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Roll-Cage's Hollow-Tubing Specification Assessment for an Off-Road Buggy

Mohd Amir Shazwan Hashim[1], Muhammad Izzat Nor Ma'arof[1*], Nur Qistina Binti Jamaludin[1], Lim Khai Hen[1], Nurzaki Ikhsan[2], Girma Tadesse Chala[3]

[1]Faculty of Engineering and Quantity Surveying (FEQS), INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia
[2] Pengajian Kejuruteraan Mekanikal, Kompleks Kejuruteraan Tuanku Abdul Halim Mu'adzam Shah, Universiti Teknologi MARA (UiTM), Jalan Ilmu 1/1, 40450 Shah Alam, Selangor Darul Ehsan Malaysia
[3]International College of Engineering and Management, P.O. Box 2511, C.P.O Seeb 111, Muscat, Oman

***Email:** amirshazwan.hashim@newinti.edu.my

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Abstract: For an off-road buggy car, the roll cage is one of the most important safety features which needs to be integrated in the overall chassis design. The structure must be able to provide protection to the driver under various load conditions – especially during roll-over. The objective of this study was to determine the optimal roll cage assembly's hollow-tubing diameter for the INTI University's off-road buggy. The BAJA SAE standard was followed in designing the roll-cage. Based on the BAJA SAE standard, comparisons were made between two (2) hollow-tubing which were 21.3mm and 26.9 mm in outer diameter and with similar wall thickness of 2.3mm. The CAD model was developed via the Inventor software and Finite Element Analysis (FEA) was conducted via the ANSYS software. The result showed that for frontal impact, side impact and roll-over, the pipe with the outer diameter of 26.9mm has higher values safety factor at 2.8; against 1.79 for the 21.3mm. This is due to the difference in second moment of inertia, where, a tubing with higher second moment of inertia, has higher bending strength and stiffness. Nonetheless, the 21.3mm hollow tubing is still a good option for selection if factors such as minimal production cost and vehicle's mass are of priority. In accordance to the BAJA SAE standard, the safety factor for the roll-cage needs to be within the range of 1.5 to 2. Thus, the 26.9mm tubing is overdesigned and could be omitted. For future studies, other assessments such as material selection for the roll-cage could be conducted.

Keywords: BAJA SAE; Roll-cage; Factor of Safety; Finite Element Analysis

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Introduction

For an off-road buggy car, the roll cage is one of the most important safety features which needs to be integrated in the overall chassis design (Nor et al., 2020). The structure must be able to provide protection to the driver under various load conditions – especially during roll-over (Shazwan et al., 2020).

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The common practice to mount a roll cage onto the chassis is by permanent joint such as welding. It is generally strong due the impact force will concentrate on the welded point, with the condition that the welding is done correctly and this could only be done by a high-skilled labour. However, in order to make a multipurpose vehicle to become interchangeable between a formula car and off-road buggy car, the roll cage should be a detachable component by using semi-permanent integration method, i.e., mechanical fasteners such as nuts and bolts. The roll cage is selected to be detachable for the purpose of allowing the vehicle to enter different types of competition where the roll cage is of different specifications. In order to connect the roll cage either by bolted or welded, another aspect need to be considered is depend on the design of the roll-cage. Figure below shows the designs that have been proposed by Ana Pavlovic and Zivkovic 2016.

The objective of this study was to determine the optimal roll cage assembly's hollow-tubing diameter for the INTI University's off-road buggy. The BAJA SAE standard was followed in designing the roll-cage. Based on the BAJA SAE standard, comparisons were made between two (2) hollow-tubing which were 21.3mm and 26.9 mm in outer diameter and with similar wall thickness of 2.3mm.

Methodology

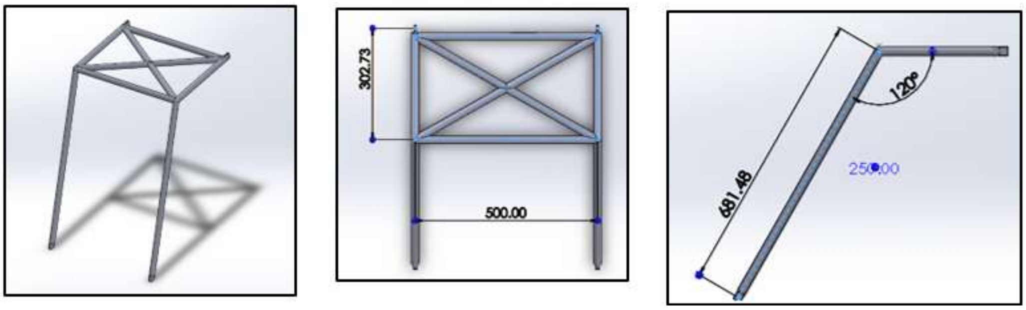

Figure 1. Roll cage design

Figure 1. shows roll cage design. The CAD model was developed via the Inventor software and Finite Element Analysis (FEA) was conducted via the ANSYS software.
FEA is the tools that enables us to study the behaviour of an object under influences of external factors. The analysis was done to this design is static analysis which is the impact of the roll cage on its stress and displacement caused by external forces. The procedure of this analysis is outline as followed:

Table 1. Mechanical properties of material

No.	Material	Mechanical properties	
1.	Aluminium Alloy 1060-H14	Young Modulus	: 6.9e+10 N/m^2
		Poisson's Ratio	: 0.33
		Mass density	: 2705 kg/m^3
		Thermal expansion coefficient	: 2.36e-05/K
		Yield strength	: 90000000 N/m^2
2.	Steel 4340	Young Modulus	: 2.05e+11 N/m^2
		Poisson's Ratio	: 0.29
		Mass density	: 7850 kg/m^3
		Thermal expansion coefficient	: 1.23e-05/K
		Yield strength	:470000000 N/m^2
3.	Chrome stainless steel	Young Modulus	: 2E+11 N/m^2
		Poisson's Ratio	: 0.28
		Mass density	: 7800 kg/m^3

Thermal expansion coefficient	: 1.1e-05/K
Yield strength	: 172339000 N/m^2

Three types of different materials which is aluminium alloy 1060-H14, steel 4340 and chrome stainless steel is applied in each design with different dimension (21.3 x 2.3 and 26.9 x 2.3). The mechanical properties of each design are shown in the Table 1.
There are 3 types of analysis is carried out on the roll cage design, namely front impact, side impact, and roll over (See Table 2). Each analysis needs to apply external force before doing the meshing. The force by using analytical calculation with different direction of crash.

Table 2. External forces

Impact	**Force (N)**
Front impact	788
Side impact	315
Roll over	945

Newton's 2^{nd} Law of motion formula is applied in order to calculate the amount of force exerted onto the roll cage.

$$F = ma \tag{1}$$

The static analysis involve in this calculation is taken from the roll cage, since the main-focus is involved with the analysis of the roll-cage, Hence the mass of the roll cage and the acceleration of this object will be use to analyse the front impact, side impact, and roll over force.

Result and Discussion

Table 3 shows analysis results and data for factor of safety. Front and side impact simulations analysis for deformation, Von-Mises stress and factor of safety are depicted in Figures 3 and 4, respectively.

Table 3. Analysis result and data for factor of safety.

Pipe size (mm)	Material	Front impact test	Side impact test	Roll over test
21.3 x 2.3	Steel	1.27E+01	1.17E+01	1.40E+01
	Aluminium	1.62E+00	1.49E+00	1.79E+00
	Chrome	3.07E+00	2.72E+00	3.30E+00
26.9 x 2.3	Steel	1.47E+01	1.46E+01	2.24E+01
	Aluminium	1.87E+00	1.86E+00	2.86E+00
	Chrome	3.55E+00	3.45E+00	5.27E+00

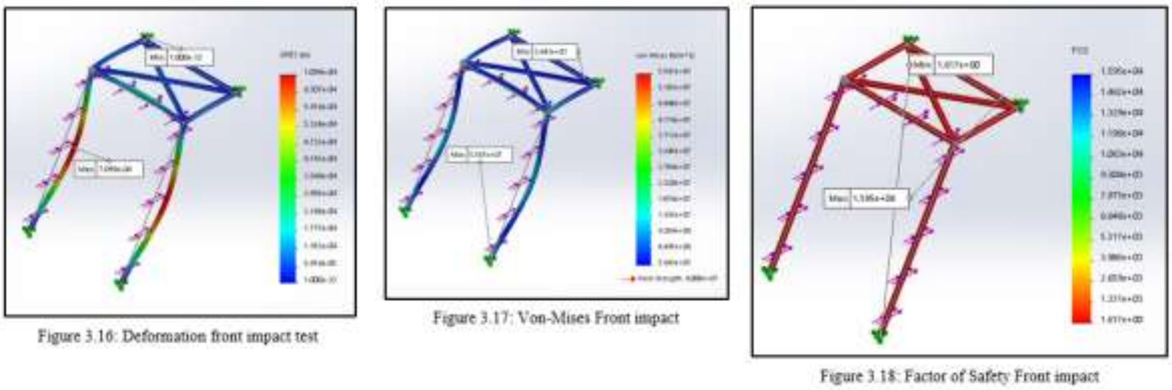

Figure 2. Front impact simulation analysis for deformation (left), Von-Mises stress (middle) and factor of safety (right).

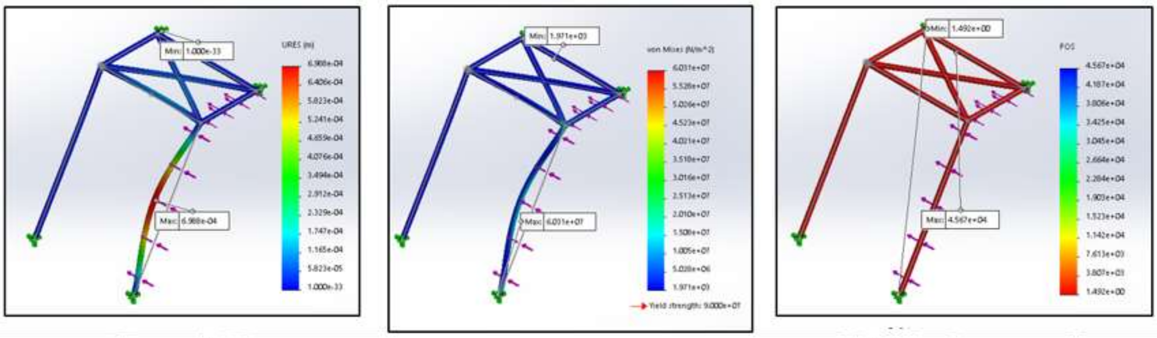

Figure 3. Side impact simulation analysis for deformation (left), Von-Mises stress (middle) and factor of safety (right).

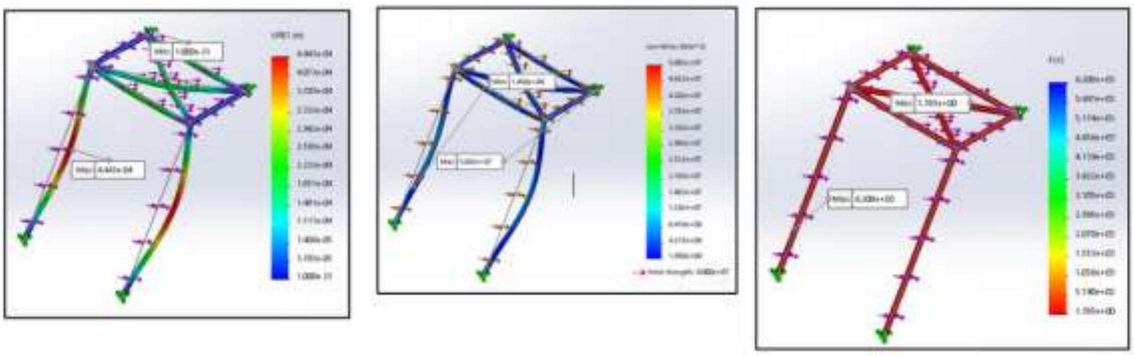

Figure 4. Side impact simulation analysis for deformation (left), Von-Mises stress (middle) and factor of safety (right).

The result showed that for frontal impact, side impact and roll-over, the pipe with the outer diameter of 26.9mm has higher values safety factor at 2.8; against safety factor at 1.79 for the 21.3mm. This is due to the difference in second moment of inertia, where, a tubing with higher second moment of inertia, has higher bending strength and stiffness. Nonetheless, the 21.3mm hollow tubing is still a good option for selection if factors such as minimal production cost and vehicle's mass are of priority. In accordance to the BAJA SAE standard, the safety factor for the roll-cage needs to be within the range of 1.5 to 2. Thus, the 26.9mm tubing is overdesigned and could be omitted. For future studies, other assessments such as material selection for the roll-cage could be conducted.

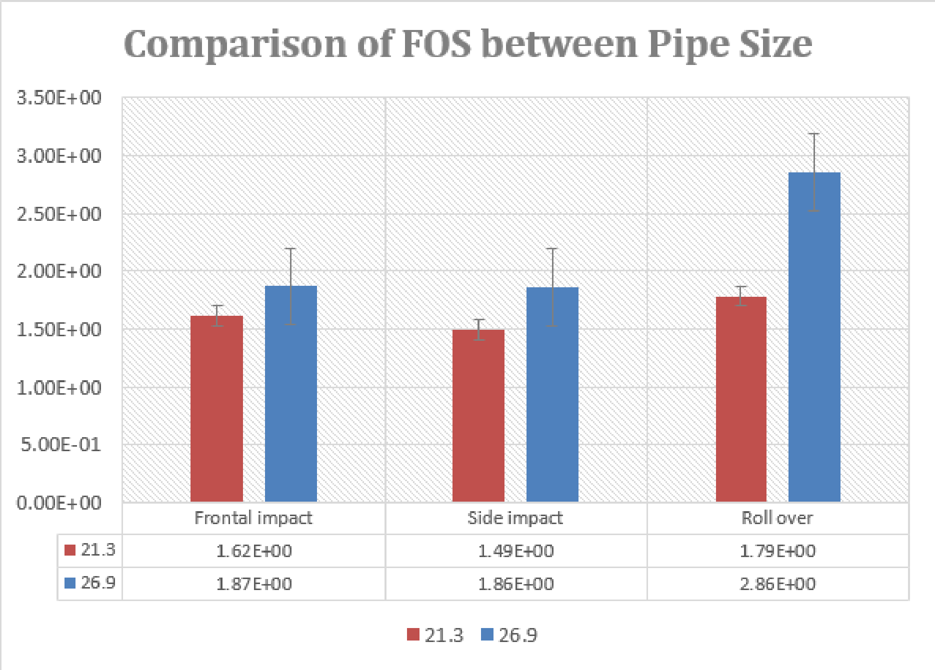

Figure 5. Comparison of Factor of safety against the impact test on outer diameter pipe 21.3mm and 26.9mm

Figure 5 shows the comparison of factor of safety against impact test on outer diameter pipe of 21.33 mm and 26.9 mm. Design B is tested on two different number of pipe size. The comparison is made between the outer diameter of the pipe which is 21.3mm and 26.9 mm with the same wall thickness 2.3mm. The main purpose of this experiment is to study which pipe size is suitable to be select for the roll cage design B.

The graph in the Figure 5, shows that the pipe with outer diameter 26.9mm has higher values factor of safety. This is due to the difference in second moment of inertia. Pipe with higher second moment of inertia, has higher bending strength and stiffness. However, when the diameter is less, the weight will be less. Therefore, it is better to choose the available diameter that is least to satisfy the design considerations.

Although the values factor of safety for outer diameter 21.3mm is less compare to 26.9mm, but still the pipe size is safe to be used as the factor of safety is in the range of 1.5 to 2. The pipe size of 26.9mm is overdesigned in the roll over test. Thus, from the experiment the pipe size with outer diameter 21.3mm is selected for the roll cage design B.

Conclusions

Conclusively, the result showed that the design was indeed acceptable and satisfactory. The design is indeed safe and in accordance to the BAJA SAE's requirements. Even so, for the purpose of continuous improvement and sustainability the design could still be acknowledged as over-designed. Thus, for future studies, other assessments such as the truss design, the overall specifications and designs for the roll-cage could be conducted.

Acknowledgements

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