increases in M1T2 (1.80) and M1T3 (2.0677). The M2T1 model has a value of 1.9174, which also increases in M2T2 (2.2527) and M2T3 (2.624). The average increase in safety factor due to the increase in thickness reached 16.95%, while the difference in material types with the same thickness showed an average difference of 26.20%. All models have met the minimum safety factor limit of 1.5, indicating that the floor pan structure is within safe limits.

3.9 Floor Pan Mass Value Analysis Result

After the strength analysis was conducted, the next step was to analyze the floor pan mass of each material and thickness variation. The aim is to evaluate the effect of both variables on the total mass, as mass affects the energy efficiency, acceleration and power consumption of the vehicle. This data is used as a consideration in determining the most optimal floor pan design in terms of strength and weight.

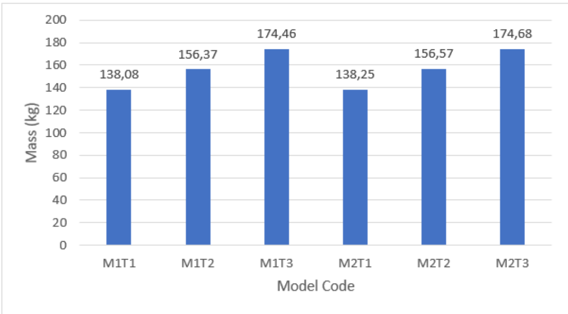


Figure 10. Floor Pan Mass Value Result

Based on Figure 10, the mass of the floor pan increases linearly as the material thickness increases. Model M1T1 has a mass of 138.08 kg, increasing in M1T2 to 156.37 kg, and M1T3 to 174.46 kg. The same thing happened with the M2 model, namely 138.25 kg (M2T1), 156.57 kg (M2T2), and 174.68 kg (M2T3). The average increase in mass due to the increase in thickness reached 12.4%, while the difference due to different materials with the same thickness was only 0.13%. This shows that increasing the material thickness has a significant effect on increasing the mass of the floor pan.

4 Conclusion

Based on the analysis, increasing the thickness of the material is proven to reduce the von Mises stress (14.48% on average) and displacement (15.58% on average), and increase the safety factor (16.95% on average). Different material types with the same thickness resulted in small differences in von Mises stress (0.27%), displacement (5.29%), and safety factor (26.20%). The mass of the floor pan increased linearly with thickness, with an average increase of 12.4%. Model M2T1 was selected as the best design because it showed an optimal balance between structural strength (von Mises 161.68 MPa), deformation (6.6796 mm), safety factor (1.9174), and mass efficiency (138.25 kg), which met the standard safe limit for application in a medium MPV class battery electric vehicle.

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