DOI: 10.5604/01.3001.0014.1959
Volume 100 • Issue 1 • May 2020
Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Modelling analysis of high effect of roll hoop main on the strength of student car formula chassis

M. Tamjidillah [a], R. Subagyo [a,*], H. Isworo [a], H.Y. Nanlohy [b]
[a] Department of Mechanical Engineering, Faculty of Engineering, Universitas Lambung Mangkurat, Banjarmasin, Indonesia
[b] Department of Mechanical Engineering, Jayapura University of Science and Technology, Jayapura, Indonesia
* Corresponding e-mail address: rachmatsubagyo@ulm.ac.id
ORCID identifier: https://orcid.org/0000-0001-6129-7395 (R.S.); https://orcid.org/0000-0002-1529-8992 (H.I.); https://orcid.org/0000-0003-3108-2179 (H.Y.N.)

ABSTRACT

Purpose: To analyse the strength of materials by means of optimization, find the best value of the strength test of mutually influential materials with a variation of roll-hoop height.

Design/methodology/approach: The research began with the design of a three-dimensional model by varying the height of the roll-hoop on chassis types: A, B, C, D, E, F, G, H ,and I. The height of the main roll hoop at each chassis is: 502, 504, 506 508, 510, 512, 514, 516 and 518 mm. Then by using the student version of Autodesk Inventor, a simulation is made to test: Deflection, Normal stress, Shear stress (T-x / T-y) and Torsional stress. The results of this test are used to analyse the types of chassis that have been designed so that the best chassis design is obtained.

Findings: The results obtained in this study are the value of Normal stress decreases with increasing roll-hoop height, and applies inversely to the torsional stress value. Deflection values tend to be stable with increasing roll-hoop height, while Shear stress T-x and T-y values tend to fluctuate.

Research limitations/implications: The chassis material uses carbon steel which has mechanical property values in accordance with 2015 FSAE Standard regulations.

Practical implications: The optimization results of the design of the roll hoop height on the chassis show that the chassis type B with the main roll hoop height of 504 mm is the best with the lowest deflection value and the difference in tension according to the FSAE rules.

Originality/value: The research that has been done only tests the strength of the ingredients separately. In this study trying to analyse the strength of the material by way of optimization to find the best value from the strength test of material that influence each other with a variation of roll-hoop height.

Keywords: Student formula car, Autodesk Inventor, Roll-hoop play, Normal stress, Torsional stress

Reference to this paper should be given in the following way:
M. Tamjidillah, R. Subagyo, H. Isworo, H.Y. Nanlohy, Modelling analysis of high effect of roll hoop main on the strength of student car formula chassis, Journal of Achievements in Materials and Manufacturing Engineering 100/1 (2020) 26-40.
DOI: https://doi.org/10.5604/01.3001.0014.1959

ANALYSIS AND MODELLING

1. Introduction

The chassis is an important part of the car because the chassis is a framework that connects many types of mechanical components. Car components that are connected to the chassis include suspension system, braking system, engine, body, and tires [1]. Poor chassis design and strength can cause mechanical parts to fail so that they don't function properly. Therefore, the chassis is referred to as the backbone for all car systems. Just like the human body, its backbone plays an important role in holding other body organs, muscles and skin. The other main function of a car chassis is to handle the dynamic and static loads it carries with the hope that the chassis has a low failure rate of distortion and deflection due to the load.

Research on chassis has been carried out, among others: research conducted by [2], focusing on the investigation of static and dynamic characteristics such as torsional rigidity and the natural frequency of car chassis. Then the research by [3] makes an analysis of the design development, optimization, and testing technology of the Formula SAE (Society of Automotive Engineers) chassis, predicting future trends, good theoretical references are provided for the design and research framework as a follow-up. Chassis design research with CAD (Computer-Aided Design) software such as Pro-Engineers has been carried out by [4]. The results of this study were able to make a chassis with a very high safety factor. Then research by [5], tried to overcome the shortcomings of the previous design by finding safe welding techniques and avoiding brittle failure at the chassis connection. Research on modelling and simulation of a formula one chassis car chassis has been carried out by [6]. Modelling analysis was performed using ANSYS and the results of this analysis were presented using the results of numerical calculations.

Subsequent research on the distribution of static and dynamic loads that calculate analytically is followed by extensive studies of various boundary conditions to be applied during various FEA (Finite element analysis) tests [7]. Stress distribution, lateral displacement during static, dynamic and frequency modes are analysed. The results of this study found sufficient safety factors as needed. This research succeeded in increasing the torsional stiffness by 2.46 times compared to the old design. Then able to reduce the weight of the chassis by 1.125 times the previous weight. While the ratio of the increasing percentage of torsional stiffness to decreasing percentage of weight is: 13.15:1.

Research conducted by [8] discusses the distribution of frame loads under conditions: lateral, vertical and horizontal longitudinal. This study was conducted on understanding the relationship between machine elements and drivers that meet ergonomic requirements. In ergonomics, factors such as driver visibility, seat tilt, thermal insulation, etc. are considered. The chassis design is done with CAD (Computer-Aided Design) software. The design model was prepared using the highest driver anthropometric parameters in accordance with SAE (Society of Automotive Engineers) rules and prior design knowledge. Static and dynamic load distributions are calculated analytically followed by extensive studies of various boundary conditions applied during various FEA (Finite Element Analysis) tests conducted at ANSYS. The results of stress distribution analysis, static load, dynamic load, and frequency, found a very high safety factor, namely: 3.85.

In 2013, [2], conducting research focused on investigating static and dynamic characteristics such as torsional stiffness and natural frequency in car chassis. This analysis was carried out using the Finite Element Method and an experimental approach. This research succeeded in making modifications to the existing chassis by using the PRO-E modelling software. The results of this modelling analysis can increase torsional rigidity and natural frequency of the chassis.

To make improvements to several problems related to the chassis so that it can work well has been investigated by [9]. This research was conducted by designing three chassis made according to the 2017/2018 SAE (Society of Automotive Engineers) standards. All three chassis undergo an analysis test consisting of Main roll hoop test, Front roll hoop test, Static shear, Side-impact, Static torsional. The results of this test resulted in one of the chassis being chosen as the best design in terms of Von Mises Stress and its torsional displacement. The results of this study can reduce chassis weight by 16.7% and increase torsional stiffness by 37.74%.

The most recent chassis research carried out by [10], this study created the Student Formula car chassis design using

Autodesk Inventor. In this study, the best chassis strength is optimized by testing the Normal stress on deflection, shear stress and torsional. The results of this study varied the length of the main roll hoop (110-150 mm) and found the best length of the 125 mm main roll hoop, which was then used as a reference in this study.

The strength of the chassis is greatly influenced by the type of material used, where the materials that meet the requirements are: lightweight, rigid, and very safe to produce with reasonable production costs [7]. The chassis must be compact and resistant to static and dynamic loading. Poor chassis design and strength can cause failure for other components. Therefore, the chassis can be called the backbone for all car systems [11]. To determine the strength of the material when receiving a load is done by Deflection, Normal Stress, Shear stress and Torsional stress [10,12]. In several studies that have been carried out it turns out that the height of the roll-hoop affects the stress value and deflection of the chassis material [9]. Much research has been done but only tested the strength of the ingredients separately. In this study, we try to analyse the strength of the material by means of optimization to find the best value of the strength test of material that influence each other with a variation of roll-hoop height.

2. Materials and methods

2.1. Material

The mechanical properties of the 2015 FSAE standard chassis material are shown in Table 1. In this rule, the strength of the chassis material has a minimum of mechanical properties above predetermined values. To accommodate the demands of the design which must have high-security figures, carbon steel has mechanical properties as shown in Table 2.

Table 1.
Mechanical properties of standard SAE Formula chassis materials

Mechanical Properties	Value	Standard FSAE 2015
Young's Modulus (E)	200 GPa	√
Yield Strength (Sy)	305 MPa	√
Ultimate Strength (Su)	365 MPa	√

The results of checking the mechanical properties possessed by Carbon steel in Table 2 (checkmark) indicate that all the properties of this carbon steel meet the requirements for safe chassis design.

Table 2.
Mechanical properties of carbon steel

Mechanical Properties	Value of Material Strength	Requirements	
		Yes	No
Mass Density	7.850 g/cm^3	√	
Young's Modulus	200 GPa	√	
Poisson's ratio	0.290	√	
Yield strength	350 MPa	√	
Ultimate Tensile Strength	420 MPa	√	
Thermal Conductivity	47.600 W/m. K	√	
Linear Expansion	0.0000120 1/°C	√	
Specific heat	0.480 J/kg. K	√	

Table 3 shows the results of the analysis using the Autodesk Inventor of the chassis designed using carbon steel material. The results of this analysis show the values of Mass, Area, volume, Centre of gravity and moment of Inertia from Chassis in full.

The provisions for chassis mass according to FSAE 2015 are 77 kg driver mass and minimum vehicle mass of 300 kg. The chassis mass that was designed in the research was 446.267 kg (Tab. 3) fulfilling the requirements.

Table 3.
Results from the Autodesk Inventor analysis on chassis

Results of chassis design	Value of chassis analysis design
Mass	446.267 kg
Area	85560.762 mm^2
Volume	404681.016 mm^3
Centre of Gravity	x= -60.833 mm y= -79.111 mm z= -319.436 mm
Moment of Inertia (I_x)	16336.697 mm^4
Moment of Inertia (I_y)	16336.697 mm^4

The dimensions of the material used in this chassis are 26.9 mm x 2.5 mm round tube for front and main roll hoop components, while other components such as roll hoop bracing, front bulkhead, side-impact structure, and mainframe parts use round tube 26.9 mm x 3 mm. The purpose of using a hollow structure is to make the chassis design lighter.

2.2. Research method

The research began with the design of a three-dimensional model, as shown in Figure 1 by varying the height of the roll-hoop on chassis types: A, B, C, D, E, F, G, H, and I. The height of the main roll hoop at each – the chassis are: 502, 504, 506, 508, 510, 512, 514, 516 and 518 mm. Then by using the student version of Autodesk Inventor a simulation is made to test: Deflection, Normal stress, Shear stress (T-x / T-y) and Torsional stress. The results of this test are used to analyse the types of chassis that have been designed so that the best chassis design is obtained.

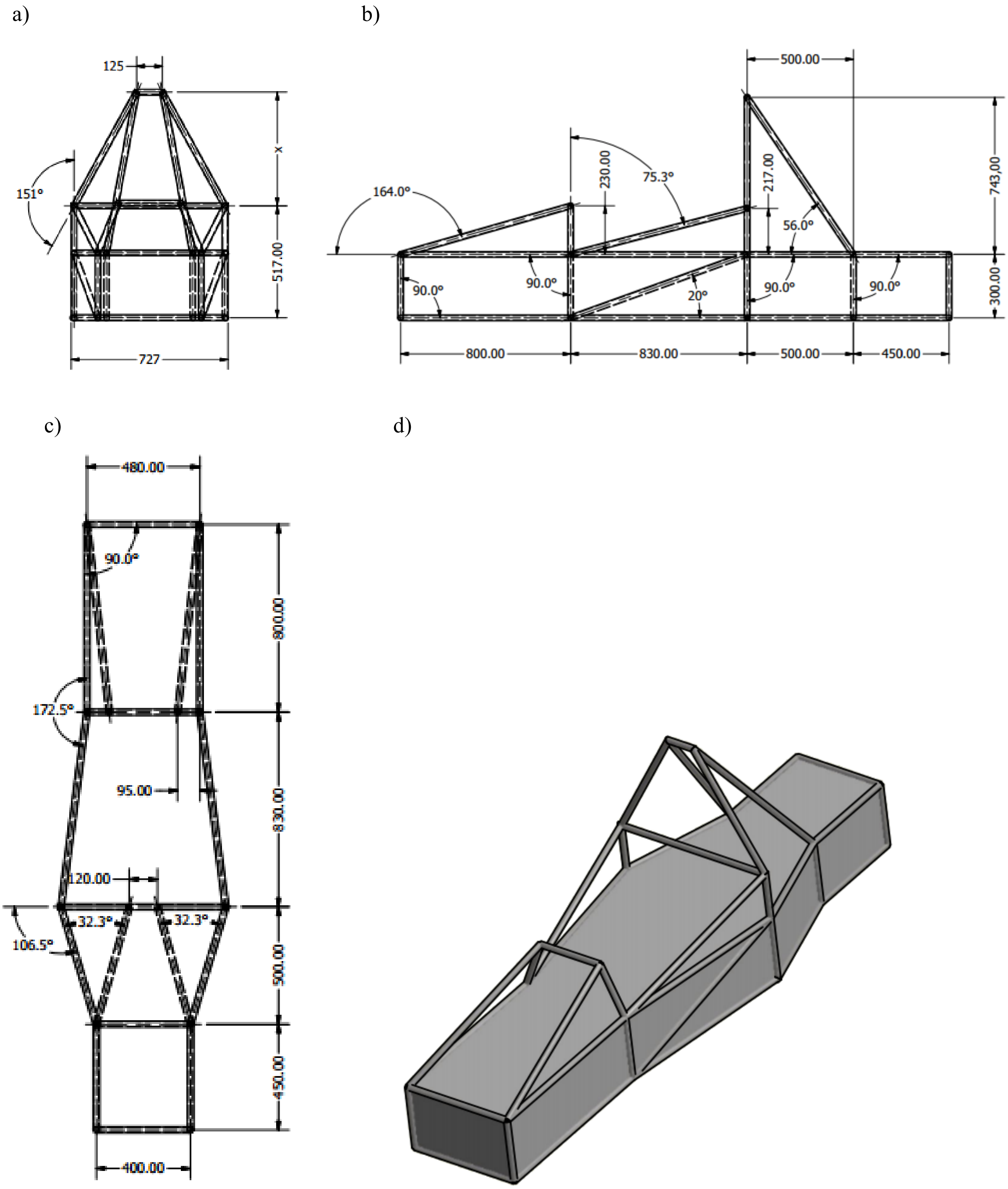

Fig. 1. The planned chassis dimension: a – front view; b – to the right side; c – top view; d – object

The simulation process is carried out with the following steps (Fig. 2): Installing Autodesk Inventor 2015 software on the NoteBook, making a 2015 FSAE chassis with variations in the height of the main roll hoop, testing the chassis including (deflection, stress, and torque), boundary conditions (stress <yield stress, deflection <25 mm), design analysis and completion.

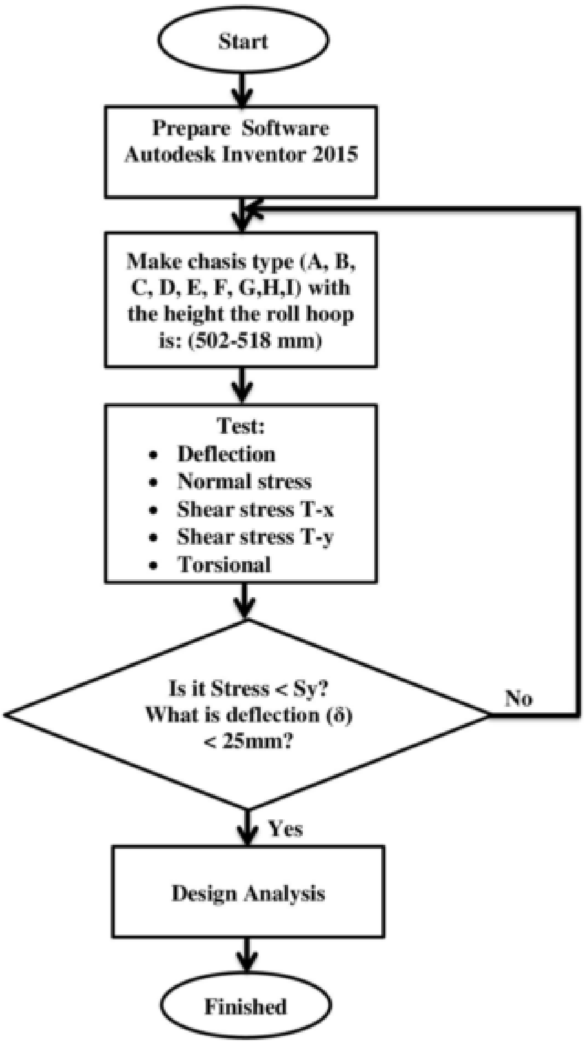

Fig. 2. Flow chart of research stages

Figure 3 is a chassis design framework made with static loading F1 = 9 kN, F2 = 6 kN and F3 = 5 kN (in accordance with 2015 FSAE rules). The static force F1 is the loading in the y-axis vertical direction, F2 is the x-axis horizontal direction loading and F3 is the z-axis direction loading as shown (black circle mark). The reactions that occur due to static loading are R1, R2, R3 and R4 (marked red arrows).

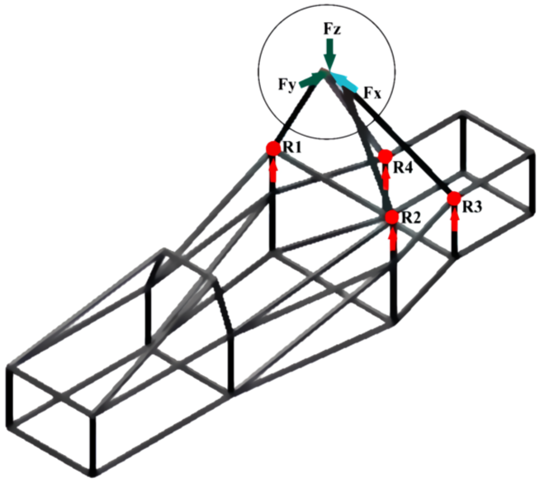

Fig. 3. Load diagram in order: F1 = 9 kN, F2 = 6 kN and F3 = 5 kN

Chassis sections according to FSAE 2015 are divided into three namely: Front bulk hoop, Main roll hoop and Side Impact. This research, is more focused on the main roll hoop so that the analysis of the free body diagram is placed on the main roll hoop.

Analysis of the highest welding joint failure occurs at the closest connection to the loading of Fx, Fy and Fz. therefore the Deflection, Normal Stress, Shear stress and Torsional stress tests are focused on the connections R1, R2, R3 and R4 that receive direct loading.

3. Results and discussion

3.1. Results

Chassis design simulation type A, which has a roll-hoop height of 502 mm, with constant loading values of F1, F2, and F3 respectively: 9 kN, 6 kN, and 5 kN are shown in Figure 4. Normal stress simulation results are shown in Figure 4a, deflection of Figure 4b, shear stress (Tx, Ty) in Figure 4c and 4d and torsional Figure 4e. Normal stress, deflection, Shear stress, and Torsional simulation results vary in value on the chassis which is indicated by differences in colour. The lowest value is shown in blue and the highest value is shown in red. The highest values on Normal stress, Displacement, Shear stress, and Torsional occur at the tops of the chassis marked with black circles. This shows that the higher the roll-hoop play affects the five elements analysed. To find out the ideal height of the main roll-hoop, optimization is done by connecting two/three variables: the height of the main roll-hoop to torsional, normal stress, shear stress (T-x, T-y) and deflection.

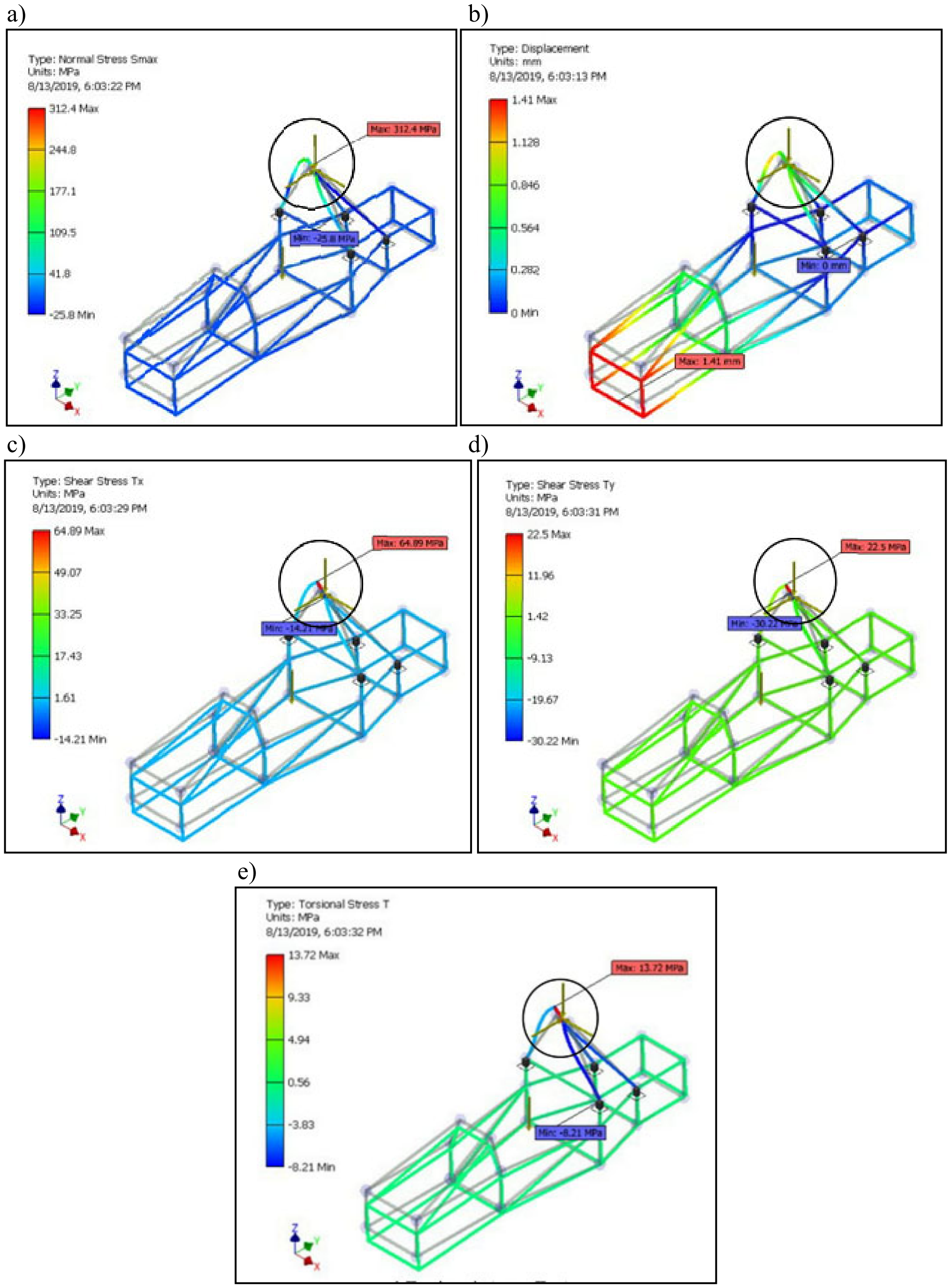

Fig. 4. Autodesk Inventor simulation results on chassis type A (roll-hoop height = 502 mm):a) normal stress test, b) deflection test, c) shear stress (T-x) test, d) shear stress (T-y) test, e) torsional stress test

Table 4 shows the results of simulation values: normal stress, deflection, shear stress (x, y) and torsional on the chassis model (A-I). The loading conditions F1 = 9, F2 = 6 and F3 = 5 kN, resulting in varying values of normal stress, deflection, shear stress and torsional. Normal stress value decreases with increasing height of playing roll-hoop is inversely proportional to torsional stress. Deflection values tend to be stable while the value of shear stress T-x and T-y tends to fluctuate.

Table 4.
Autodesk Inventor simulation results in normal stress, deflection, shear stress T-x, shear stress T-y and torsional stress tests on chassis design type (A-I)

Type chassis	High roll hoop, mm	Load F1, kN	Load F2, kN	Load F3, kN	Normal Stress, MPa	Deflection, mm	Shear stress T-x, MPa	Shear stress T-y, MPa	Torsional stress, MPa
A	502	9	6	5	312.4	1.410	64.89	22.50	13.72
B	504	9	6	5	249.7	1.410	29.79	22.53	13.77
C	506	9	6	5	302.8	1.138	65.09	30.24	13.83
D	508	9	6	5	302.9	1.410	65.19	30.25	13.88
E	510	9	6	5	303.1	1.410	65.29	30.26	13.93
F	512	9	6	5	313.1	1.410	65.39	22.46	13.99
G	514	9	6	5	303.4	1.410	65.49	30.28	14.04
H	516	9	6	5	303.6	1.410	65.60	30.29	14.10
I	518	9	6	5	307.9	1.208	8.99	31.48	14.15

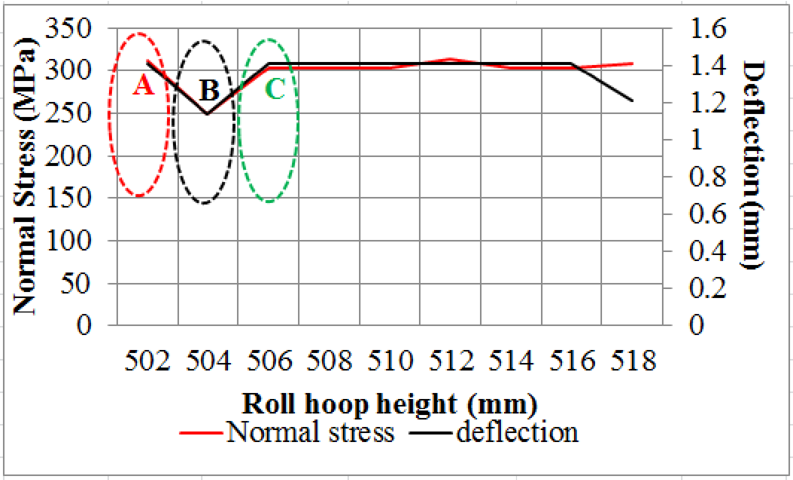

Fig. 5. Graph of the relationship between the height of the main roll-hoop to normal stress and deflection

3.2. Discussion

Figure 5 is a graph of the relationship between the height of the main roll-hoop to the Normal stress and deflection that occurs in the chassis when experiencing loading. This graph shows three important points that occurred namely: points A, B, and C, where point A has coordinates (502 mm, 312.4 MPa, 1.410 mm), point B (504 mm, 249.7 MPa, 1.410 mm) and points C (506 mm, 302.8 MPa, 1.138 mm). Of the three types of chassis only chassis type B whose value meets the FSAE standard, that is the value of Yield Strength is below the specified limit. The relationship between the height of the main roll-hoop with Normal stress and deflection shows a stable value with increasing height of the main roll-hoop as shown in Figure 5.

Figure 6 simulation results on the height of the main roll-hoop 502 mm, 504 mm and 506 mm. These results show the same Displacement value on chassis A and B, with a displacement value of 1.410 mm and a difference of 0.272 mm lower when compared to type C chassis which has a displacement value of 1.138 mm. Simulation results on deflections of 502, 504 and 506 mm are shown in Figures 6b, 6d, and 6f (black circle). While the normal stress simulation results, shown in Figures 6a, 6c, and 6e (red circle) obtained different results where the value of normal stress type A: 312.4 MPa highest followed by type C: 302.8 MPa, then type B: 249.7 MPa. This shows that the best design was obtained at 504 mm main roll-hoop height based on the consideration of values: Normal stress and its deflection as shown in Table 5.

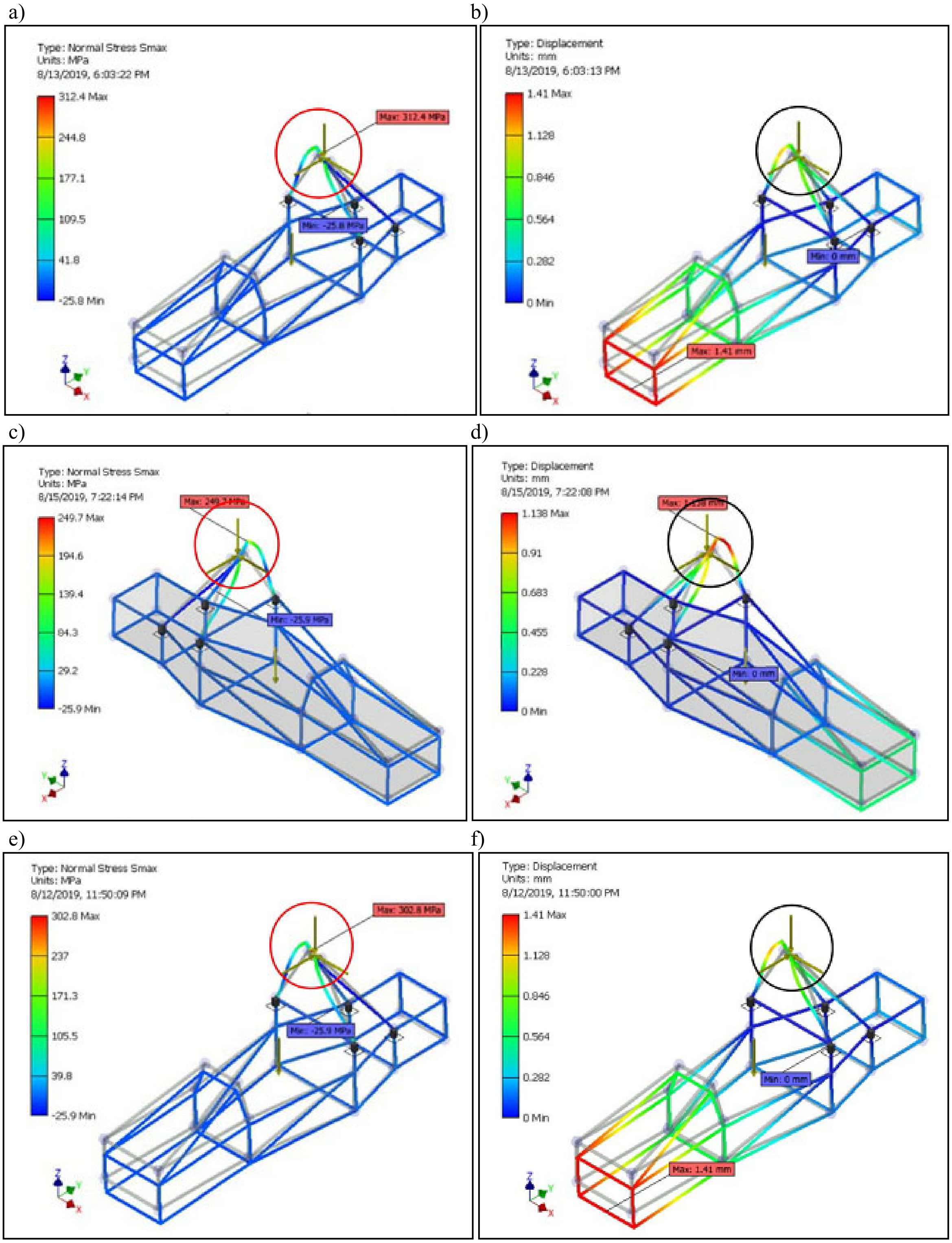

Fig. 6. Autodesk Inventor simulation results on normal stress and deflection: a) normal stress 502 mm, b) deflection 502 mm, c) normal stress 504 mm, d) deflection 504 mm, e) normal stress 506 mm, f) deflection 506 mm

Table 5.
Table normal stress of deflection

Type chassis	High roll hoop, mm	Load (F1, F2, F3), kN	Normal stress, MPa	Deflection, mm	Decision
A	502	9, 6, 5	312.4	1.410	x
B	504		249.7	1.138	The best value
C	506		302.8	1.410	x

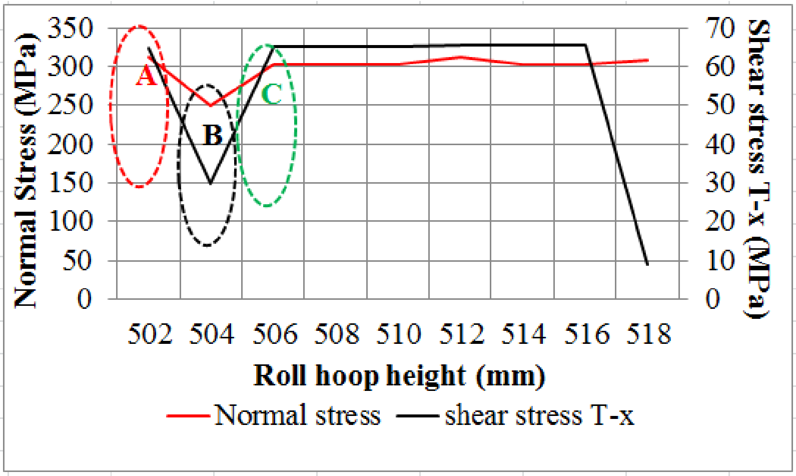

Fig. 7. The relationship graph between the height of the main roll-hoop to the normal stress and shear stress (T-x)

Figure 7 shows the relationship between the height of the main roll-hoop to normal stress and shear stress T-x. This graph, shows there are three types of the best chassis, namely: chassis type A (red ellipse mark) shows the normal stress value (312.4 MPa), Tx shear stress (64.89 Mpa) with the height of the main roll-hoop (502 mm) meet in one point. Type B chassis (black ellipse mark) shows normal stress value (249.70 MPa), shear stress T-x value (29.79 Mpa), with 504 mm main roll-hoop height. The type C chassis (green ellipse mark) has a normal stress value (302.8 MPa), a shear stress T-x value (65.09 MPa) with the height of the main roll-hoop (506 mm) where the positions of the three points are intersecting. From the results of this test, it can be concluded that the chassis with a 504 mm main roll hoop height has the best normal stress and shear stress (T-x) values. The result of the relationship between the height of the main roll hoop to normal stress and shear stress T-x is fluctuating up and down as shown in Figure 7.

The Autodesk Inventor simulation results are shown in Figure 8, where the results of Normal stress at the height of the main roll hoop: 502, 504 and 506 mm show almost the same results as shown in Figures 7a,c,e (black circle mark). This is caused by differences in the value of normal stress that is not too far away. Whereas the shear stress shown in Figures 7b,d,f (red circle marks) shows a difference in simulation results where the chassis of the 502 mm T-x roll hoop stress peak is red as shown in Figure 7b (red circle mark). The same thing happened at the top of the 506 mm roll hoop shown in Figure 7f (red circle mark). Unlike the top of the 504 roll hoop has a lower stress marked in blue as shown in Figure 7d (red circle mark). The results of this simulation can be concluded that the blue colour on the chassis height of the main roll hoop: 504 mm (shown in Figure 7b) has a lower Shear stress value compared to the value of shear stress on the height of the main roll hoop 502 mm and 506 mm, as shown in Figure 7b and 7f (red circle sign).

The results of the Normal stress value on Shear stress Tx, are shown in detail in Table 6, with chassis types: A, B, and C. To analyse in detail Autodesk Inventor simulations on Normal Stress and Shear stress is shown in Figure 8. Differences in the simulation results of Normal values Stress is not so obvious, this is due to the stable normal stress value as shown in Figure 8. Different things happen to shear stress whose value fluctuates enough to produce a different simulation. Shear stress chassis type A and C, dominated by light blue and red at the top of the main roll hoop, this indicates that the stress that occurs on the main roll hoop is quite high. Unlike the case with chassis type B in the predominance of green and blue at the top of the roll hoop which shows lower Shear stress. The results of this analysis show the value of type B Shear stress is lower than type A and C chassis. Type B chassis with 504 mm main roll hoop has a Shear stress value of 29.79MPa with the lowest stress difference of 219.91 as shown in Table 6.

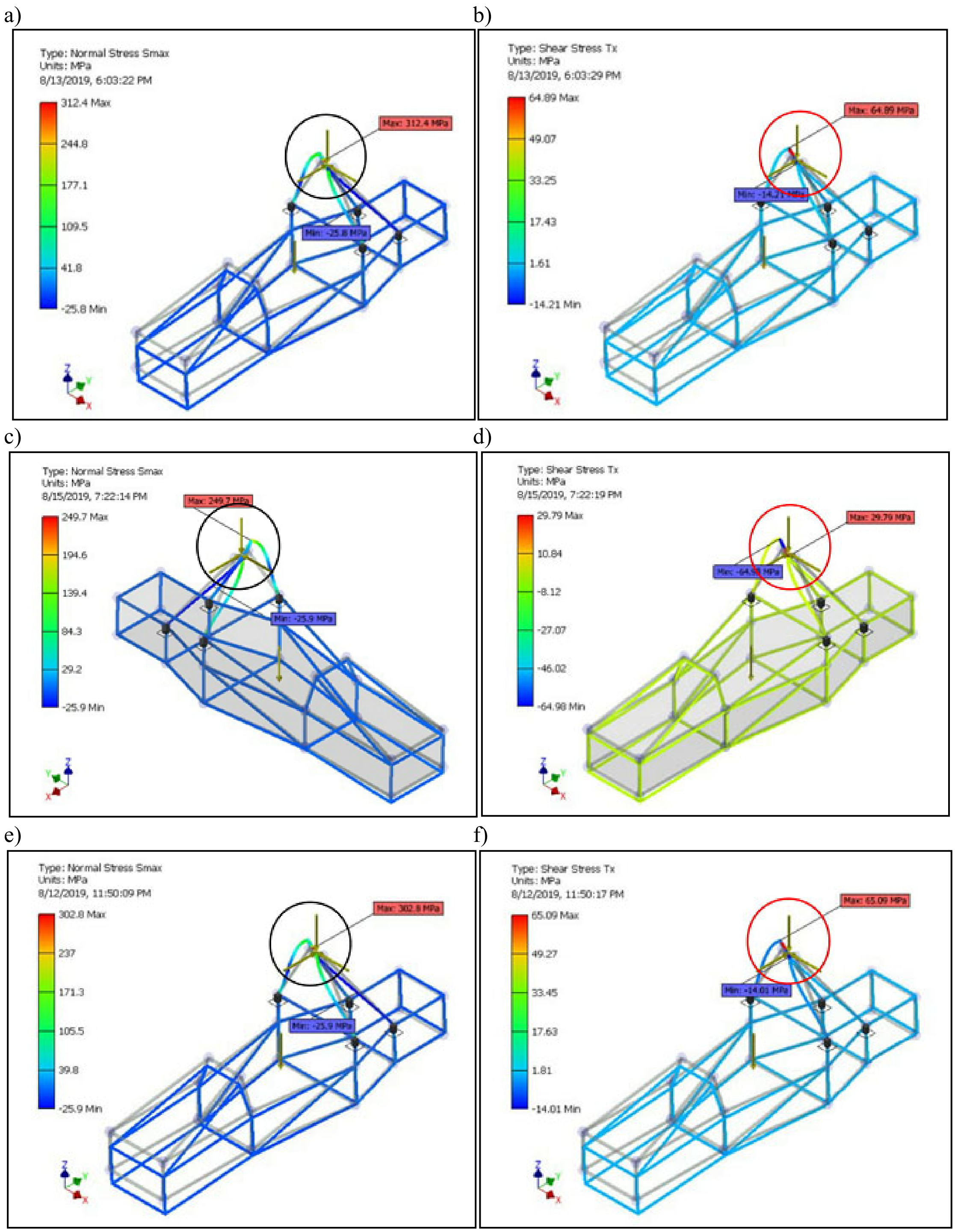

Fig. 8. Autodesk Inventor simulation results on normal stress and shear stress T-x: a) normal stress 502 mm, b) shear stress (T-x) 502 mm, c) normal stress 504 mm, d) shear stress (T-x) 504 mm, e) normal stress 506 mm, f) shear stress (T-x) 506 mm

Table 6.
Table of normal stress values for shear stress T-x

Type chassis	High roll hoop, mm	Load (F1, F2, F3), kN	Normal stress, MPa	Shear stress T-x, MPa	Stress difference, MPa	Decision
A	502	9, 6, 5	312.4	64.89	247.51	x
B	504		249.7	29.79	219.91	The best value
C	506		302.8	65.09	237.71	x

Table 7.
Table of normal stress values for shear stress T-y

Type chassis	High roll hoop, mm	Load (F1, F2, F3), kN	Normal stress, MPa	Shear stress T-y, MPa	Stress difference, MPa	Decision
A	502	9, 6, 5	312.4	22.50	289.90	x
B	504		249.7	22.53	227.17	The best value
C	506		302.8	30.24	272.56	x

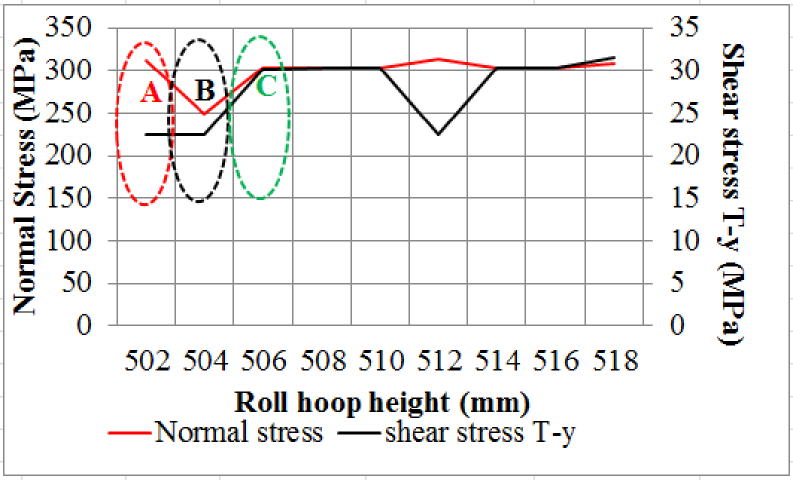

Fig. 9. The relationship graph between the height of the main roll-hoop to the normal stress and shear stress (T-y)

From Figure 9, there are three best types of chassis, namely: type A (502 mm; 312.4 MPa; 22.50 MPa), type B (504 mm; 249.7 MPa; 22.53 MPa) and type C (506 mm; 302.8 MPa; 30, 24 MPa). The results of the graph relationship between the height of the main roll-hoop to Normal stress and Shear stress Ty, the best results are obtained on chassis type B, with (height of the main roll-hoop: 504 mm, normal stress: 249.70 MPa and shear stress 22.53 MPa) as shown in Table 7. The results of this study can be concluded that the relationship between the height of the main roll-hoop to normal stress and shear stress in the y-axis direction is fluctuating up and down.

The results of the Autodesk Inventor simulations on Normal stress and Shear stress T-y on chassis types A, B, and C are shown in Figure 10. The difference in the value of Normal stress on chassis types A, B, and C is not so apparent. Unlike the case with the Shear stress value, as shown in Figure 10b,d,f this is due to the stress difference that occurs. Shear stress value on chassis type A and C is dominated by green which shows a higher stress value when compared to type B chassis which is dominated by light blue. The results of this analysis show a more recommended type B chassis.

Figure 11 shows the graph of the results of the torsional test with variations in the height of the main roll hoop: 502, 504, 506, 508, 510, 512, 514, 516 and 518 mm. The results of this test show varying torsional values. The highest torsional value occurs in type C chassis with a value of 13.83 MPa and the lowest value occurs in type A chassis followed by type B, with torsional values of 13.72 and 13.77 MPa respectively. However, based on the difference in stress between normal stress and torsional stress type B chassis is recommended in terms of safety as shown in Table 8.

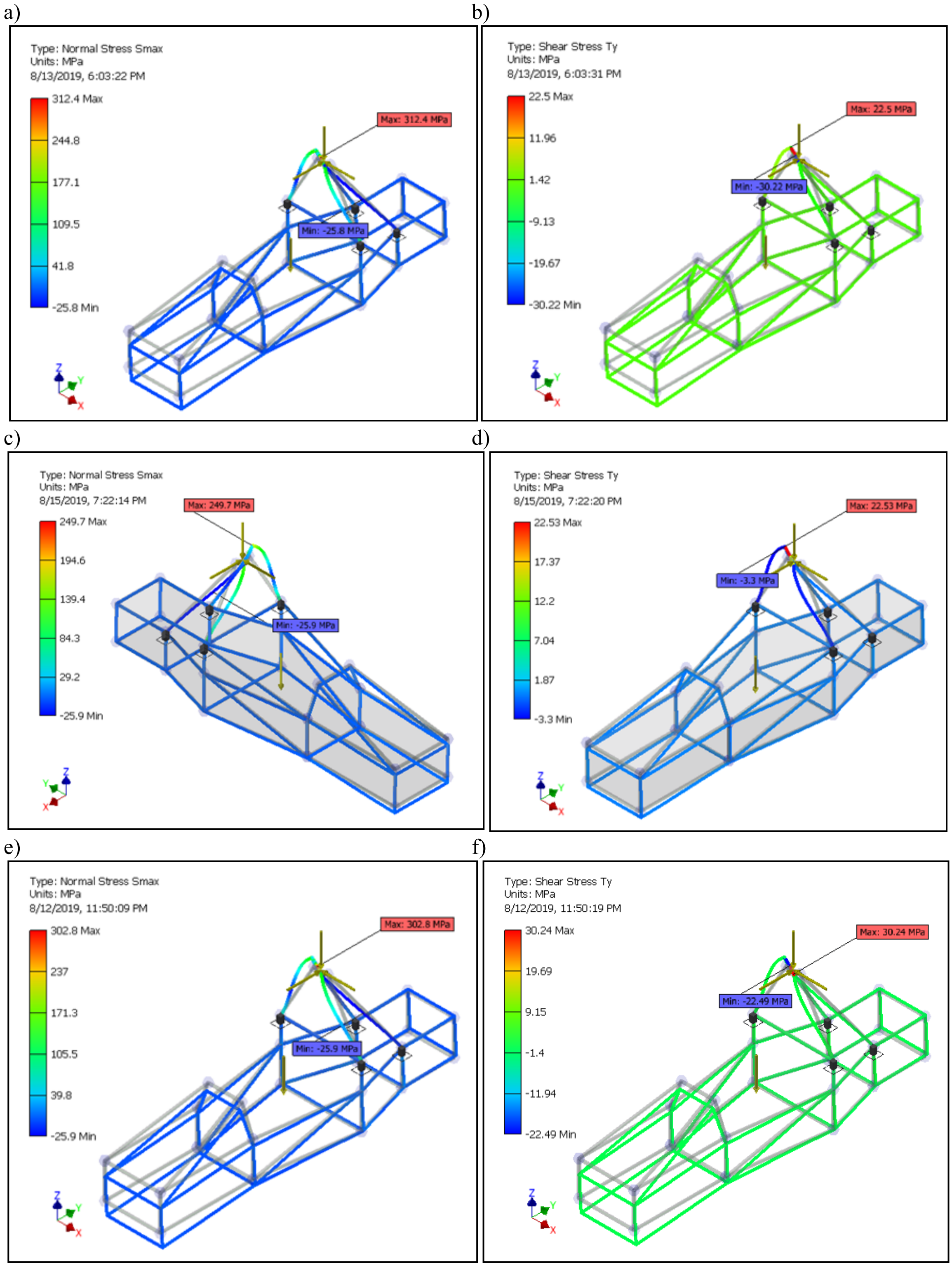

Fig. 10. Autodesk Inventor simulation results on normal stress and shear stress T-y: a) normal stress 502 mm, b) shear stress T-y 502 mm, c) normal stress 504 mm, d) shear stress T-y 504 mm, e) normal stress 506 mm, f) shear stress T-y 506 mm

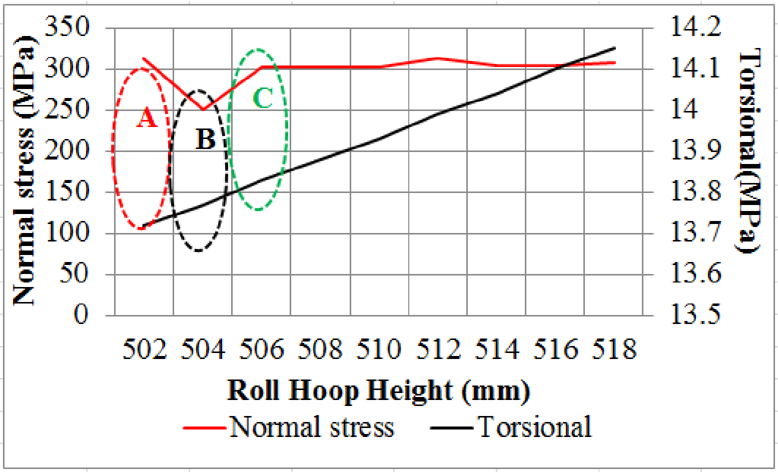

Fig. 11. Graph of the relationship between roll-hoop height and torsional

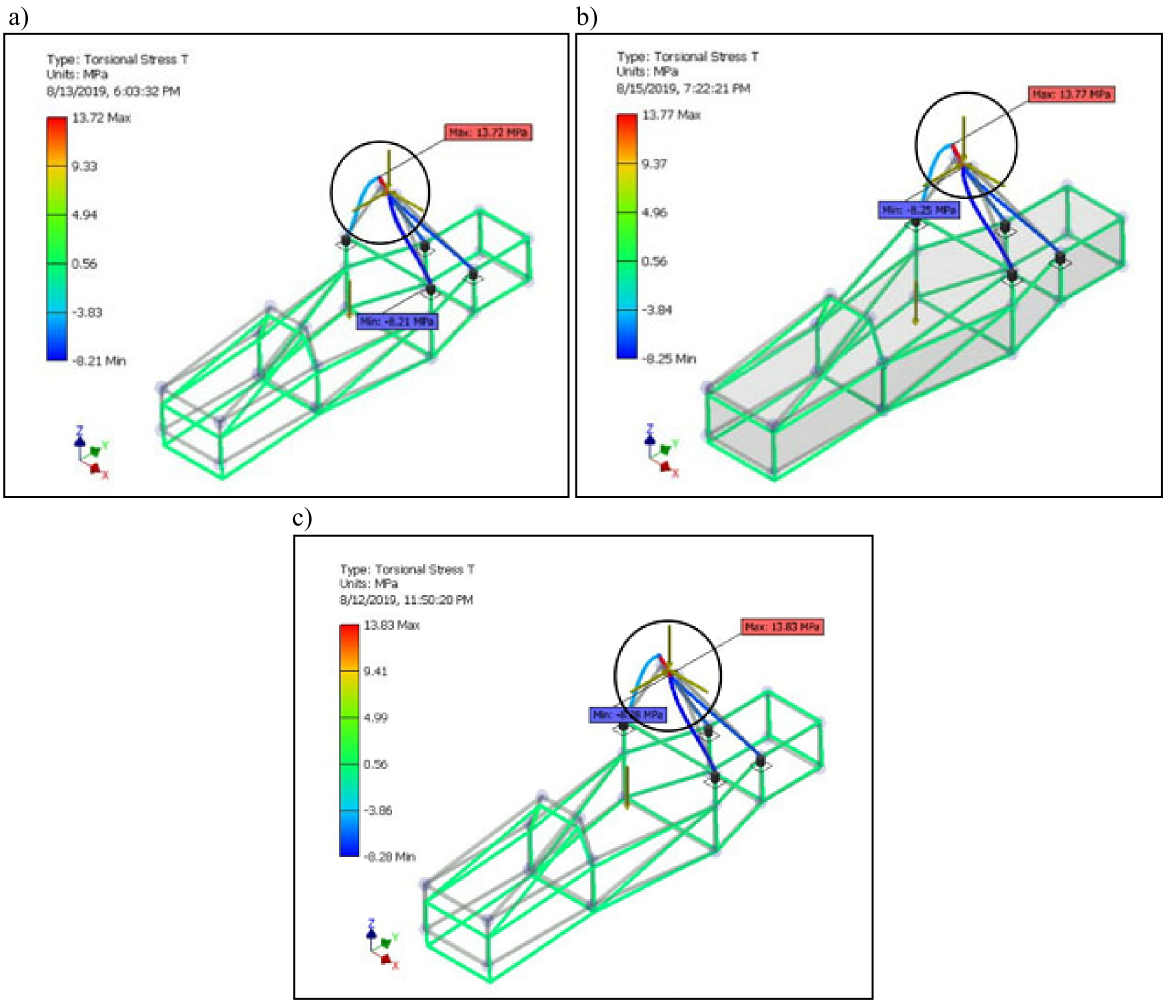

Fig. 12. Results of Autodesk Inventor simulation on torsional stress: a) torsional stress 502 mm, b) torsional stress 504 mm, c) torsional stress 506 mm

Table 8.
Table of torsional values in chassis (A-I)

Type chassis	High roll hoop, mm	Load (F1, F2, F3), kN	Normal stress, MPa	Torsional stress, MPa	Stress difference, MPa	Decision
A	502	9, 6, 5	312.4	13.72	298.68	x
B	504		249.7	13.77	235.93	The best value
C	506		302.8	13.83	288.97	x
D	508		302.9	13.88	289.02	x
E	510		303.1	13.93	289.17	x
F	512		313.1	13.99	299.11	x
G	514		303.4	14.04	289.36	x
H	516		303.6	14.10	289.50	x
I	518		307.9	14.15	293.75	x

Figure 12 shows the results of the torsional test with Autodesk Inventor. The results of this torsional test show a not so striking difference in the three chassis as shown in Figure 12a,b, and c (black circle). This is caused by the results of Torsional values that are not far adrift between the two. From Figure 11 it can be concluded that the relationship graph between the height of the main roll-hoop to torsional is increasingly increasing in value with the increasing height of the main roll hoop and applies vice versa. While the relationship between the height of the main roll hoop to the Normal stress tends to be stable.

Table 8, shows the torsional values on all chassis types (A-I), on the static loading of 9, 6 and 5 kN. Torsional value results vary and production values that are not too far away, and this table shows the value of the difference in stress that occurs in the chassis as a whole and the results obtained type B chassis, with the height of the main roll hoop: 504 mm, has the smallest value difference of 235.93 MPa. Therefore chassis type B is more recommended in terms of safety as shown in Table 8.

4. Conclusions

From the results of this study it can be concluded as follows:

1. Normal stress value decreases with increasing roll-hoop height and applies in reverse to the torsional stress value.
2. Deflection values tend to be stable with increasing roll-hoop height, while Shear stress T-x and T-y values tend to fluctuate.
3. The optimization results of the design of the roll hoop height on the chassis show that the chassis type B with the main roll hoop height of 504 mm is the best with the lowest deflection value and the difference in stress.

References

[1] R.K. Sahu, S.K. Sahu, S. Behera, V. Santosh Kumar, Static Load Analysis of a Ladder Type Chassis Frame, Imperial Journal of Interdisciplinary Research 2/5 (2016) 2454-1362.

[2] N.V. Palde, V.L. Kadlag, Design improvement and analysis of car chassis for Static and Dynamic Characteristics, International Engineering Research Journal 238-244.

[3] Y. Wang, J. Liu, Y. Li, N. Yang, Research on Optimization of Formula SAE Truss-Frame, MATEC Web of Conferences 95 (2017) 07008. DOI: https://doi.org/10.1051/matecconf/20179507008

[4] N.G. Jogi, A.P. Take, Y. Asolkar, S.M. Aftab, Review Work on Analysis of F1 Car Frame Using Ansys, International Journal of Research in Engineering and Technology 03/04 (2014) 215-217.

[5] A. Kashikar, S. Mhatre, A. Gunpalli, R. Chavan, A. Shukla, Design and Analysis of Formula Car Chassis, International Journal of Research Publications in Engineering and Technology 3/3 (2017).

[6] A. Singh, A. Tiwari, S. Kalsa, A. Kumar, A. Kant, Design and Simulation of F-1 Car Chassis, International Journal of Engineering Development and Research 6/2 (2018) 434-439.

[7] R. Pal Singh, Structural Performance Analysis of Formula SAE car, Jurnal Mekanikal 31 (2010) 46-61.

[8] P.R. Shahade, A.K. Kaware, Structural Performance Analysis of Formula SAE Car, International Journal of Pure and Applied Research in Engineering and Technology 2/9 (2014) 307-320.

[9] M.L. Mohamad, M.T.A. Rahman, S.F. Khan, M.H. Basha, A.H. Adom, M.S.M. Hashim, Design and static

structural analysis of a race car chassis for Formula Society of Automotive Engineers (FSAE) event, IOP Conference Series: Journal of Physics 908 (2017) 012042. DOI: https://doi.org/10.1088/1742-6596/908/1/012042

[10] R. Siswanto, R. Subagyo, H. Isworo, F. Gapsari, Modeling Analysis of the Effect of the Main Roll Hoop Length on the Strength of Formula Student Chassis, Eastern-European Journal of Enterprise Technologies 4/7(100) (2019) 22-29. DOI: https://doi.org/10.15587/1729-4061.2019.162833

[11] J.S. Nagaraju, U. Hari Babu, Design And Structural Analysis of Heavy Vehicle Chassis Frame Made of Composite Material By Varying Reinforcement Angles of Layers, International Journal of Advanced Engineering Research and Studies 1/2 (2012) 70-75.

[12] H. Hazimi, Ubaidillah, A.E.P. Setiyawan, H.C. Ramdhani, M.Z. Saputra, F. Imaduddin, Vertical Bending Strength and Torsional Rigidity Analysis of Formula Student Car Chassis, AIP Conference Proceedings 1931/1 (2018) 030050-1–030050-8. DOI: https://doi.org/10.1063/1.5024109