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Simulation Of Electric Scooter Frame With Broadtrack Model Using Finite Element Method

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Abstract— **The frame is a main component for electric scooter construction which must have high distortion resistance to minimize the failure risk. This study aims to design a frame for electric scooter with broadtrack model and 1200 W of wheel drive motor power. The simulation was conducted by Finite Element Method (FEM) using Aluminum 6061 and Steel AISI 1020 as the material frame. The down tube used rectangular profile pipe and others used cylindric profile. The frame was generated in 3D model and been analysed using static structural. The results showed the biggest maximum stresses and also the smallest deformation given by steel AISI 1020 are 84,852 Mpa and 0.1082 mm, respectively. The minimum safety value for AISI 1020 steel material is 2.3813 and 6061 aluminum alloy is 1.5518. These show that the effect of mechanical properties on steel AISI 1020 is better than aluminum 6061. Overall, the Electric scooter frame should be recommended using steel AISI 1020.**

Index Terms— **Aluminium 6061; Electric skuter frame; FEM; Steel AISI 1020.**

Abstrak– **Rangka adalah komponen utama dan penting pada sepeda yang mana harus memiliki ketahanan distorsi yang tinggi untuk meminimalisir resiko cidera. Penelitian ini bertujuan untuk merancang rangka skuter listrik dengan model broadtrack dan motor listrik 1200 W. Rangka disimulasi dengan Metode Elemen Hingga (MEH) menggunakan material Aluminum 6061 dan Steel AISI 1020. Profil rangka pada bagian pipa bawah adalah persegi sedangkan yang lainnya silinder. Rangka dimodelkan dalam bentuk tiga dimensi dan dianalisis menggunakan perhitungan struktur statis. Hasil menunjukan nilai tegangan maksimum dan deformasi terkecil pada steel AISI 1020 adalah 84,852 Mpa dan 0.1082 mm. Nilai faktor keamanannya adalah 2.3813 untuk steel AISI 1020 dan 1.5518 untuk Aluminum 6061. Hal ini menunjukan penggunaan material steel AISI 1020 lebih baik daripada aluminum 6061. Secara keseluruhan, rangka skuter listrik direkomendasikan terbuat dari material steel AISI 1020.**

Kata Kunci— **Aluminium 6061; Metode elemen hingga; Rangka scooter listrik; Steel AISI 1020.**

I. INTRODUCTION

Electric vehicle is an eco-friendly transportation with electric propulsion power from motor that give an affordable and efficient mode for driving [1]. This innovation has been being enhanced for resulting the fast, powerfull propulsion, eficient performace and comfort [2]. Not only transportation mode, electric vehicle also can be used as medical tool to train body movement in rehabilitation [3].

Generally, electric vehicle has frame, wheel, brake, suspension, motor, battery, and others. But, the most importance component is frame that receive amount of vertical stiffness from driver and vehicle components [4]. So the frame should be made from material that has good mechanical properties like steel or alumunium or alloy. It aims to minimize the failure risk caused by the maximum loads of driver and components, or the resistance like aerodynamic force, surface of road, and inclined road [5]. Furthermore, the material and modelled frame can effect the stiffness of frame that has correlation with driver comfort and ergonomic [6].

Study about chassis of electric bike had been conducted based on stress, strain, and deformation at critical locations that obtained by FEM. The study showed that the external forces should be added for calculating the internal forces during maximum acceleration and maximum braking [1]. An electric bike chassis had been designed using solidworks then investigated its stability by performing static structural test [7]. An electric tricycle for post-stroke rehabilitation had been simulated the frame strength of Alumunium 6061 using FEM [8]. Three-wheeled electric bike frame in tadpole configuration had been investigated by the static strength structural using the FEM [9]. Scooter frame designed with various type of profile tube such as circular dan elliptical. Based on FEM simulation, the displacement and stress value are different for each under the various load condition. The circular profile tube had small deformation and high von misses stress [10].

This study focused on designing and analyzing the electric scooter frame by considering the type of material such as steel AISI 1020 and aluminium 6061. The analysis can be conducted by experimental or simulation, but there are 10% error of differences between experimental modal analysis and finite element analysis [4]. So the electric scooter frame would be analyzed using the Finite Element Method (FEM) to determine the strength, displacement, and safety factor [11].

II. METHOD

This study was conducted by, first, estimating the propulsion power by considering the driver and components weight and also the resistance. Second, designing the frame in 3D modelling using SolidWorks opensource software. Third, estimating the distributed load on the frame. Forth, simulating and analyzing the static structural on frame using Finite Element Method in ANSYS opensource software. This study investigated two kind of materials on a frame such as steel AISI 1020 and aluminium 6061. The stress, displacement and safety factor at critical locations were compared based on numerical results.

III. SOLUTION

The electric scooter had affected by aerodynamic resistance (drag) force, rolling resistance force, and slope resistance, as shown in Fig 1.

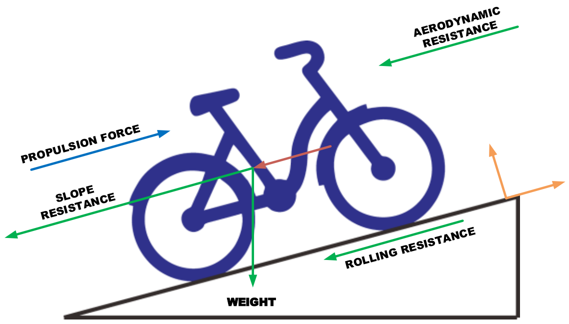


Figure 1. Free body diagram of a scooter moving up an inclined surface

A. Total mass

The factor affects used to select drive motor power. Total mass (m_t) was assumed from driver weight, frame weight and components weight (eq.1) that can be determined from:

(1)

B. Aerodynamic resistance

The aerodynamic resistance R_A depends on driver's frontal area A_f and relative velocity and also effected by wind desity ρ and drag coeffient C_d. The aerodynamic resistance forced can be calculated as:

$$R_A = 0.5 \times \rho \times A_f \times C_d \times V^2$$
$$R_A = 0.5 \times 1,2\ {}^{kg}/_{m^3} \times 0.5\ m^2 \times 1 \times (8.33\ {}^{m}/_{s})^2 = 20,8167\ N \quad (2)$$

C. Rolling resistance

The rolling resistance R_R is calculated from friction coefficient on the road surface. It is affected by tire type, road surface, and total mass.

$$R_R = m_t \times g \times C_r \quad (3)$$

The rolling resistance coeffiecient (C_r) of asphalt is 0,004 and ground is 0,008. So, the rolling resistance that occur on the asphalt is 4.65 N and on the ground is 9.413 N.

D. Slope resistance

On the inclined road, the electric scooter need more power for sustaining the driver and the scooter weight, it can be said slope resistance that is affected by degree of inclined surface road and velocity. If the slope degree get bigger, the slope resistancee force will be bigger.

$$R_S = m_t \times g \times \sin\theta \tag{4}$$

Electric scooter is assumed pass on two conditions such as flat road and inclined road. The slope resistance force on th flat road is 0 N. The maximum inclined surface road arround 10% that is 5,71° so the slope resistance force is 115.79 N.

E. The total of resistance

The total of resistance is derived from aerodynamic resistance, rolling resistance, and slope resistance.

$$F_t = R_A + R_R + R_S \tag{5}$$

So, the total resistance values based on flat and inclined asphalt are 25.5232 N and 141.3144 N. Then, the total resistance values based on flat and inclined ground are 30.2297 N and 146.0209 N.

F. The motor power

The motor power is obtained from resistance force total F_t times with velocity V.

$$P = F_t \times V \tag{6}$$

So, the e-scooter will have 4 powers based on 4 conditions, such as on flat and inclined asphalt are 212.6 W and 1177.14 W, then on flat and inclined ground are 251.81 W and 1216.3 W. From this calculation, the motor power is recommended in range 212,6083 - 1216,3541 watt.

G. The frame design

The frame and e-scooter design were constructed in 3D modelling using CAD Software, like Fig 2 and 3. The simulation was conducted to only frame based on finite element analysis in Ansys Workbech Software. There were two analysis were done based on frame material, first material is Steel AISI 1020 and second material is Alumunium Alloy 6061.

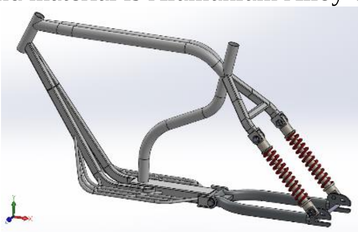


Fig 2. The frame of e-scooter


Fig 3. The design of e-scooter

In pre-processing stage, the Steel AISI 1020 material was set into the frame for first simulation then the second simulation the material was changed to Alumunium Alloy 6061. The mesh was generated in tetrahedon and hexahedon shape, 1 mm of element size, 10.515.579 nodes, and 4.319.224 elements. Then, the fix boundary condition was located on head tube and rear axle. There are 2 loads were set on the frame such as driver weight and component weight that was depicted by Fig. 4.(a). First, the driver weight was assumed in maximum value was $w = 100kg$ and distributed on the frame based on driver ergonomic using empirical equation [12] such as.

$$F = (empirical\ equation) \times 9.81\ {}^{m}/_{s^2} \tag{7}$$

Second, scooter's components weight were put on 4 points based on the location of component put (Fig. 4.(b)), such as seat tube (F_1), head tube (F_2), bracket part (F_3), and top tube (F_4).

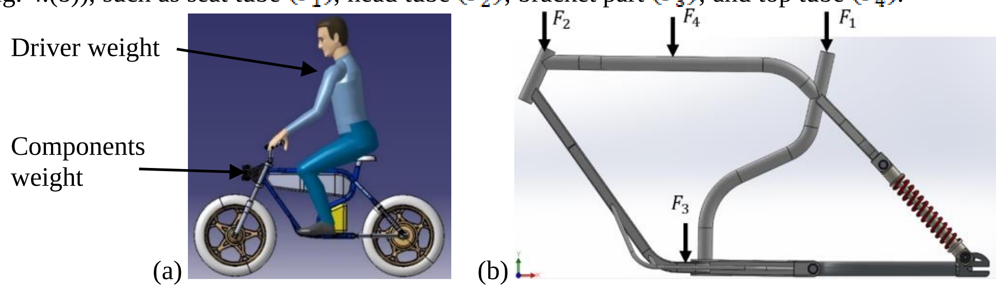


Figure 4. (a) Loads put on the frame, (b) Load points on the frame

The 1st point is F_1, where F_1 consist of head, neck, and torso (0.5940w – 2.20) and saddle-seatpost component times with gravitation force:

$$
\begin{aligned}
F_1 &= (m_{head,neck,torso} + m_{saddle} + m_{seatpost}) \times g \\
F_1 &= ((0.5940w - 2.20) + 0{,}5 + 0{,}33)kg \times 9.81\ {}^{m}/_{s^2} \\
F_1 &= (57.2 + 0{,}83)kg \times 9.81\ {}^{m}/_{s^2} = 569{,}2743\ N
\end{aligned} \tag{8}
$$

The 2nd point is F_2, where F_2 consist of upper arm, forearm, and hand (0.0505w + 0.01) and throttle, handle brake, and handle bar times with gravitation force:

$$
\begin{aligned}
F_2 &= (m_{upper\ arm,fore\ arm,hand} + m_{throttle} + m_{handle\ brake} + m_{handle\ bar}) \times g \\
F_2 &= ((0.0505w + 0.01) + 0.3 + 0.6 + 0.65)kg \times 9.81\ {}^{m}/_{s^2} \\
F_2 &= (5.06 + 1.55)kg \times 9.81\ {}^{m}/_{s^2} = 64.8441\ N
\end{aligned} \tag{9}
$$

The 3rd point is F_3, where F_3 consist of controller, reducer, and battery times with gravitation force:

$$
\begin{aligned}
F_3 &= (m_{controller} + m_{reducer} + m_{battery}) \times g \\
F_3 &= (0.25 + 0.107 + 5.12)kg \times 9.81\ {}^{m}/_{s^2} \\
F_3 &= 53.7294\ N
\end{aligned} \tag{10}
$$

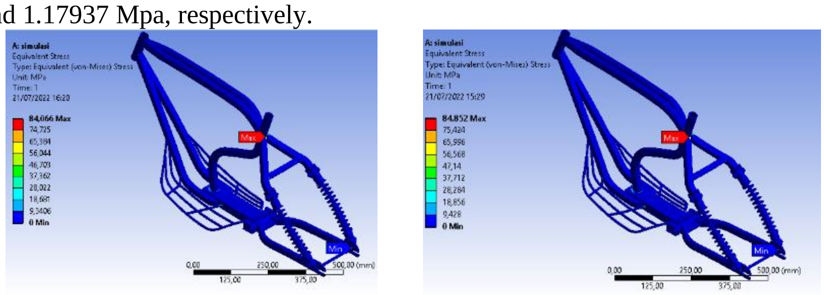
The 4th point is F_4, where F_4 consist of thigh, calf, foot (0.1582w+0.05) times with gravitation force:

$$
\begin{aligned}
F_4 &= (m_{thigh,calf,foot}) \times g \\
F_4 &= (0.1582w + 0.05)kg \times 9.81\ {}^{m}/_{s^2} \\
F_4 &= 155.6847\ N
\end{aligned} \tag{11}
$$

In the simulation stage, parameters set was total deformation, equivalent stress (von-mises), and safety factor. The numerical calculation process of static structural simulation is carried out using ANSYS Workbench. In the post-processing stage, the simulation resulted the influence and comparison between aluminum 6061 and steel AISI 1020 on the frame design with the same scooter geometry.

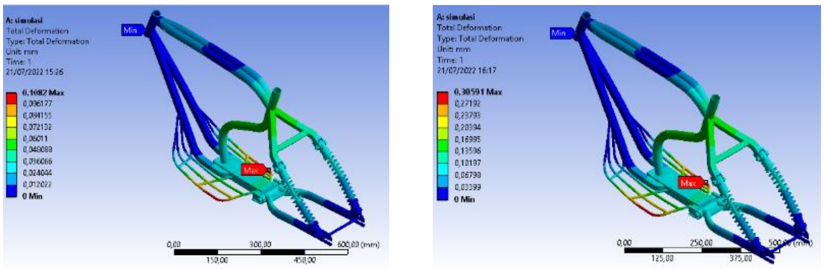
IV. RESULT AND DISCUSSION

Fig.5 depicts the AISI 1020 steel of frame material is deformed with a maximum stress equivalent value of 84.852 MPa on the upper seat stay profile and an average stess equivalent value of 1.7973 MPa. Meanwhile, the aluminum 6061 of frame material has the maximum and average equivalent stress are 84,066 MPa and 1.17937 Mpa, respectively.



(a). Steel AISI 1020 frame (b) Aluminum 6061 frame

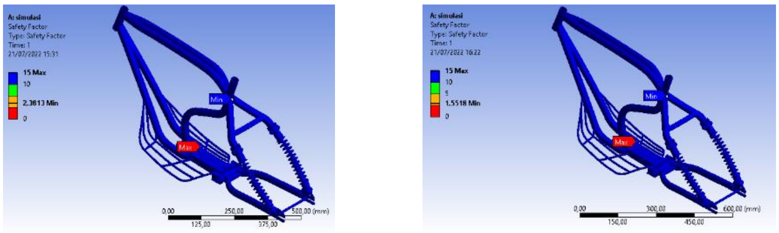
Figure 5. Equivalent stress analysis



(a). Steel AISI 1020 frame (b) Aluminum 6061 frame

Figure 6. Total deformation analysis

Figue 6 showed the total deformation value of AISI 1020 steel of frame material is 0.1082 mm on footholder section. Meanwhile, the total deformation value of aluminum 6061 of frame material is 0.30591 mm on footholder section.



(a). Steel AISI 1020 frame (b) Aluminum 6061 frame

Figure 7. The safety factor analysis

In figure 7, the average safety factor of AISI 1020 steel and aluminum 6061 of frame material is 14.99 and 14.98, respectively.

Table 1 Simulation results data

	Aluminium 6061			Steel AISI 1020		
	Equivalent stress (MPa)	**Total Deformation (mm)**	**Safety factor**	**Equivalent stress (MPa)**	**Total Deformation (mm)**	**Safety factor**
Maximum	84,066	0,30591	15	84,852	0,1082	15
Average	1,17937	0,075936	14,985	1,7973	0,026949	14,998
Minimum	0	0	1,5518	0	0	2,3813

The mechanical properties and deformation of the simulation and two different materials are listed in Table 1. It showed that there is no significant difference of Von Mises maximum stress value between the steel AISI 1020 frame and Aluminium 6061. It was proved from the isotropic materials are under the same force and neither reaches the plastic regime [13]. Aufar (2019) get no significant difference between AL 6061-T6 and AISI 1020 of electric three-wheeled bike frame [9]. In this simulation, the maximum stress concentration occurs in the seat tube and the top tube connection which is the critical location. Djoeli (2021) conducted static simulation on triangular structure road bike frame and showed the critical location happened in he seat tube and the top tube connection [13]. The Al 6061 frame has bigger maximum displacement around 0,3 mm than AISI 1020 that is occured in footholder section. Djoeli also get the maximum displacement in footholder section. The circular profile tube had small deformation and high von misses stress [10]. The minimum safety factor value for a structure capable of withstanding dynamic loads is 2-3 [14]. The minimum safety factor value on steel AISI 1020 of the frame material is greater 0.53% than aluminum alloy 6061, this proves that the steel AISI 1020 material is safer to use than aluminum because the resistance of the steel AISI 1020 frame is greater. From this it can be seen that the difference in the value of material properties will cause a difference in the strength value of the material, the higher the mechanical properties of a material, the better the material is used because it has the resistance to maintain its shape and dimensions against the deformations received

V. CONCLUSIONS

This research can be concluded that the design of the e-scooter that is adopted from a broadtack model can be realized into a prototype. The specification of the prototype is that the motor power ranges from 250-1250 Watts using rear-wheel drive. With this power, this prototype will be able to drive at a speed of 30 km/h both on flat roads and on inclined surface roads a maximum of 10% that is 5.71°. The frame can be fabricated using AISI 1020 steel material and is able to withstand a rider load of 100 kg.

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