STRUCTURAL ASSESSMENT OF ALTERNATIVE URBAN VEHICLE CHASSIS SUBJECTED TO LOADING AND INTERNAL PARAMETERS USING FINITE ELEMENT ANALYSIS

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Abstract

Chassis is one of the most important parts of a vehicle, which is the primary supporting structure of a vehicle where other parts are attached to. Pioneer research indicates that chassis tends to receive excessive loads, and possibly causes undesirable behavior such as cracks or major failure. Several other studies have also shown interest on the influence of certain materials on chassis behavior when receiving load, however not specifically discussed. Based on these studies, it can be concluded that further research on chassis needs to be performed to produce research data for future consideration in assessment and development of the chassis design of a vehicle. Several subjects which can be research opportunity in terms of vehicle chassis are the effect of variations in the thickness of the developed chassis, the influence of different materials, and the effect of the value of the force applied on the strength. This paper aims to assess behavior tendency of the alternative urban vehicle chassis by Bengawan Team under certain operational factor which is external load, and internal factors i.e. material and dimensions. Assessment of these parameters will be performed on the alternative urban vehicle chassis which is a designed vehicle by college students of Universitas Sebelas Maret to participate in a national energy-efficient car contest held by the Ministry of Research, Technology and Higher Education, Republic of Indonesia. Modeling and numerical analysis is conducted using finite element approach by Autodesk Fusion 360 software. The acquired results of this study indicate reduction trends occur in strength as the thickness of the material decreases. In terms of loads, changes in load distribution is spotted in several cases due to differences in the value of the load, and based on the material, the difference in material strength causes variation of force distribution to the front and rear directions of the chassis.

Keywords: Finite element analysis, Material thickness, Material types, Urban vehicle chassis, Working load.

1. Introduction

In the current era, society demands for vehicles, including as private and mass transportation. Illustration of the vital role of the transportation can be assumed large scale work of 1 ton of coal or nickel distribution from one continent to another. Unavailability of ship as water transportation and truck as land transportation will make the distribution is hampered. In 2018, there are at least 380 million commercial vehicles and approximately 1.2 million passenger cars in the world shown in Fig. 1 [1]. This number is expected to increase rapidly until the beginning of the new decade, which it can be concluded that it is very difficult to conceive this world without vehicles, especially cars that are very commonly used across the globe.
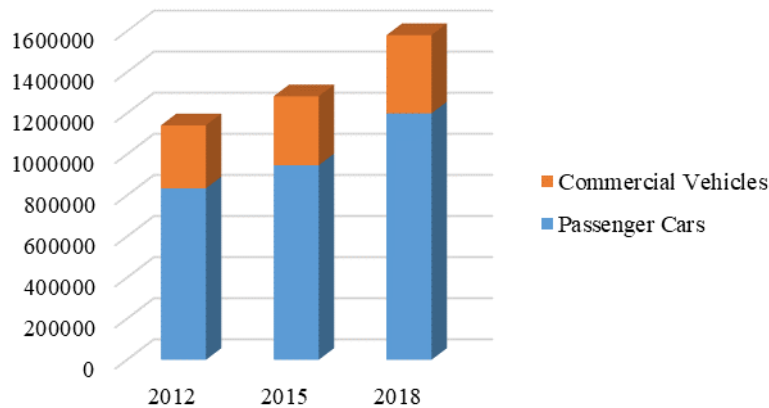

Fig. 1. Numbers of passenger cars and
commercial vehicles in use across the globe [1].

The first car widely known made in 1769 by Nicolaus-Joseph Cugnot and the car chassis itself was firstly discovered by Charles and Frank Duryea. A vehicle, such as car has at least 3 main parts, i.e. chassis, body and engine. The body is the outermost part of a vehicle and the engine is the driving part of the vehicle, while the chassis is an internal frame that guides the production of a vehicle, as well as supporting other parts such as body, engine, passenger, and other vehicle components [2]. Until now, there are 4 types of chassis that are often used in the car industries, such as *monocoque*, space frame, chassis backbone, and ladder frame. *Monocoque* is a type of chassis which body part and chassis structure are fused [3]. Ladder frames are one type of chassis which is given such a name because of the shape that resembles a ladder. This type of chassis is the oldest among all types of chassis and is generally used in heavy vehicles such as truck which has significant issues to overcome the increasing demands for higher performance, lower weight in order to satisfy fuel economy requirements. Materials that are usually used to make this chassis are shaped blocks which are then joined together with rivet or weld connections [4]. In another study of vehicle design, there are challenges for chassis which needs to be conquered by those who demand to develop car vehicles. It is to distribute stresses all over the vehicle to avoid high levels of stress on a single point of a vehicle. It was found that the vehicle chassis was required to have sufficient mechanical performance and low weight [3].Overall

the studies that we take into consideration can be found on Table 1. Adequate mechanical performance is set as target so that the vehicle chassis does not experience plastic deformation when receiving loads, whether it is the loading of the driver, engine, body, or other parts. If the vehicle chassis deform or bent will cause a poor handling / uneven handling due to improper alignment geometry and other mechanical issues e.g. driveline components can wear excessively and spacing in body parts is all wrong/uneven. The idea behind the concept of the lighter chassis of the vehicle is that the lower weight in the same power needed to move it, then the vehicle can automatically save more fuels [5, 6].

This paper is addressed to analyse the behaviour of the chassis when a variety of applied loads is located on the chassis by considering variation of material thickness and the material type. By applying selected variations, the alternative urban vehicle designed by students of Universitas Sebelas Maret will be analysed by finite element approach to obtain performance data which is projected to be a guide or consideration in developing the chassis in the future.

Table 1. Pioneer works related to chassis and structural analysis.

Scholars	Subjects	Findings
Airale et al. [3]	Carbon fiber monocoque for a hydrogen prototype for low consumption challenge	The vehicle chassis was required to have sufficient mechanical performance and low weight.
Patil [4]	Stress analysis of automotive chassis with various thicknesses	Materials that are usually used to make this chassis are shaped blocks which are then joined together with rivet or weld connections.
Wang et al. [5]	Strength, stiffness, and panel peeling strength of carbon fiber-reinforced composite sandwich structures with aluminum honeycomb cores for vehicle body	Famous car brands no longer uses high strength steel material as its constituent material on their chassis.
Kaluza et al. [6]	Analyzing decision-making in automotive design towards life cycle engineering for hybrid lightweight components	The idea behind the concept of the lighter chassis of the vehicle is that the lower weight in the same power needed to move it, then the vehicle can automatically save more fuels.
Guron [7]	Finite element analysis of cross member bracket of truck chassis	The ladder frame, which rectangular hollow profiles are welded to form chassis is selected as the chassis type

		considering its simplicity, lightweight, and ease of construction.
Ghalazy [8]	Applications of finite element stress analysis of heavy truck chassis: survey and recent development	The result of truck ladder chassis analysis is maximum stress and strain levels are found in the section of chassis where engine and transmission are mounted.
Mat et al. [12]	Design and analysis of 'eco' car chassis	Although the goal of the vehicle competition discussed before is fuel efficiency, the chassis must still be stiff enough for good handling and has sufficient strength to support all working/ applied loads.
Hidayat et al. [20]	Shell eco marathon urban concept type chassis chassis	The data from Autodesk Inventor simulation and manual calculation of Shell Eco-Marathon (SEM) urban concept chassis static analysis.
Zahid [27]	Implementing monte carlo simulation model for revenue forecasting under the impact of risk and uncertainity	The risk analysis, management, Monte Carlo simulation model, and crystal ball package software.
Zahid et al. [28]	Establishing a simulation model for optimizing the efficiency of the CNC machine using a reliability-centered maintenance approach	The simulation model, CNC machine, reliability-centered maintenance (RCM), failure mode and effect analysis (FMEA).

2. Development of Chassis Technology

As we know that finite element analysis (FEA) produce comprehensive result data and it could generate the physical response of the system at any location which is very useful in engineering especially in vehicle and structural assessment. Related to vehicle and structural assessment, pioneer works have been performed by the respective parties. Monika et al. made a research about optimization of truck TATA 1612 chassis with constraints of shear stress, equivalent stress, and deflection to reduce the weight of the vehicle using CATIA v5 for the modeling and ANSYS Workbench12 for the finite element analysis. ANSYS used because it provides detail data and easy to operate. It was found that the weight of the vehicle reduced by 8.72% by changing the dimension of the cross-member of chassis [7].

Related to vehicle and structural assessment, pioneer works have been performed by the respective parties. Mahmoodi et al. [8] conducts the stress and dynamic analysis of truck ladder chassis. The main purpose is to design a lightweight chassis by selecting the material type and cross section profiles based on maximum normal stress that obtained through ABAQUS software. ABAQUS is a software application which can be used for modeling and analyzing mechanical components, pre-processing, and visualizing finite element analysis result. The result is maximum stress and strain levels are found in the section of chassis where engine and transmission are mounted. Deore et al. perform a research regarding different thicknesses for cross members and side members of truck. Result of the research indicates implementation of different thickness on cross member at critical stress point is preferred than changing the thickness of side member and position of chassis for reduction in stress and deflection levels [9].

Karaoglu et al. analyze the stress of heavy duty truck chassis with riveted joints using ANSYS. Researchers vary the side member thickness and connection plate thickness with length change to observe the effect of it. The conclusion indicates that choosing an optimum plate length is the best solution for decreasing the stress values than changing the side member thickness using local plates [4]. Neeraja et al. investigate various materials to confirm the best material for two wheeler chassis frame using ANSYS. Conclusions indicate that according to static and modal analyses, carbon epoxy material was the best material compared to other materials [10]. Up to this day, the vehicle chassis still continues to experience developments which cannot be separated from the mentioned studies as a guide. Coming from a famous car brand such as Audi, which in the Audi A8 series no longer uses high strength steel material on the general chassis. This Audi series became the first car with aluminum chassis which is successfully mass produced. Even Lamborghini in the Murcielago series no longer applies metal material as its constituent material, but it uses carbon fiber [5].

Compared to previous works, this paper analyzes some parameters of the alternative urban vehicle chassis based on the material type, thickness of material, and load given. As a geometrical model, an alternative chassis which is inspired by vehicles used at the Indonesian energy-efficient car contest to be numerically modelled, and then finite element analysis is conducted to acquire estimation of structural performance under selected parameters.

3. Design and Simulation
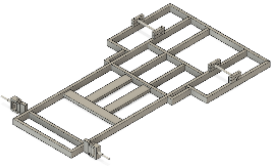
3.1. Geometrical design and modelling

An alternative urban vehicle is a type of vehicle which is designed and constructed by college students to participate in KMHE (energy-efficient car contest). It is a national energy-efficient car contest held by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia annually where the winner is the one that can travel the longest distance with the least amount of fuel consumption. This contest aims to find innovative ideas to create vehicles that the world needs, the energy-efficient vehicles.

There are 2 categories in this competition, it is prototype and urban concept. The urban concept category is a fuel-efficient vehicle that looks like a passenger car today. Urban concept vehicle must meet special regulations set by KMHE committee. The overall height of it should be between 100-130 cm, the width

between 120-130 cm, total length between 220 and 350 cm, track width at least 100 cm for the front wheel and 80 for the rear wheel, and the wheelbase at least 120 cm. All regulations are stated in KMHE technical regulation 2019 [11]. These regulations are the guidance to design the chassis used in this research.

The chassis design of the participating vehicle in the competition was chosen since the prospect is very promising, which it has high potential in terms of concept implementation on the widely used urban vehicles. Therefore, it is quite relevant to take this chassis as a research subject which the data results are projected to be used as the consideration of future vehicle chassis production. Although the goal of the vehicle competition discussed before is fuel efficiency, the chassis must still be stiff enough for good handling and has sufficient strength to support all working/applied loads [12]. The chassis must be able to accommodate its engine and driver. The state regulation that the driver should have minimum weight of 70 kg [11], and the engine is assumed approximately 15 kg. The ladder frame, which rectangular hollow profiles are welded to form this chassis geometry, is selected as the chassis type considering its simplicity, lightweight, and ease of construction [7].

**Table 2. Chassis design scenario.**

Design	Material	Thickness
	Carbon Steel	0.4 mm
	Aluminum 6061	0.9 mm
	CFRP	1.4 mm

In the current research, alternative urban vehicle chassis by Bengawan Team is investigated by composing a series of technical scenario. The first part is designed to involve three material types, i.e., carbon steel, aluminum 6061, and carbon fiber reinforced plastic. The second part considers the material thickness which is applied to the chassis with values 1.4 mm, 0.9 mm, and 0.4 mm. The current chassis used by the team has 1.2mm thickness, so the 1.4 mm and 0.9 mm thicknesses are chosen as a comparison to the current chassis while the 0.4 mm was chosen as a reference to find the minimum thickness can be reached. The third part is the applied loads which assume engine and driver as the main contributors. Variation of the 3-load design is considered, such as engine only, driver only, and both engine and driver. The designed research scenario is summarized in Table 2, the details of the design (meshing, structural constraint, and force applied) showed in Fig. 2, and the research flow presented in Fig. 3. Investigation is performed to obtain the safety factor, stress, displacement, and strain. Autodesk Fusion 360 is selected as an instrument for modeling and simulation in this work which technical methodology is presented as follows:

- The thickness of the model is adjusted then the material type is applied.
- Static analysis is performed on chassis assembly with load variation to estimate physical influence of the parameter mentioned to the chassis.

Table 2. Specification modification, where:
NW (Net weight), P (Payload), and TW (Total weight).

	Low Carbon Steel (N)	Al 6061 (N)	CFRP (N)
0.4 mm	NW: 149.7	NW: 51.5	NW: 27.3
	P: 599.25	P: 482.4	P: 549.9
	TW: 748.95	TW: 533.9	TW: 577.2
0.9 mm	NW: 217.7	NW: 74.9	NW: 39.7
	P: 5066	P: 3824.15	P: 5391.95
	TW: 5283.7	TW: 3899.05	TW: 5431.3
1.4 mm	NW: 282.3	NW: 97.1	NW: 51.4
	P: 11211.5	P: 8950.5	P: 10234
	TW: 11493.8	TW: 9047.6	TW: 10285.4
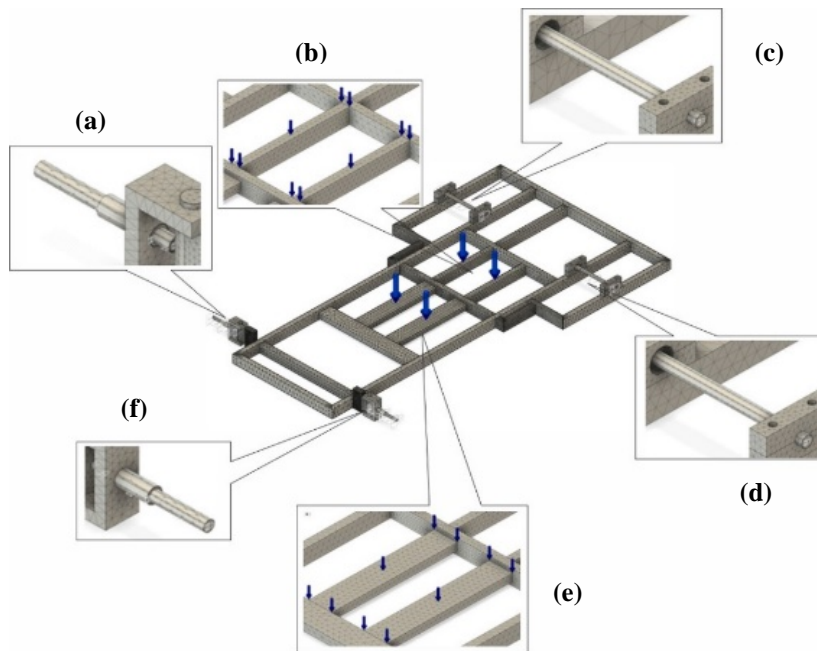
Fig. 2. Alternative urban vehicle chassis meshing, where:
(a), (c), (d), (f) are the structural constraint; (b) is the force applied
on z axis (-150 N); (e) is the force applied on z axis (-700 N).

The vehicle chassis is designed with rectangular hollow sections. The section has a 1 x 2 in of dimension with thickness variation. After designing, the mesh generated with the mesh criteria shown in Table 2 to the chassis then applied 3 different loading conditions, i.e. static load (dead load) of engine (15 kg), driver (70 kg as stated in regulation for minimum driver weight), and combination both of it (engine and driver). As for the dead load analysis, the loads are specified at specific points on the chassis. Value of the assumed loads are 150 N, 700 N and 850 N with assumption 1 N equals with 0.1 kg. In the simulation, the front and rear wheel shaft of the chassis is the supported constraints of the frame. Varied material properties were assigned to the model.
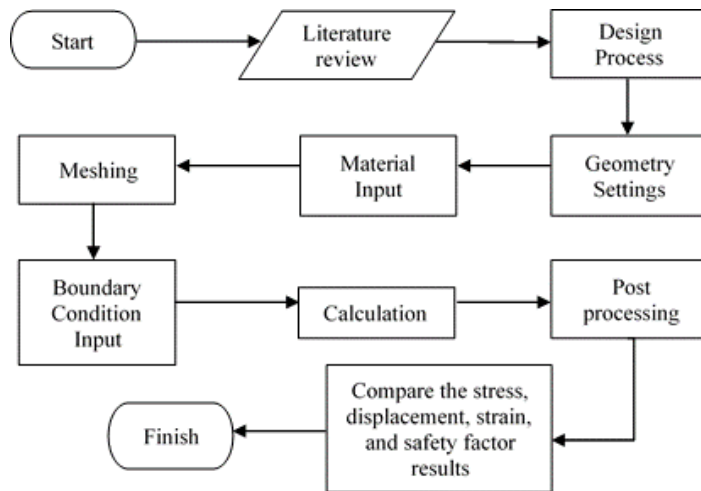
Fig. 2. Research flow of the current study.

It is the carbon steel that usually used for heavyweight truck chassis, aluminum 6061 which widely used in KMHE, and CFRP that used by only a few team abroad on a similar contest as a new innovation to replace the aluminum. The meshing criteria are shown in Table 4 and the material properties are given in Table 5.

Table 3. Mesh criteria applied on the model.

Avg. Element Size (% of model size)	10
Scale Mesh Size Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	No
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

Table 4. Material properties for the chassis model.

Parameter	Low Carbon Steel	Al 6061	CFRP
Shear modulus (MPa)	79700	25864	53000
Young's Modulus (GPa)	200	68.9	133
Poisson's ratio (-)	0.29	0.33	0.39
Density (g/cm³)	7.85	2.7	1.43
Yield strength (MPa)	350	275	300
Tensile strength (MPa)	420	310	577

This simulation is completed to obtain the safety factor, stress, displacement, and strain data as the results. Safety factor or *factor of safety* in engineering is defined as the ratio of a structure's absolute strength (structural capability) to actual applied load. This is a measure of the reliability of design manufacture [13]. Stress is obtained by dividing the magnitude P of the load by the cross-sectional area A [14]. Strain ϵ is defined as the ratio of deformation to length [15]. The displacement is the difference between the initial and final position of a point on a structure [16]. The governing

equation for the static analysis shown in Eq. (1) and the mentioned parameters are presented in mathematical expression as displayed in Eqs. (2) to (4) [17-20].

$$\{F\} = [K] \{U\} \tag{1}$$

$$FoS = \frac{\sigma_y}{\sigma_w} \tag{2}$$

$$\sigma = \frac{P}{A}, \ \tau = \frac{F}{A'}, \tag{3}$$

$$\epsilon = \frac{\delta}{L} \tag{4}$$

where: *{F}* is "known" loads; *[K]* is "known" (geometry, material properties,…elements), *{U}* is to be determined (displacements); *FoS* is the factor of safety; σ_y is the yield stress; σ_w is the working stress; σ is the normal stress; *P* is the force; *A* is the surface area which is perpendicular to the force; τ is the shear stress; *F* is the force; A' is the surface area which is parallel to the force; ϵ is the strain; δ is the deformation; *L* is the length.

3.2 Benchmarking on the chassis analysis

This research uses Shell Eco-Marathon (SEM) urban concept chassis static analysis as the benchmark. It provides data from Autodesk Inventor simulation and manual calculation. Autodesk Inventor is a program specifically designed for engineering purposes such as product design, machine design, mold design, construction design, or other engineering purposes. Autodesk Inventor is a parametric feature-based solid modeling program, meaning that all objects and geometric relationships can be modified again even though the geometry is ready, without the need to start over. The design of the SEM urban concept chassis used aluminum 6061 hollow with total dimension of 2060 x 600 mm. The chassis consists of 7 support beam (25 x 25 mm) and 2 aluminum (40 x 40 mm) main beam. There are three loads (driver leg, driver body, and machine) applied on the chassis on each part of the support beam. The driver leg is loaded 98.1 N from the mass of driver's leg approximately and supported by a single support beam. The driver body supported by 2 supports beams is loaded by 294.3 N from the body mass approximately. Machine support beam is loaded by 196.2 N from machine mass and also supported by 2 support beams [20]. The geometry of SEM urban concept chassis and the load distribution on it shown in Fig. 4. Ratio of manual calculation, simulation of Autodesk Inventor and simulation of Autodesk Fusion 360 are explained in Tables 6 to 8.
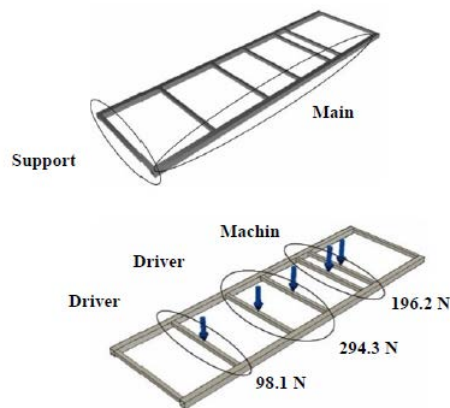

Fig. 3. SEM chassis and load distribution.

Table 5. Benchmark result of the variation I.

Parameter	Manual [20]	Autodesk Inventor [20]	Autodesk Fusion 360 (current)	R_1 (%)	R_2 (%)
1st Principle Maximum Stress (MPa)	8.48	7.80	6.97	82.19	89.36
Displacement (mm)	0.150	0.080	0.075	50	93.750
Safety Factor	-	15	15	-	100

Table 6. Benchmark result of the variation II.

Parameter	Manual [20]	Autodesk Inventor [20]	Autodesk Fusion 360 (current)	R_1 (%)	R_2 (%)
1st Principle Maximum Stress (MPa)	12.7	11.71	8.86	69.76	75.66
Displacement (mm)	0.220	0.120	0.095	43.182	79.167
Safety Factor	-	15	15	-	100

Table 7. Benchmark result of the variation III.

Parameter	Manual [20]	Autodesk Inventor [20]	Autodesk Fusion 360 (current)	R_1 (%)	R_2 (%)
1st Principle Maximum Stress (MPa)	4.25	3.90	3.49	82.12	89.49
Displacement (mm)	0.070	0.040	0.037	52.857	92.5
Safety Factor	-	15	15	-	100

where: R_1 is ratio between manual calculation and Autodesk Fusion 360 and R_2 is ratio between Autodesk Inventor and Autodesk Fusion 360.

4. Results and Discussion

Alternative urban vehicle chassis designed by Bengawan Team - Universitas Sebelas Maret to participate in KMHE was modelled and simulated using finite element method (which is also suitable methodology for simulation of lightweight and solid structures subjected to various phenomena [21-26]) different materials, different loads, and different thicknesses to produce reference data to develop car chassis. The obtained results are physical behavior of the chassis after the defined parameters are applied, i.e. the value of minimum safety factor, maximum stress, maximum displacement, and maximum strain as presented in Figs. 5 to 8. Based on the overall data, carbon steel's chassis is concluded as the strongest among of all proposed materials with consideration to safety factor values in the thinnest material. This tendency is also supported by occurred stress and strain, which indicates that the structure is capable to withstand higher stress level but the chassis

experienced lower strain value. The global data in this table is discussed further in in coming subsection for each applied parameter specifically.
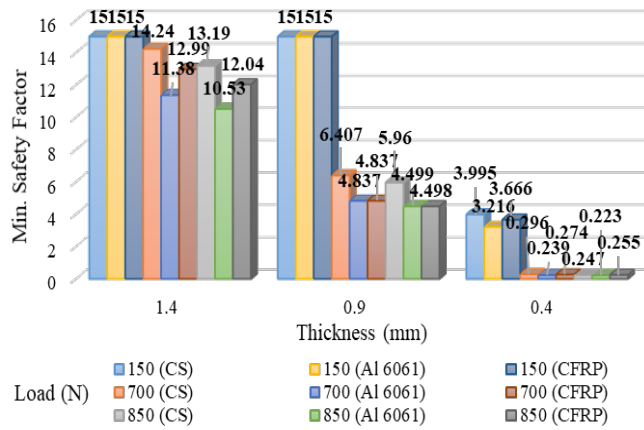

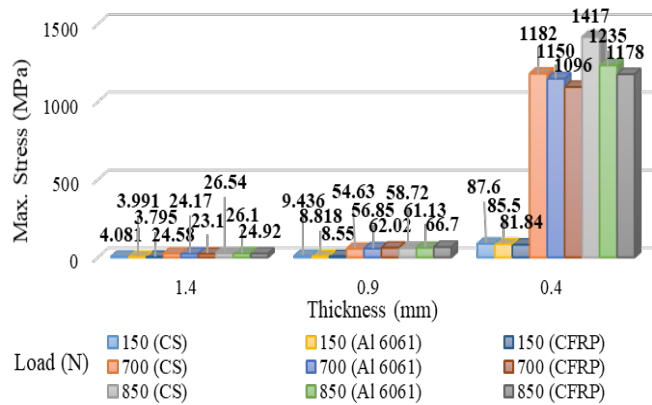**Fig. 4. Minimum safety factor simulation result.**
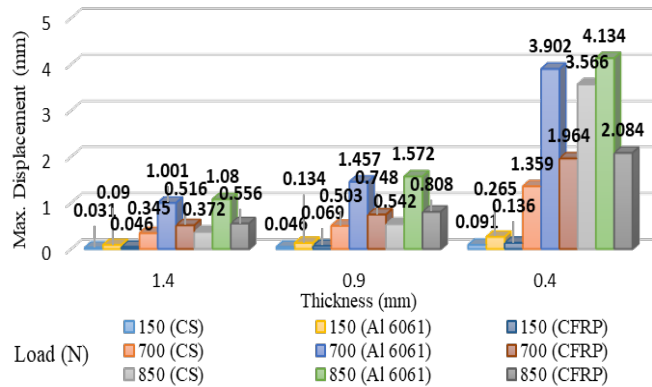

Fig. 5. Maximum stress simulation result.

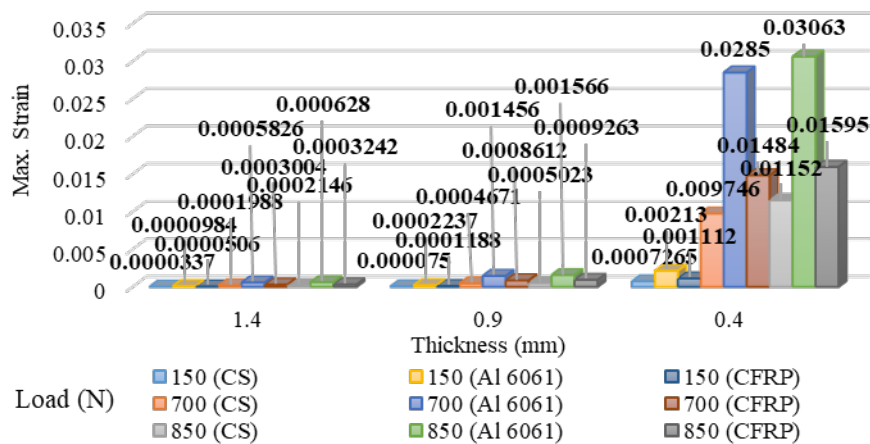

Fig. 6. Maximum displacement simulation result.

Fig. 7. Maximum strain simulation result.

4.1. Effect of material

Effects of different materials on the chassis are shown in the Tables 4 to 7 which indicated that with the same load applied on the chassis with the value of 850 N and the same material thickness 1.4 mm, the highest maximum stress is 26.540 MPa (carbon steel), and the lowest value is 24.920 MPa (CFRP). In terms of the maximum strain, the lowest is 0.0002146 (carbon steel) and the highest is 0.0006280 (aluminum 6061). Result data of the geometrical displacement, the lowest value is 0.372 mm (carbon steel) and the highest is 1.080 mm (aluminum 6061). The minimum safety factor under same the condition (load 850 N and thickness 1.4 mm) obtains the highest value is 13.190 (carbon steel) and the lowest is 10.530 (aluminum 6061).

Figure 9 indicates that based on the effect of material during load 850 N and thickness 1.4 mm are applied, the stress is approximately 10 MPa surrounding location of the applied load for the carbon steel material, and on the same location, it is only 7.5 MPa for the CFRP material. Stress gets distributed all over the chassis and reaches their maximum on region of the front and back structural constraints. Based on the von Mises stress concept that used in this analysis, the stress value indicates the ability of the structure to hold the applied load, and in this case, the maximum stress are still below their own yield strength so it can be concluded that these two materials will not fail in this simulation configuration.

On the same discussed case, simulation result shows that the most appearance of strain value in carbon steel material is 0.000075, and 0.0001125 in CFRP material. Both of strain are mostly located around the location of the load applied. These maximum strain value and its location shown in Fig. 10. Based on strain equation expressed in the Section 3, these strain values show that on the same length, the aluminum 6061 material will experience more deformation compared to carbon steel material.
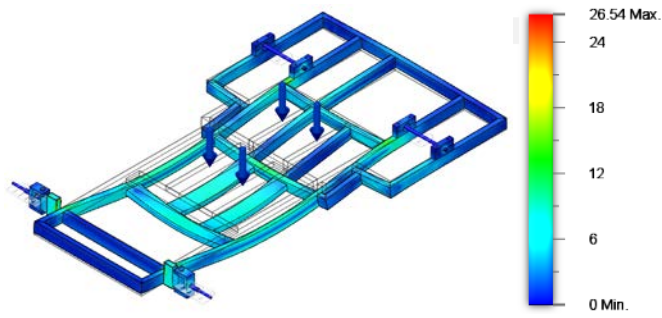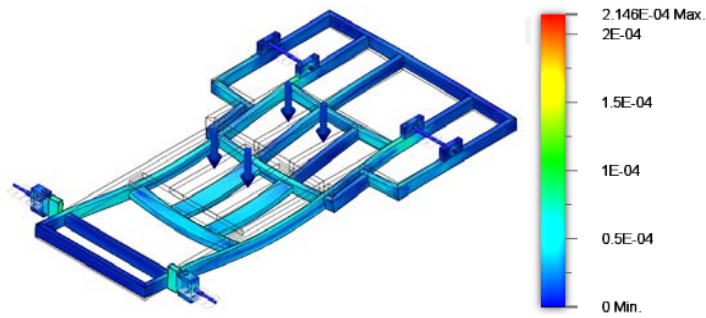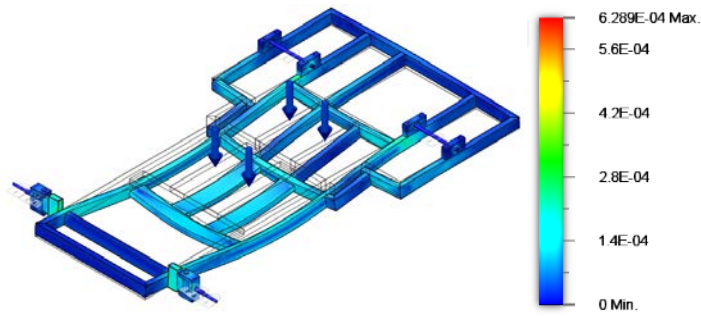
(a) Low carbon steel.
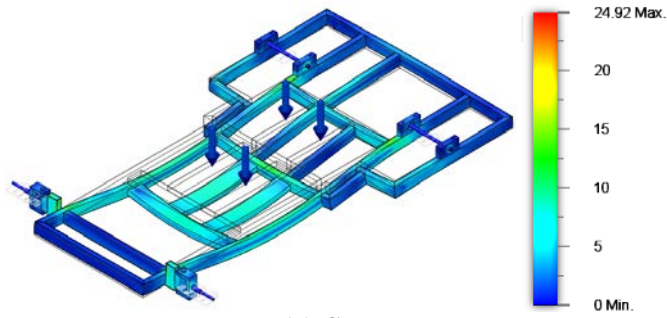
(b) CFRP.

Fig. 8. Maximum stress simulation result (Load 850 N, thickness 1.4 mm).

(a) Low carbon steel.

(b) Al 6061.

Fig. 9. Maximum strain simulation result (Load 850 N, thickness 1.4 mm).

Based on the effect of material, in the simulation case of 850 N on load and 1.4 mm, the thickness with material type is varied, and the highest and lowest of maximum displacement of the Al 6061 and carbon steel are discussed. Results of these materials show that the maximum displacement value occurs on the location of the driver (assumed to be 750 N) but in different value. The carbon steel material only has 0.372 mm of displacement while the Al 6061 material displays 1.080 mm displacement. This tendency indicates that when the load applied, the structure with material Al 6061 on the red area shown in Fig. 11 will move approximately 1 mm from its initial position, and the structure with the applied material carbon steel only moves about 0.4 mm.
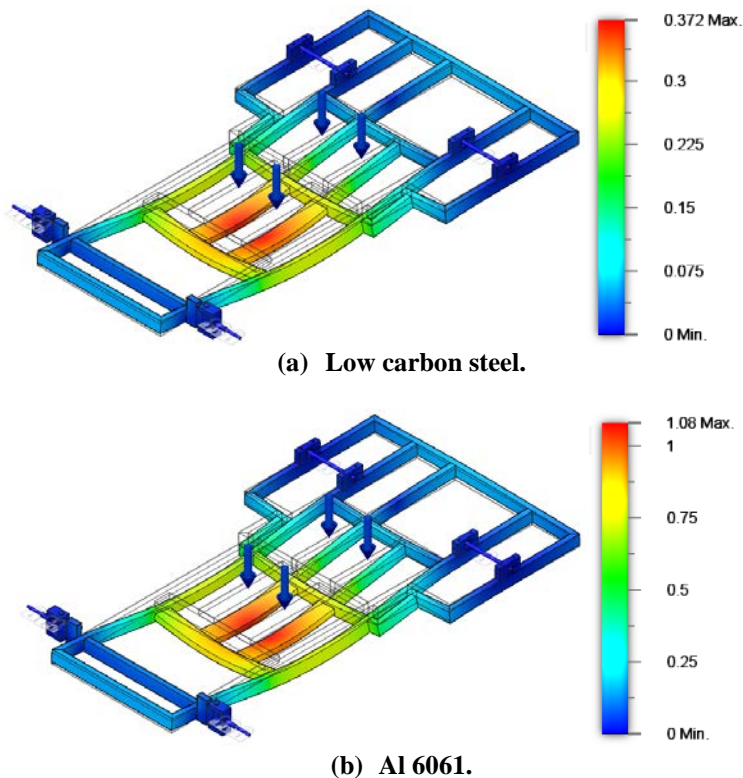
(a) Low carbon steel.

(b) Al 6061.

Fig. 10. Maximum displacement result (Load 850 N, thickness 1.4 mm).

Figure 12 shows that on the same simulation case previously discussed, structure with both carbon steel and Al 6061 material have a uniform color all over it. It means that the safety factor of both structures are higher than 6. The other differences between these two results are the minimum value of safety factor, which the carbon steel shows 13.190, and the Al 6061 is only 10.530. Since in this case the working stress is same, these values of safety factor indicates that material carbon steel has higher yield strength and better against working load on the structure than the Al 6061.

Based on the result summary in Fig. 13, higher safety factor of certain applied material to the chassis influences displacement of the chassis part followed by the lowest level of maximum strain. The overall behaviors are linear, such as in the

case of CFRP which has quite high safety factor, the maximum strain is also relatively high among all selected material. This phenomenon occurs as the material properties of CFRP has higher tensile strength compared to the aluminum, which in other hand this material is inferior in terms of yield strength compared to carbon steel.
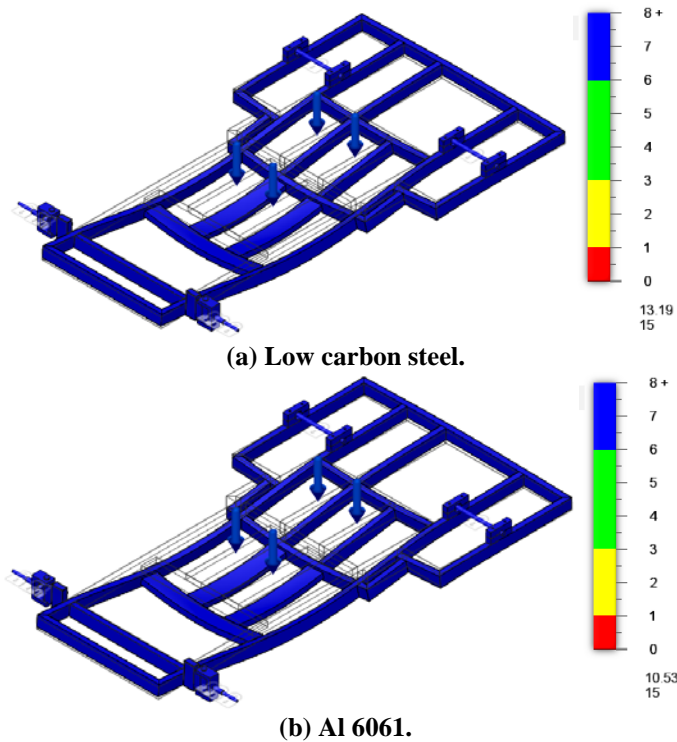

(a) Low carbon steel.

(b) Al 6061.

Fig. 11. Minimum safety factor result (Load 850 N, thickness 1.4 mm).
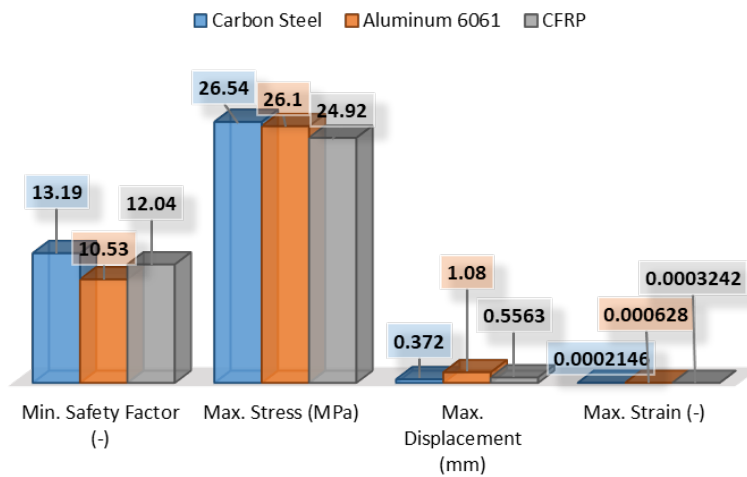
Fig. 12. Effect of material.

4.2. Effect of thickness

Application of different material thicknesses on the chassis shows that for the same type of material (in this case is CFRP) and the same load (700 N), the maximum stress value of the thickness 1.4 mm is 23.100 MPa, and the thickness 0.4 mm produces the highest value 1096 MPa. For the maximum displacement value, the highest value occurs in thickness 0.4 with value 1.964 mm, while the thickness 1.4 results the lowest value 0.516 mm. The highest maximum strain value in this case is 0.0148400 and the lowest is 0.0003004. The lowest minimum safety factor value is obtained 0.274 for thickness 0.4 mm, and the highest is 12.990 for thickness 1.4 mm.

Tendency of maximum stress is displayed in Fig. 14, which indicated that capacity to withstand stress level for thickness 0.4 mm is very small and the structure would fail because this stress level surpasses the CFRP tensile strength. On the other hand, the structure with 1.4 mm thickness is quite strong to maintain the structure in its elastic area considering that the maximum stress 23.100 MPa is far below the CFRP's yield stress.
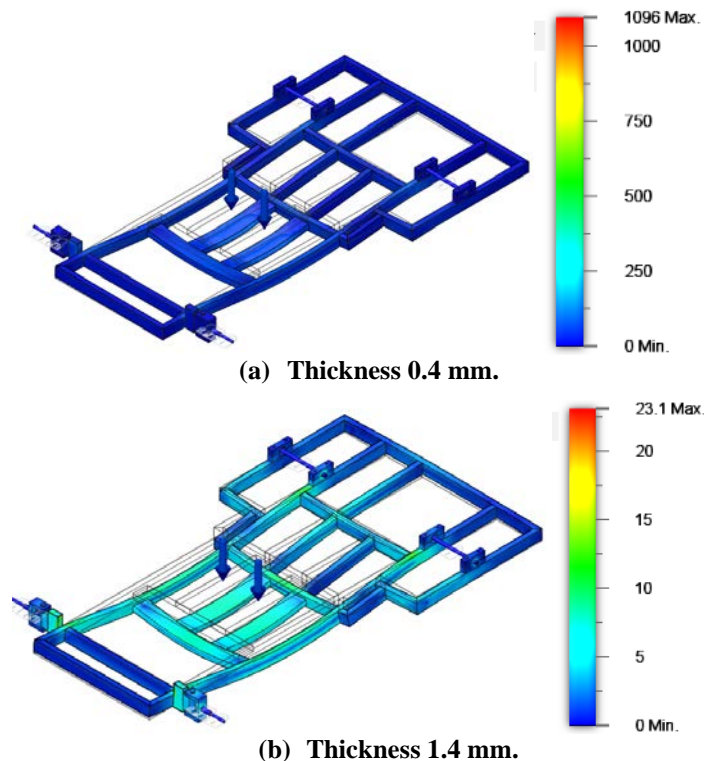

(a) **Thickness 0.4 mm.**

(b) **Thickness 1.4 mm.**

Fig. 13. Maximum stress simulation result (Material CFRP, load 700 N).

On the same simulation case which the CFRP is the applied material type and 700 N is given, while the material thickness of the chassis is varied. Fig. 15 shows that the maximum displacement value for both the thicknesses 0.4 mm and 1.4 mm occurs at the same location where the applied force. The displacement on the structure with 0.4mm thickness is almost two times of the 1.4 mm thickness. This phenomenon indicates that the displacement value of the observed chassis decreases as the structural thickness increases.
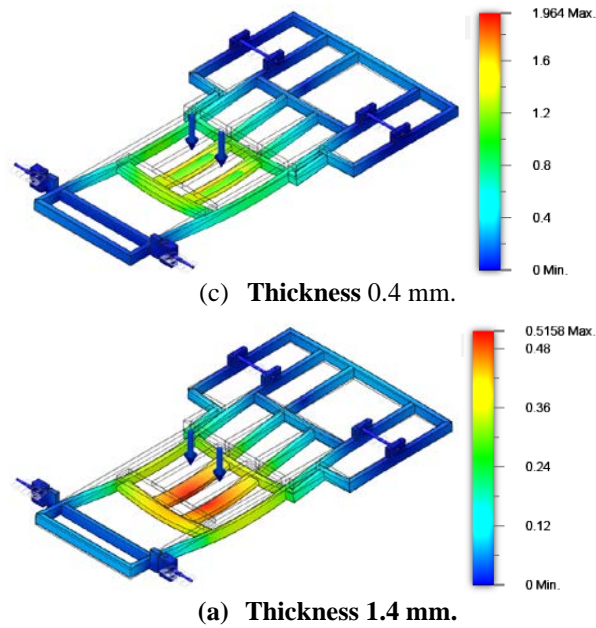
(c) **Thickness** 0.4 mm.

(a) **Thickness 1.4 mm.**

Fig. 14. Maximum displacement result (Material CFRP, load 700 N).

Based on the effect of thickness, on simulation case of the CFRP as the used material type, and 700 N of applied load on the chassis while the material thickness is varied. Fig. 16 shows that structure with 1.4 mm thickness has more strain value than the 0.4 mm thickness. This value indicates that the more the structural thickness, the structure is expected to experience higher strain value.
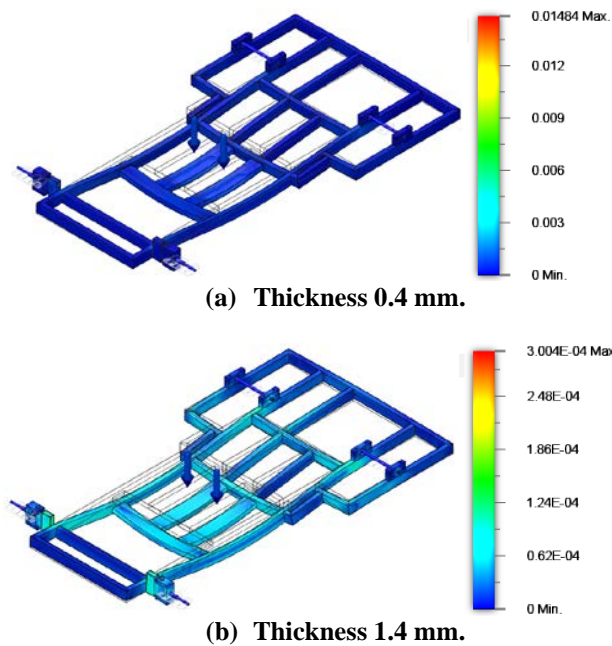

(a) **Thickness 0.4 mm.**

(b) **Thickness 1.4 mm.**

Fig. 15. Maximum strain simulation result (Material CFRP, load 700 N).

On the same discussed simulation case which the CFRP as the applied material type and the material thickness is varied, Fig. 17 shows that the structure with 1.4 mm thickness has higher safety factor value than the 0.4 mm thickness. The maximum safety factor in this simulation is 15, and the chassis with 1.4 mm thickness has 12.990, and the minimum level of 0.4 mm thickness is only 0.274. It indicates that the thicker the structure designed than the safer it is against applied loads.
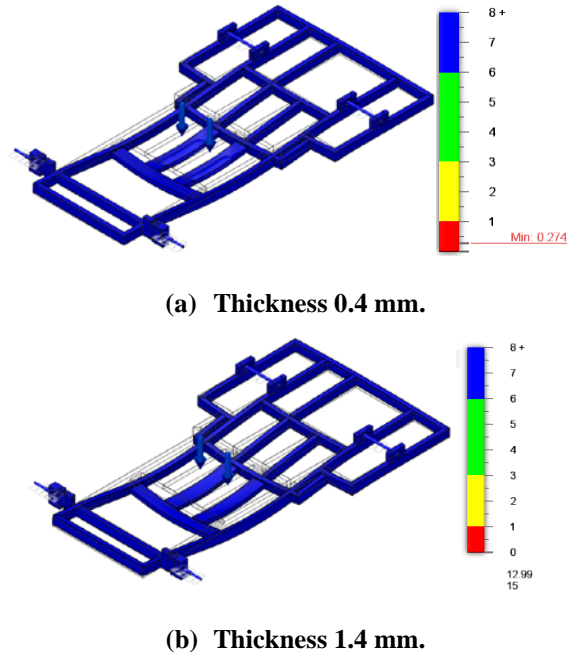

(a) Thickness 0.4 mm.

(b) Thickness 1.4 mm.

Fig. 16. Minimum safety factor result (Material CFRP, load 700 N).

As an overall summary of simulation results in this subsection, a case is chosen to highlight the effect of thickness on the alternative urban vehicle chassis. Case of the CFRP as assumed material, and 700 N of load applied on the chassis, while the material thickness is altered. Fig. 18 shows that the behavior of the changes in thickness which is higher safety factor has less stress, displacement, and strain. This tendency are linear and equally proportional for thickness increment in range of 0.4 to 1.4 mm.
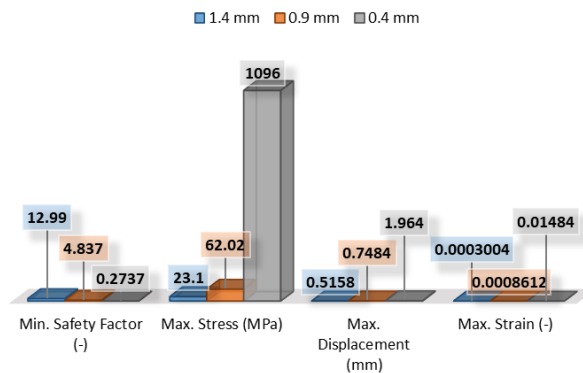

Fig. 17. Effect of thickness.

4.3. Effect of load

Applied load to the chassis structure gives effect to the simulation results obtained, such as in terms of aluminum 6061 material with a thickness of 1.4 mm. It was found that the lowest stress value is 3.991 MPa and the highest is 26.100 MPa. For the displacement value, the lowest is 0.090 mm and the highest is 1.080 mm. The lowest maximum strain value is obtained to be 0.0000984 and the highest is 0.0006280. The lowest value for the lowest safety factor is 10.530 and the highest is 15.

Based on the effect of load, one case of the simulation is discussed, which scenario on the aluminum 6061 and 1.4 mm chassis thickness is considered while the applied load is varied. Fig. 19 displays a phenomenon which the load 850 N produces more stress than the load 150 N. Since the area where the force applied are the same, this tendency is in line with the force-stress equation in Section 3, which the higher the force applied then the occurred stress on the object (same section area) increases.
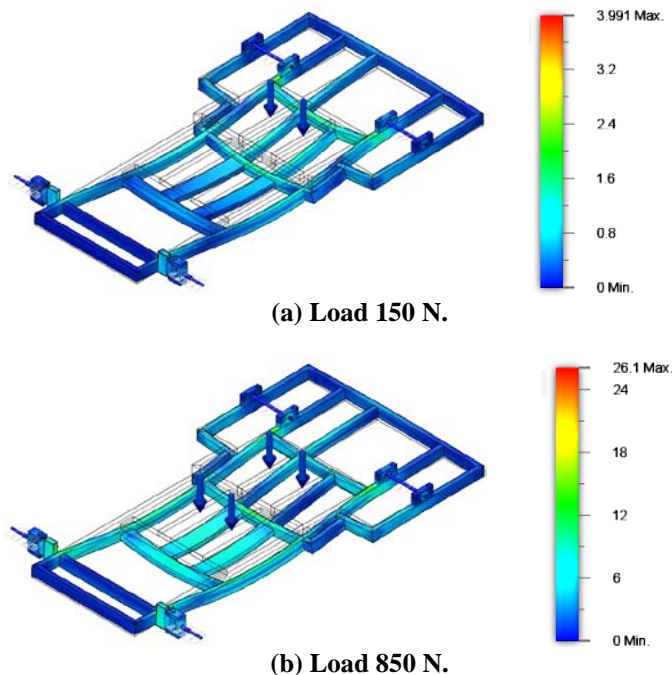

(a) Load 150 N.

(b) Load 850 N.

Fig. 18. Maximum stress result (Material Al 6061, thickness 1.4 mm).

Based on the simulation result of this case (aluminum 6061 as the material type and 1.4mm material thickness), different location and value of maximum displacement occurs after several selected loads are applied to the chassis. When the load is 150 N, the maximum displacement value is 0.090 located surrounding the center of the chassis while the other one is 1.080 which is located on the right side of the highest force applied (700 N) shown in Fig. 20. The displacement value indicates that higher applied load causes higher value of movement of the structure from its initial position.
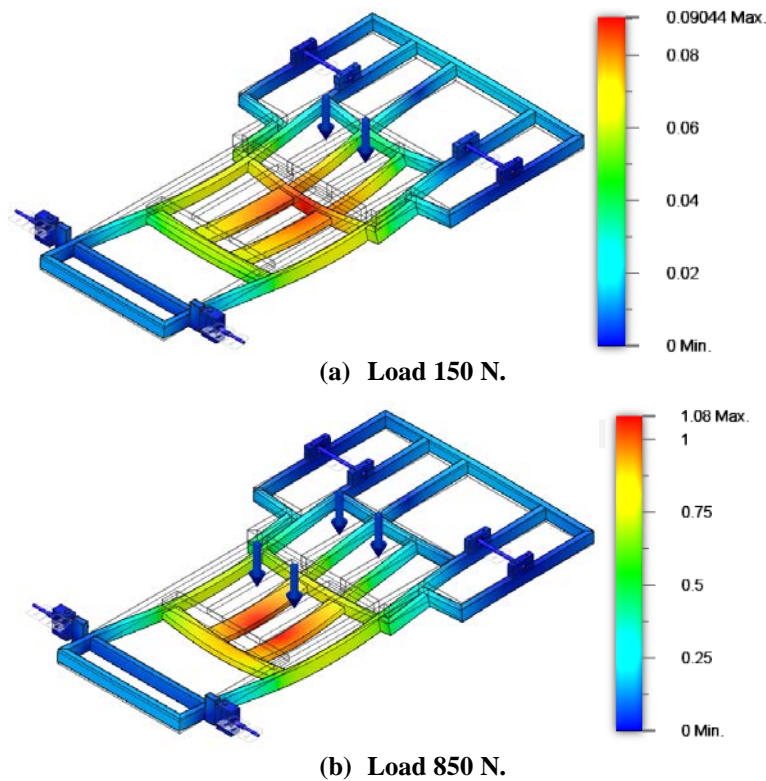
(a) **Load 150 N.**

(b) **Load 850 N.**

Fig. 19. Maximum displacement result (Material Al 6061, thickness 1.4 mm).

Figure 21 is adduce of strain behavior that the strain value when the load 150 N and 850 N are applied to the chassis result 0.0000984 and 0.0006280, respectively. The higher the applied load to the chassis the more strain value produced, and it indicates that the chassis will definitely deform much more. This indication is in line with the strain equation as expressed in previous Section 3.

On the same simulation case which focus on load effect, the data shows that the highest safety factor value is found in 150 N load with a value of 15, and the lowest is 850 N load with a value of 10.53. The reduction in safety factor value is caused by the increasing stress on the chassis, which the more load added to the chassis, the less safety the subject as it approaches yield limit. As a summary of this subsection (Fig. 22), it is known that lower load decreases the stress, displacement, and strain values while the safety factor increases along with the load reduction. This occurrence are overall linier for all selected parameters in this works, such as the 150 N load has the least stress, displacement, and strain. However, the same case results the highest safety factor compared to the other.

Based on Fig. 23, it is known that value of load influences the parameter studied in this research. Lower load decreases the stress, displacement, and strain value while the safety factor increases along with the load reduction. This occurrence are overall linear such as the 150 N load has the least stress, displacement, and strain but has the highest safety factor compared to the other.
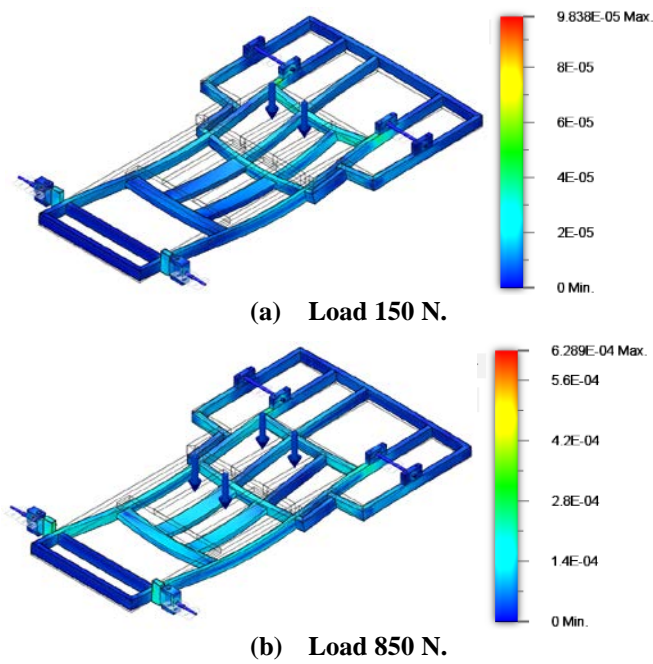
(a)   Load 150 N.

(b)   Load 850 N.

Fig. 20. Maximum strain result (Material Al6061, thickness 1.4 mm).

(a) Load 150 N.
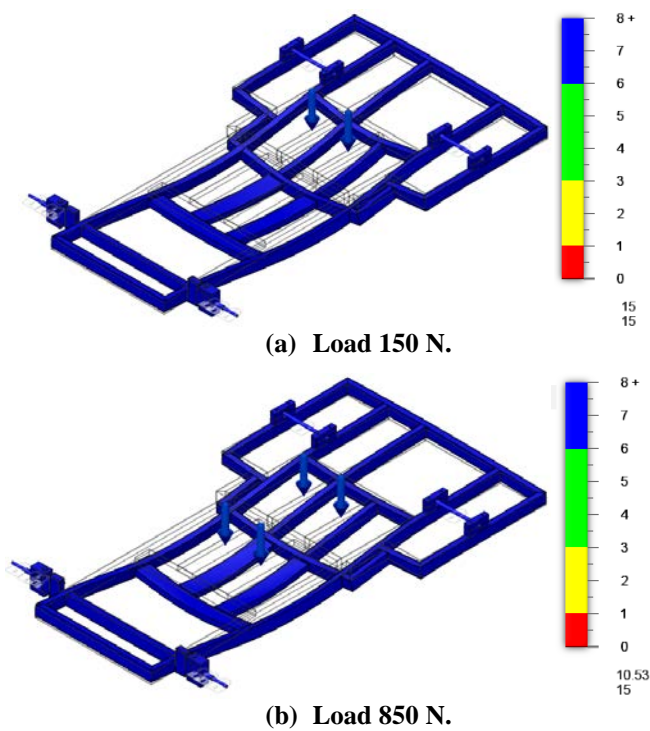

(b) Load 850 N.

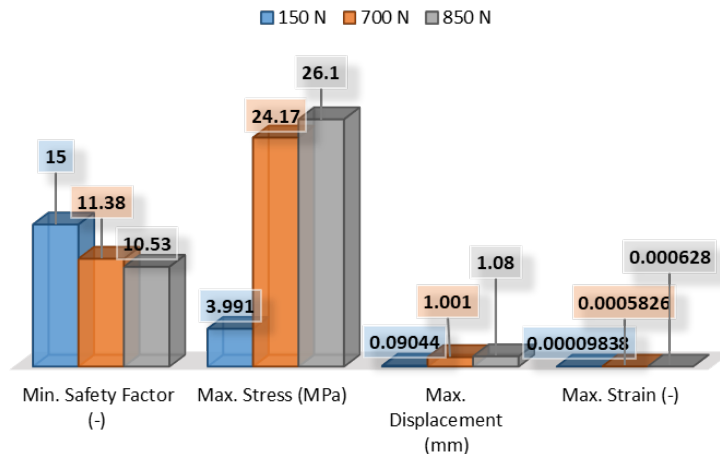**Fig. 21. Minimum safety factor (material Al 6061, thickness 1.4 mm).**

Fig. 22. Effect of load.

5. Conclusions

Alternative urban vehicle chassis was modelled and simulated using Autodesk Fusion 360 software. The simulation was done on the alternative urban vehicle chassis which is a structural frame with different type of materials (carbon steel, aluminum 6061, and carbon fiber reinforced plastic), diverse frame thicknesses (1.4 mm, 0.9 mm, and 0.4 mm), and distinct loads (150 N, 700 N, 850 N).

Based on the calculation results, the alternative structure of the urban vehicle chassis shows several behaviors due to operational (load combination) and internal factors (structural thickness and material). The effect of the type of used material provides an increment in terms of value of the safety factor and maximum stress, while a reduction in the value of maximum displacement and maximum strain. In this case, the strength parameter increases as the material which has higher yield strength is used that could be analyzed from the material properties in Section 2 (Low carbon steel > CFRP > Al 6061). The influence of the thickness of the frame is shown by the tendency of the maximum stress, maximum displacement, and the maximum strain which increase as well as the tendency of reduction of the safety factor along with the reduction in the frame thickness. The thinner the frame is the stress will increase because the area is smaller, which is in line with the equation in chapter 2 and the displacement increase because thin frame has least material to bear the load received. Thin frame also reduce the length of the chassis which caused the strain increase according to Equation (4) in Section 2 while the safety factor reduced because thin frame has lower strength. Effect of the applied loading to the urban vehicle chassis is summarized as an increase in the value of maximum stress, maximum displacement, and maximum strain while value of the safety factor is reduced as the load increases. Stress, displacement, and strain are increasing because when the load increases the force is bigger in accordance to equations on chapter 2 while the safety factor is reduced because the increasing of the load has bigger force that is able to damage the chassis.

Future research in terms of structural optimization is highly encouraged to be performed. Simulation data of this work is suitable reference for analysis to obtain the most suitable combination for chassis structures. Methodology of the current

study is possibly extended to develop chassis for low cost green car (LCGC) which requires light chassis while it is capable to maintain working loads during operations.

Acknowledgments

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