Static Linear Stress Analysis of Road Bike Frame Design Using Finite Element Method

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ABSTRACT
This paper presented the stress analysis of road bike frame to investigate the strength and safety factor of road bike frame. Bicycle manufacturers must ensure the performance and comfort of the product to comply with applicable standards. Various factors should be considered to obtain a proper design of a bike and the stress within the structure is necessary to be studied to avoid crash. Experimental frame testing is quite expensive, therefore numerical methods such as FEM are currently applied to predict the performance of road bike frames. In this study, the Finite Element Method (FEM) was used to see the maximum stress from two types of road bike frame with linear static analysis. The loading cases used in this study consist of three different static loading cases with 100 kg rider weight. Static simulation results show the maximum von Mises stress value from the overall loading cases is 164.5 MPa for the type 1 frame and 123.9 MPa for the type 2 frame. The minimum safety factor value for the type 1 frame is 1.67 and 2.22 for the type 2 frame.

Keywords: *Bike Frame, FEM, Static Stress Linear Analysis*

1. INTRODUCTION

The construction of the University of Sultan Ageng Bicycle is one of the cheap and practical means of transportation, because the price is relatively cheap, the cost of use is economical because it does not require fuel, and maintenance is easier than motorized vehicles [1,2]. The use of bicycles has become more popular than ever, especially for young people in some developing countries. Based on a survey conducted in Bandung, it shows that around 47.42% of bicycle users are aged between 17 and 25 years [3,4]. The use of bicycles as a mode of public transportation is expected to reduce the number of motorized vehicles so that traffic and emissions in the city can be reduced. Increased interest in bicycles has also contributed to the development of the bicycle industry. The bicycle industry in Indonesia is one of the most advanced industries in Asia, in addition to China, Taiwan and India. Some types of bicycles that are commonly used are mountain bikes (MTB), BMX, folding bicycles, hybrid bicycles, fixie bicycles, tandem bicycles, city bicycles, and road bikes [5].

The main component in designing the construction of a bicycle is the frame component. This frame is a support for the entire bicycle construction which is very influential on the strength of a bicycle construction [6]. In designing bicycles, industry players must ensure the performance and comfort of the product to comply with applicable standards. Various factors should be considered to obtain a proper design of the bike, especially on the frame, because it is an essential part of bicycles. A fatal failure that impact the rider is the failure that occurs on bike frames, so the stress within the structure is necessary to be studied to avoid the crash [7]. This can be obtained from direct frame testing, but experimental testing requires no small cost.

Finite element method is a method of analyzing a structure by discriminating a workpiece so that it becomes a finite number of elements. The use of the finite element method is widely used to analyze the structure because it is easier and cheaper to do. Sani et al. have conducted research on on bicycle frames that compares two methods, namely the finite element method (FEA) and the experimental method (EMA). The results of their research show that although there are still errors between the two methods, the finite element method is proven to be able to provide results that are close to the experimental method. Meanwhile, Gupta & Rao have used the finite element method to analyze mountain bike frames.

The research was carried out by varying the type of material on the bicycle frame against five given loading cases to determine stress and deformation that occurred in the frame [8–12]. In this study, the finite element method was used to determine the strength of the road bike frame using linear static analysis for three different loading cases. This static analysis with the finite element method is expected to see the stress distribution and maximum von Mises stress happened for each road bike frame model.

2. METHODS

2.1 Material Identification

In this study, the determination of the frame material used refers to previous research paper and material catalogue. Gupta & Rao have done similar research using Aluminium 6061-T6 as one of the materials used in bicycle frame [12]. The data was used in this research for the stress analysis of road bike frames. The properties of materials were shown in Table 1.

Table 1. Material specification Steel AISI 4130 and Aluminum 6061-T6.

Properties	Steel AISI 4130	Aluminum 6061-T6	Unit
Density	7.85	2.7	g/cm^3
Poisson ratio	0.3	0.33	
Yield strength	435	276	MPa
Tensile strength	670	310	MPa
Fatigue strength	335	96.5	MPa

2.2 Road Bike Frame Modelling

In this study, the object used are two types of road bike frames. The models of road bike frame were built in Solidworks 2016 software and then imported to the Altair software. Figure 1 displayed the road bike frame models for simulation in Altair 2019 software.

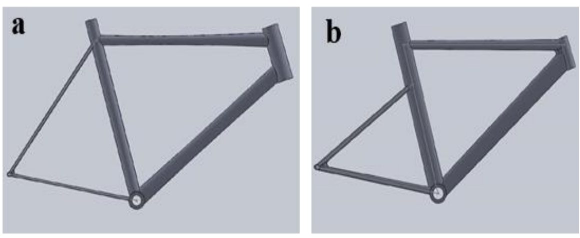

Figure 1. Design of road bike frame (a) type 1, (b) type 2.

2.3 Static Linear Simulation

The simulation of the static structure loading analysis on the road bike frame is carried out to determine the maximum stress of road bike frame models under three different loading cases. From the existing structural road bike frame design, simulations were carried out using Altair software. The static simulation in this research is divided into two, static loading due to the weight of the rider in the sitting riding position and standing riding with the rider's weight of 100 kg. In sitting riding case, the amount of load on the head tube is 5% of the rider's weight, on the seat tube is 50% of the rider's weight, and the rest is on the bottom bracket. Meanwhile, in the case of standing riding, the load on the head tube is 10% of the rider's weight and twice the weight of the rider on the bottom bracket [13]. The input forces used in the third loading case follows the reference journal [14] with simplification, where there are forces on the handlebar which simplified to a moment acting on the head tube. The input forces of each loading cases can be seen in Figure 2.

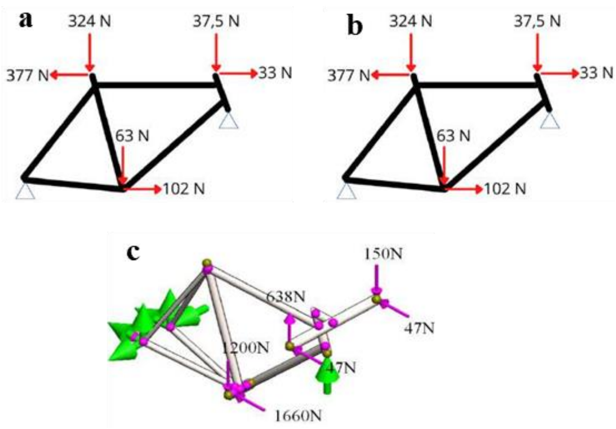

Figure 2. The input forces of loading case in (a) sitting riding, (b) standing riding, (c) third loading case with moment in head tube.

The first step of this simulation is inputting the road bike frame design into Altair Hypermesh 2019 software for the meshing process and simulation set-up. The meshing used in this research is 2-D mesh with quad shape as dominant element, and the thickness used is 2 mm based on previous research [12]. Meshed frame models were checked using quality index (QI) tool in Hypermesh software for twelve criteria as shown in Figure 4.

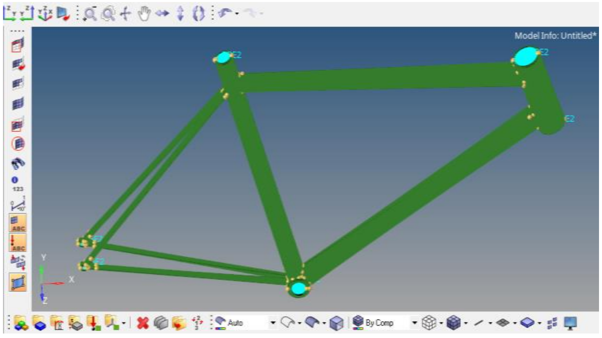

Figure 3. Meshed road bike frame model.

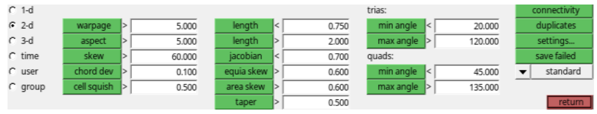

Figure 4. The element quality check panel.

The constraints used in this study were placed in below the head tube and in the rear dropout, which constraining the translational and rotational movement of road bike frame models. The next stage is to enter the material data used and provide the desired loading. The last step is running the simulations on both types of road bike frames using the Altair Optistruct 2019 software. From here, the von Mises stress maximum values from each loading cases are useful to determine the strength and safety factor value of each road bike frame design.

3. RESULTS AND DISCUSSION

One of the outputs of finite element analysis is von Misses stress which can be used to estimate the possibility of plastic deformation in the structure [15]. The output of the static linear simulation is von Mises stress distribution. It can be seen that the von Misses stress plot on the frame model is depicted using color contours. The lowest stress contour is depicted in blue, while the highest stress contour is depicted in red. The color contours displayed on the frame model can be used to determine the stress distribution in the frame.

The von Mises maximum stress results for both aluminium and steel were exactly the same for each road bike frame model, explained by the fact that the isotropic materials are under the same force and neither reaches the plastic region [16]. The simulation for the road bike frame model with static loading in the sitting riding position shows that the maximum stress that occurs is 46.3 MPa for the frame type 1 and 48.1 MPa for the type 2. The maximum stress concentration occurs around the area between the seat tube and the top tube connection as shown in Figure 5.

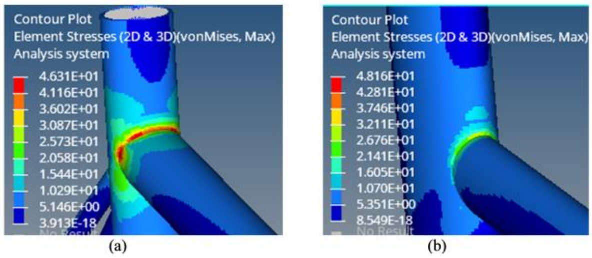

Figure 5. Von Mises distribution under sitting riding condition on frame; type 1 (a); type 2 (b)

The maximum stress that occurs is 125.9 MPa for the type 1 frame and 122.5 MPa for the type 2. The maximum stress concentration in this case occurs around the area between the bottom bracket and chain stays connection, with stress contours which can be seen in Figure 6.

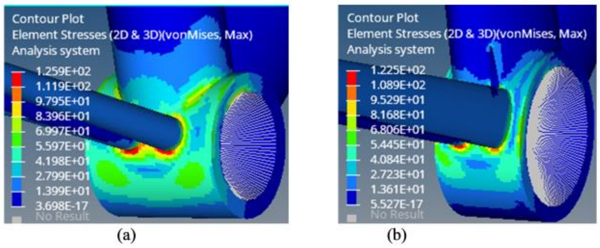

Figure 6. Von Mises distribution under standing riding condition on frame; type 1 (a); type 2 (b)

Meanwhile, the static simulation result of the road bike frame models for the third case with moment loading on the head tube showed that the maximum stress that occurs is 164.5 MPa for the type 1 frame and 123.9 MPa for the type 2. This case occurs around the connection between the head tube and the top tube, with the stress contour shown in Figure 7.

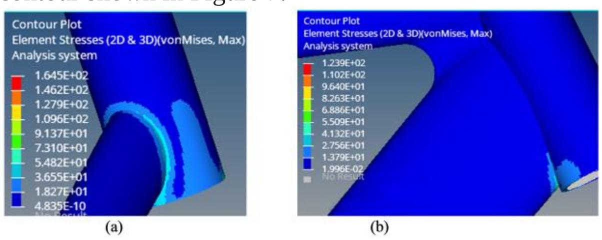

Figure 7. Von Mises distribution under third loading condition on frame; type 1 (a); type 2 (b)

The static safety factor in this research is calculated for each static loading case. The safety factor values are calculated based on yield strength material data of Steel AISI 4130 (435 MPa) and Aluminium 6061-T6 (276 MPa) for each road bike frame. The safety factor value of frame type 1 and 2 be seen in Table 2 and 3 consecutively.

Table 2. Safety factor value of road bike frame model type 1.

Loading Case	Von Mises Max Stress (MPa)	Safety Factor	
		Steel	Aluminum
Sitting riding	46.3	9.39	5.96
Standing riding	125.9	3.45	2.19
Third case with moment loading	164.5	2.64	1.67

Table 3. Safety factor value of road bike frame model type 2.

Loading Case	Von Mises Max Stress (MPa)	Safety Factor	
		Steel	Aluminum
Sitting riding	48.1	9.03	5.73
Standing riding	122.5	3.55	2.25
Third case with moment loading	123.9	3.51	2.22

4. CONCLUSION

The static linear simulation test using the finite element method has been successfully carried out with three loading cases: the sitting riding condition, standing riding, and the third loading case with moment on the head tube. The maximum von Mises stress value from all loading cases happened on the third case with 164.5 MPa for the type 1 frame and 123.9 MPa for the type 2 frame. The minimum safety factor from overall cases is also happened on the third loading case, with the value for type 1 frame is 1.67 and 2.22 for the type 2 frame.

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