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Material Selection and Analysis of Torsional Rigidity in Formula Student SAE regulation

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Abstract

The advancement of automotive technology is rapid in this era, as evidenced by the existence of autopilot vehicles that have been developed by a scientist. This progress is balanced with the knowledge that continues to develop in the world of education. Many prestigious automotive competitions are held to be a venue for student creativity and research in developing automotive technology, one of which is the Formula Student SAE. This is the background of a study to develop an engineered electric vehicle chassis, especially in Formula Student. This study aims to produce a chassis design that has torsional rigidity based on the selection of materials that have stiffness, strength, lightweight, and relative cost. The structure of the vehicle was designed following Formula Student SAE regulations. To select material, initial screening was used by the Ashby method which produce 4 material types. Optimum of selecting the material used the Simple Additive Weighting (SAW) method. Meanwhile, chassis with material selected was analyzed by using Solidworks Simulation Education software. The results of this study produced Aluminum Alloys 7075-T6 material and torsional rigidity value of 552.65 x 10^3 Nmm/degree of chassis, which could achieve the minimum torsional rigidity value set at 500 x 10^3 Nmm/degree.

Keywords: chassis, torsional rigidity, formula student, Ashby Method, Simple Additive Weighting

1. Introduction

The use of vehicles as a means of transportation is currently very important. Technological advances in vehicles continue to be developed especially autopilot vehicles. This development is carried out by research of scientists, product development by automotive industry players, and the role of students taking part in the development of technology in vehicles, by holding national or international automotive competitions, providing opportunities for students to innovate in developing technology. The Formula Student SAE Competition is one of the places to develop automotive technology. Participants are allowed to show their creativity and skill to engineer vehicles to be more effective and efficient, thus producing new innovations in the automotive. Developments are carried out on the engine, suspension system, chassis, braking system, aerodynamic body, and safety factors. Chassis is an important component of a vehicle. The main function of the chassis is to hold all the components in the vehicle [1]. The frame of the vehicle is designed by considering the vertical and roll forces during cornering [2], [3]. In automotive, the rigidity of the frame is very important. This study aims to design an electric car frame design adjusted with the Formula Student SAE regulations. The frame was designed by considering to have a lightweight, relative cost, and still have enough rigidity to resist the roll forces when cornering. This research was conducted by simulation testing using SolidWorks Education software. It determined the amount of displacement that occurs when a load is applied to both ends of the front wheel which simulates cornering. The space of the frame prioritized triangulation in its construction to reduce bending loads [4]. The resistance of the chassis is called stiffness, torsional rigidity is the resistance of the chassis to torsional forces [5], [6].

In selecting materials in this study, that used the Ashby method. The Ashby method is a systematic process for determining the materials required in the design [7]. There are several stages in selecting

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material using the Ashby method, namely first defining the needs of a material according to design requirements (translation). After being defined, the selection process (Screening) determined several candidate materials to be used, at this stage usually using bubble chart material. Then, the ranking process was done by some materials. After getting the material that is appropriate, then search for the information about the material [8].

2. Research Methodology

To achieve the analysis, this paper used several steps as shown in Figure 1.

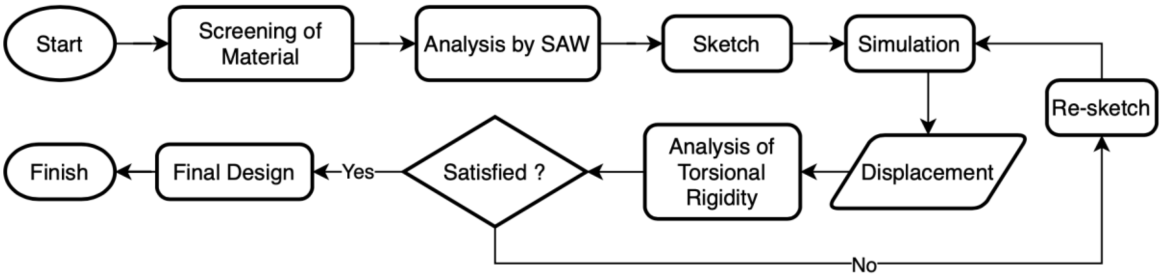

Figure 1. Flowchart

2.1 Chassis Design

The chassis design used the 3D Solidworks Education software. All sizes on the chassis were adjusted to the Formula Student SAE regulations [9]. Starting with the outline sketches a chassis, then adding a weldment feature to add tubing to the sketch as in Figure 2. The tubing had 26.3 mm in diameter with 3 mm in thickness. The overall dimension of the chassis was 1900 x 650 x 960 mm and followed the regulation of SAE.

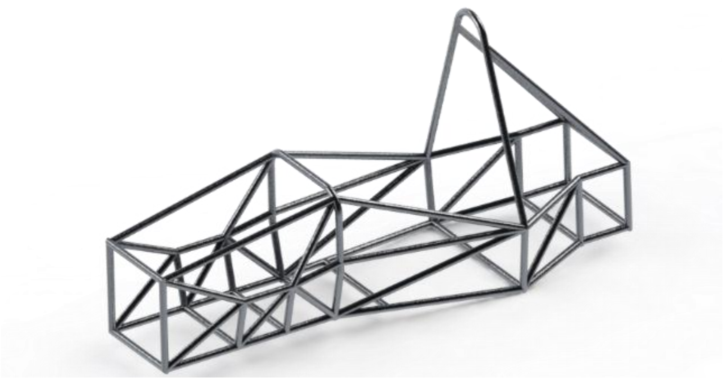

Figure 2. Chassis sketch

2.2 Material Selection

The material selection for the chassis was using the Ashby method. The chassis of the material had lightweight and relative cost. This chassis was designed to resist the bending load so that the material with sufficient strength was also needed. In this study, the strength limit is above 305 MPa was given as Formula Student SAE regulation. In addition to having strength, this material must have a stiffness to increase resistance to resist torsional loads. This study had given the limit of Young's Modulus, above 61 GPa. Granting a limit was obtained from the proportional limit of metal material with a yield strength of steel of 305 MPa based on the SAE Student Formula regulations, divided by the specific strain value of 0.005 [10]. After defining the design needs, the materials were screened by using a bubble chart to select materials that have characteristics according to design needs.

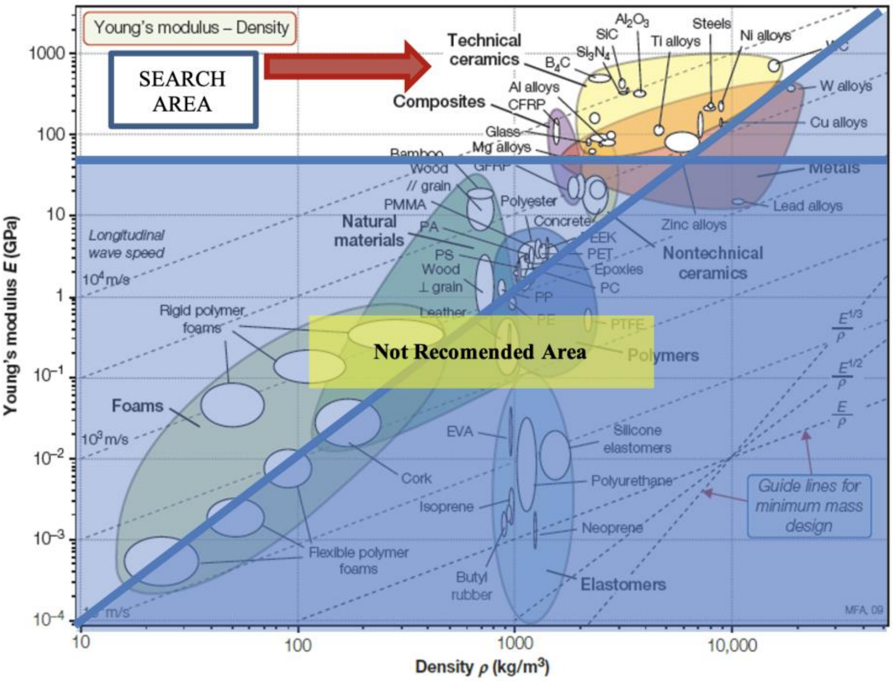

Figure 3. Young's Modulus – Density to Bubble Chart [8] (Edited by Author)

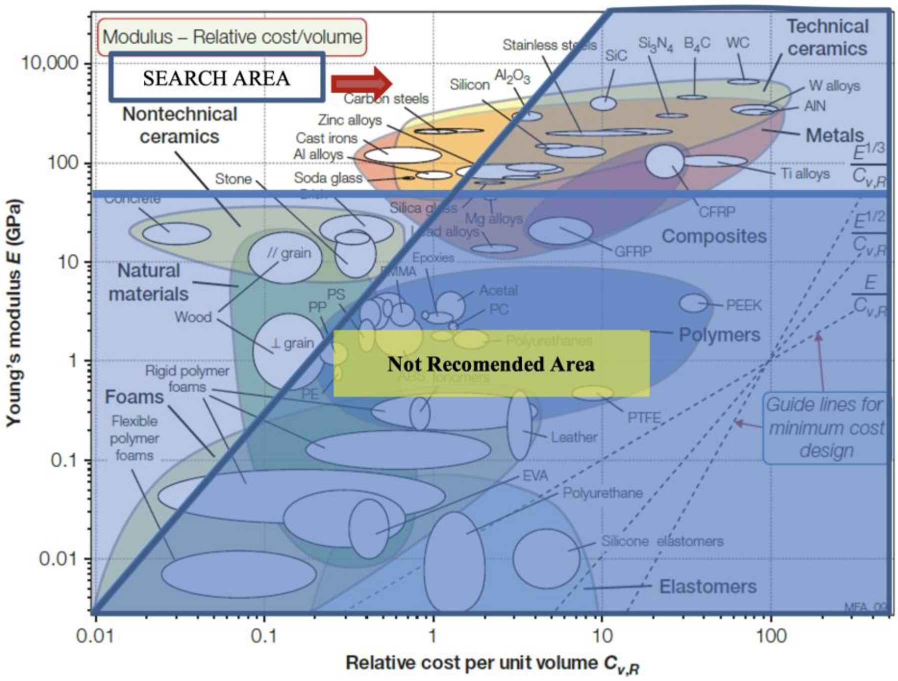

Figure 4. Young's Modulus - Relative Cost per Unit Bubble Chart [8] (Edited by Author)

Based on Figure 3 and Figure 4, materials that match the characteristics of the design requirements are zinc alloys, magnesium alloys, aluminum alloys, and steels. This bubble chart aims to find materials that have considerable stiffness, lightweight, and cost.

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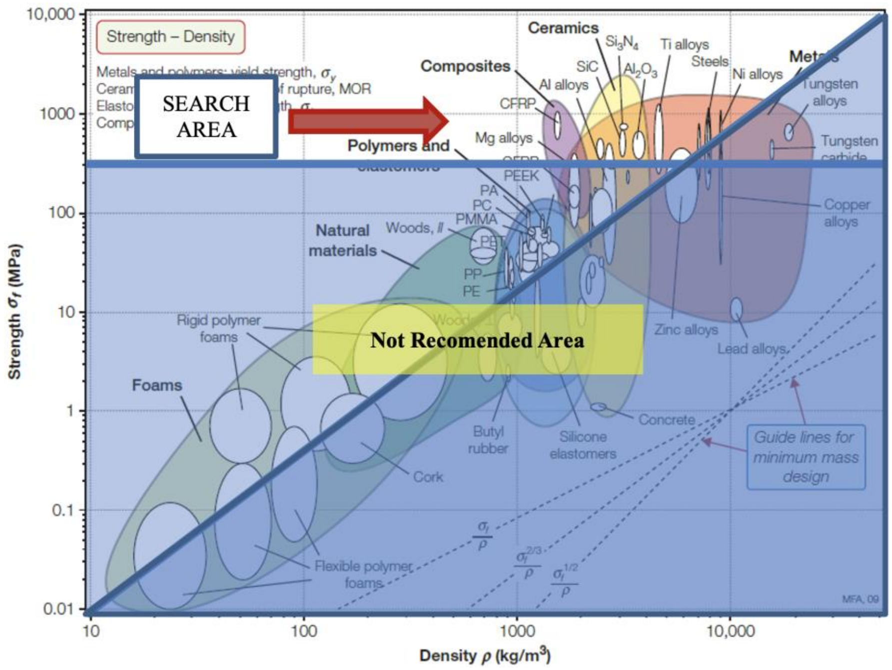

Figure 5. Strength - Density Bubble Chart [8] (Edited by Author)

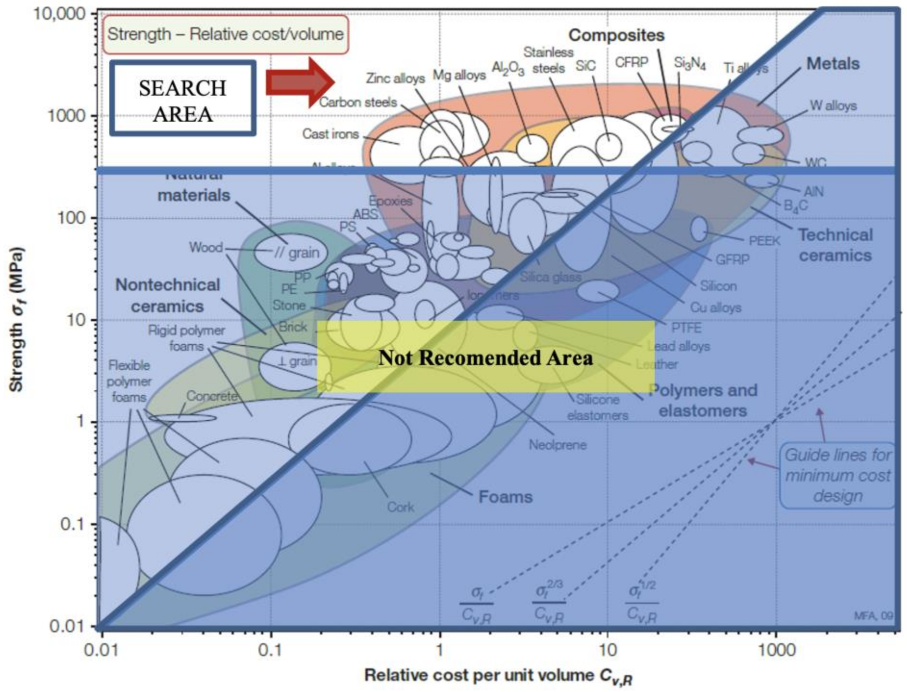

Figure 6. Strength - Relative Cost per Unit Bubble Chart [8] (Edited by Author)

Based on Figure 5 and Figure 6, materials that match the characteristics of the design requirements are zinc alloys, magnesium alloys, aluminum alloys, and steels. This bubble chart aims to find materials that have considerable strength, lightweight, and cost.

The first step was done by screening material using Ashby Method. It obtained aluminum alloy, steel, magnesium, and zinc alloy as Table 1. The next step is to rank the materials by using the simple additive weighting approach. Simple Additive Weighting (SAW) is a technique for making decisions using simple multi-attributes [11], [12]. The decision in this method was based on a weighted. Because the material needed is which has a lightweight, the cost to be considered, sufficient strength and stiffness, a weight value is made as follows:

Lightweight : 0,35

Relative cost : 0,25

Strength of Materials : 0,2

Stiffness of Materials : 0,2

Table 1. Material Screening

No.	Material	Density (kg/m³)	Young's Modulus (GPa)	Yield Strength (MPa)	$C_{V,R}$ (Figure 4)
1	Aluminium Alloys	2700	69 - 74	27 - 300	0,96
2	Steels	7800	200-210	130-700	0,99
3	Magnesium	1738	50	200-460	0,98
4	Zinc Alloys	7100	96,5	282,68	1

Furthermore, the material matrix was determined by the maximum and minimum values for each criterion.

- Density criterion, determine the minimum value by Equation 1.

$$Density\ Matrix\ value = \frac{minimum\ value}{criteria\ value} \quad \text{Eq. 1}$$

- Young's Modulus criterion, determine the maximum value by Equation 2.

$$Young's\ modulus\ Matrix\ value = \frac{criteria\ value}{maximum\ value} \quad \text{Eq. 2}$$

- Yield strength criterion, determine the maximum value by Equation 3.

$$Yield\ Strength\ Matrix\ value = \frac{criteria\ value}{maximum\ value} \quad \text{Eq. 3}$$

- Cost criterion, determine the minimum value by Equation 4.

$$Cost\ Matrix\ value = \frac{minimum\ value}{criteria\ value} \quad \text{Eq. 4}$$

The following criterion was matrix result as in Table 2:

Table 2. Matrix of material

Material	Density	Young's Modulus	Yield Strength	Cost
Aluminium Alloys	0,64132	0,365	1,5	1
Steels	0,22282	1	1,5	0,96969
Magnesium Alloys	1	0,25	1	0,97959
Zinc Alloys	0,24478	0,4825	1,413425	0,96

This matrix value would be times by the weight value that has been determined to determine the material that has the criteria according to needs. Then will be known the result as in Table 3. It produced that the aluminum alloys had a criterion according to design needs by summing each of the criteria.

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Table 3. Results of Ranking Step

Material	Density	Young's Modulus	Yield Strength	Cost	Total
Aluminium Alloys	0,22446	0,073	0,3	0,25	0,84746
Steels	0,07798	0,2	0,3	0,24242	0,82041
Magnesium Alloys	0,35	0,05	0,2	0,24489	0,84489
Zinc Alloys	0,08567	0,0965	0,28268	0,24	0,70486

2.3 Results of Design Analysis

Finite element analysis simulations were using 3D Solidworks Education software. The load on both front wheels was the same amount but in different directions, and the rear was fixed. The analysis was simulated by vehicle cornering. After getting the simulation results, the displacement value was obtained which entered into the torsional rigidity formula.

3. Results and Discussion

The results and discussion in this study include the material to be used for the chassis and analyze the chassis, whether it achieves the torsional rigidity target. From the results of selecting materials using the Ashby method, material from the Aluminum Alloy is obtained as the material used to build a vehicle chassis. Aluminum is a material with a density of 2700 kg/m^3, so it can be said to have a lighter weight than steel. The following are the characteristics of aluminum in Table 4.

Table 4. Characteristic of Aluminium [13]

Physical of Properties Material	High Pure Aluminium
Crystal Structure	FCC
Density at 20˚C (in 10^3 kg/m^3)	2.698
Melting point (˚C)	660.1
Heat Creep Coefficient 20˚~100 ˚C (10^{-6}/K)	23.9
Heat Conductivity 20˚~ 400 ˚C (W/(m.K))	238
Electrical Resistance 20˚ (10^{-8} K. W. m)	2.69
Young Modulus (GPa)	70.5
Rigidity Modulus (GPa)	26.0

There are several types of aluminum that are distinguished by their alloys. The 1xxx series is 99% pure aluminum. The 2xxx series is an aluminum alloy with copper (Al-Cu). The 3xxx series is an aluminum alloy with manganese (Al-Mn), usually used for panels or kitchen utensils. The 4xxx series is an aluminum alloy with silicon (Al-Si), which is commonly used for engine spherical materials, for example, pistons. The 5xxx series is an aluminum alloy with magnesium (Al-Mg). The 6xxx series is an aluminum alloy with magnesium and silicon (Al-Mg-Si), which is often used for construction materials or architectural frames. The 7xxx series is an aluminum alloy with zinc and magnesium (Al-Zn-Mg), widely used as a material in the best aircraft manufacturing, frame construction because this series has good weldability. The 8xxx series is an aluminum alloy with other materials [14].

Aluminum alloy 7xxx series is the material chosen for the manufacture of vehicle frames, because the vehicle frame in this study uses a space frame type, connecting the tubing by the welding process. Aluminum type 7075 T6 (Al-Zn-Mg) with heat-treated solution then artificial aging, and done artificial aging above room temperature has characteristics that match the design requirements. The following is the characteristics of the Al 7075 T6 as shown in Table 5.

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Table 5. Characteristic of Al 7075 T6 [15]

Physical of Properties Material	Unit in Metrics
Density (kg/m³)	281000
Ultimate Tensile Strength (MPa)	572
Tensile Yield Strength (MPa)	503
Modulus of Elasticity (GPa)	71,7
Shear Strength (MPa)	331

Torsional rigidity was determined by applying a force of 200 N to the point of the front wheel with the direction of the force between the right wheel and the left wheel in the opposite direction (up and down). This direction would ensure that the order meets the target torsional rigidity. The analysis process is using finite element analysis on Solidworks Simulation Education software. The results of the simulation by Solidworks are shown in Figure 7.

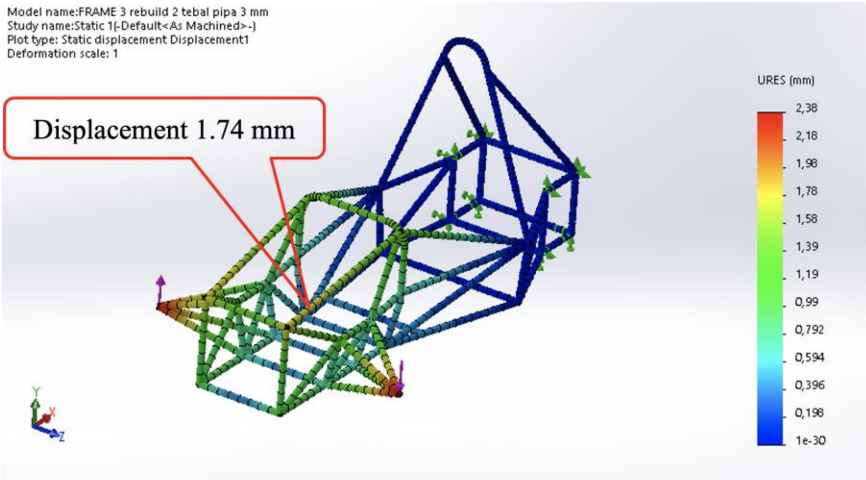

Figure 7. Displacement analysis

When the vehicle is at high speed and in turning conditions, it will produce a rolling effect. From the analysis of the first case study regarding torsional rigidity, the maximum displacement/angular deformation was 1.74 mm (shown in Figure 7). The displacement was selected because chassis in Figure 2. To determine the angle formed, the angular deformation distance must be divided by the center distance of width of vehicle (front part), which is 525 mm.

$$\psi = \frac{1{,}74}{525} \quad \text{Eq. 5}$$

$$\psi = 0.003314\, rad$$

The results obtained were angular displacement of 0.003314 rad or 0.01899 degrees. Next to calculate the torsional rigidity value, is to enter the data into Equation 6 [16], [17].

$$Torsional\ Rigidity = \frac{Torque\ Load}{Angular\ Displacement} \quad \text{Eq. 6}$$

$$Torsional\ Rigidity = \frac{(200)(525)\ Nmm}{0.01899\ degrees}$$

$$Torsional\ Rigidity = 552.65\ x\ 10^3\ Nmm/degrees$$

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The minimum torsional rigidity target was 500 x 10^3 Nmm/degree [18], while the analysis results reached 552.65 x 10^3 Nmm/degree. From these results, it can be concluded that the torsional rigidity value of the chassis design has reached the predetermined target so that when the vehicle is driving at high speed and turning, it will be stable.

4. Conclusion

The results of this study have obtained a material that fits the design needs through a systematic selection of the Ashby method, the material is Al 7075 T6, aluminum alloy with zinc and magnesium which is very suitable for building a space frame type chassis. And after analyzing the chassis construction using the finite element analysis method by the 3D Solidworks simulation design software. The resulting displacement value is 1,74 mm with a load of 200 N on the left and right front wheels in the opposite direction. The minimum torsional rigidity target was 500 x 10^3 Nmm/degree, the torsional rigidity produced by this vehicle frame after simulation was 552.65 x 10^3 Nmm/degree, so this shows the target has been exceeded. The vehicle will be stable when cornering at high speed because it will resist torsional rigidity.

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