Fatigue simulation with pedalling load and vertical load for city bike frame following British standard EN 14764

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Abstract. The frame supports both the load from the rider and the riding conditions. When the loading conditions occur repeatedly, the bicycle frame will experience fatigue failure. This study discusses the fatigue simulation for city bike frames made of titanium, intending to know the safety factor and the service life of the bicycle frame according to a pedal load and a vertical load following British Standard BS EN 14764. The bicycle frame used for this research is a frame for the city bike type, where each composing tube of the bicycle frame has a thickness of 1.2 mm. The pedalling load applied to each pedal is repeated downward with 1000 N. While the dynamic load vertically downwards with a force magnitude from 0 to +1000 N. The results of the fatigue test simulation with each type of loading indicate that the titanium material with 1.2 mm thickness is overdesigned. Therefore, it is necessary to modify the bicycle frame by reducing the thickness of the frame to 1 mm on each tube. The safety value of the resulting fatigue simulation shows a decrease due to the reduction in thickness, however it still safe in terms of the material strength limit. The resulting bicycle frame after modified is lighter, where the initial mass was 6.79 kg and reduce to 3.92 kg.

Keywords: city bike frame, fatigue simulation, titanium material, standard EN 14764

1. Introduction
The bicycle frame is the main component of a bicycle that connected to the wheels and other components. The frame supports both the load from the rider and the riding conditions. The load that occurs on the bicycle frame comes from the action-reaction force between the bicycle and the road surface conditions. When the loading conditions occur repeatedly, the bicycle frame will experience fatigue failure that occurs is hazardous because it can cause cracks, which is difficult to detect visually.

Many researchers have been simulating the strength of bicycle frames, both static and fatigue. The research includes static simulation for foldable frame bicycle [1], simulation of standard steel bicycle frame [2], stress analysis and displacement of the bike frame [3], simulation of the mechanical behaviour of bike frames made in bamboo [4], and static strength of three-wheeled electric bike frame. Also, there was a study carried out using numerical simulations regarding the
impact of material fatigue affects the appearance of bicycle crack [5], simulation in the bicycle frame during the fatigue test simulations [6], and durability of bicycle frames that experimentally investigated under the fatigue load [7].

In order to get a good service life on a bicycle frame, it is necessary to pay attention to the selection of materials used on the bicycle frame. Modifications also need to be made to the frame to improve the performance and reliability of the frame. This study discusses the simulation of fatigue for city bike frames made of titanium, intending to know the safety factor and the service life of the bicycle frame according to pedal load and vertical load following British Standard BS EN 14764 [8].

2. Methods
The bicycle frame used for this research is a frame for the city bike type. We have drawn the geometric design of the frame city bike in Computer-Aided Drawing (CAD) software based on the geometry shown in Figure 1. The mechanical properties of frame material are shown in Table 1, and each tube of the frame has a thickness of 1.2 mm. Boundary conditions are the initial input in the simulation for initiation in subsequent calculations. The boundary conditions for the fatigue test simulation on a city bike frame consist of 2 (two) types of conditions, namely the pedalling force and vertical force.

In simulation of pedalling force, it analysed the frame only, which defines the supporting elements of the simulation as rigid conditions. The load applied to each pedal is repeated downward with 1000 N at position 150 mm from the centreline of the frame on the vertical axis, as seen in Figure 2. It will carry out the test for 100,000 cycles, where one of the tests consists of the use and removal of the two acting forces.

In vertical force, the frame of the tested bicycle is attached to a stationary area to keep the rear in a fixed condition while the front axle is attached to the rollers. Apply a dynamic load vertically downwards with a force magnitude from 0 to +1000 N at a point 70 mm behind the intersection of the stable steel peg and the joint, as shown in Figure 3. It will have passed the test for 50,000 cycles with a test frequency not exceeding 25 Hz.

![Figure 1. Geometry and dimension of a frame city bike.](image)

| No. | Item                        | Dimensions |
|-----|-----------------------------|------------|
| 1   | Sizes                       | 52 mm      |
| 2   | Head Tube Angle             | 69°        |
| 3   | Head Tube Length            | 180 mm     |
| 4   | Head Tube Diameter          | 50 mm      |
| 5   | Seat Tube Angle             | 73.5°      |
| 6   | Seat Tube Length            | 520 mm     |
| 7   | Top Tube Actual             | 578 mm     |
| 8   | Top Tube Effective          | 600 mm     |
| 9   | Front Center                | 682 mm     |
| 10  | Rear Center                 | 460 mm     |
| 11  | BB Height (BB Drop/Rise)    | 50 mm      |
3. Results

In this investigation, we run both types of simulation, namely static and fatigue simulation. Figure 4 shows the result for static simulation with 1.2 mm frame thickness, (a) is for pedalling force, and (b) is for vertical force. Figure 4(a) shows that a maximum Von Mises of 215.2 MPa is found on the seat stay. From Figure 4(b), it can be seen that the maximum Von Mises occurs in the top-tube area with a value of 57.69 MPa. The seat-stay and top-tube areas are the most critical areas.

**Table 1. Mechanical Properties of Ti 3Al/2.5V**

| Properties                  | Value                      |
|-----------------------------|----------------------------|
| Density (x1000 kg/m$^3$)    | 4,484                      |
| Possion’s Ratio             | 0.3                        |
| Elastic Modulus (GPa)       | 100                        |
| Tensile Strength (MPa)      | 620                        |
| Yield Strength (MPa)        | 500                        |
| Elongation (%)              | 15                         |
| Hardness (HB)               | 256                        |
| Fatigue Strength (MPa)      | 200 at $10^7$ cycles       |
Figure 4. Maximum Von misses stress of frame with 1.2 mm thickness, for (a) vertical force, (b) pedalling force.

Table 2 shows summaries for the other performance parameters for 1.2 mm frame thickness. We can see that the minimum life result is 100 million cycles, which means that it passed the BS EN 14764 standard. However, the factor of safety from both static and fatigue simulation shows a value greater than 2. It means that the city bike frame from titanium material with a thickness of 1.2 mm is considered over design.

Therefore it is necessary to redesign the frame by reducing the thickness into 1 mm. Figure 5 shows the results for static simulation with a 1 mm frame thickness. The maximum Von Mises Stress value increased into 297.3 MPa and 62.49 MPa for pedaling force and vertical force, respectively. This result makes sense because the cross-section of the frame becomes smaller, while the load is fixed, so the stress that occurs is more significant.

Table 3 shows summaries for the other performance parameters for a 1 mm frame thickness. We can see that the value of the factor of safety for a thickness of 1 mm has decreased compared to a thickness of 1.2 mm. However, because the value is still above 1.5, so it still safe in terms of the material strength limit. These results show that the frame material with a 1 mm thickness is passed the fatigue test for pedaling and vertical loads according to the BS EN 14764 standard.

Another impressive result is the weight of the city bike frame, which has decreased significantly without sacrificing the material strength. The weight of a city bike frame with a thickness of 1 mm becomes to 3.92 kg only, compared to 6.79 kg for a 1.2 mm thickness.

Table 2. Simulation results for frame city bike with 1.2 mm thickness using Titanium material

| Parameters                     | Vertical Force | Pedaling Force |
|--------------------------------|----------------|----------------|
| Static Factor of Safety        | 2.324          | 8.664          |
| Maximum Von Mises Stress (MPa) | 215.2          | 57.69          |
| Fatigue Factor of Safety       | 7.231          | 28.52          |
| Life minimum (cycles)          | 10,000,000     | 10,000,000     |
| Frame mass (kg)                | 3.92           | 6.79           |
Figure 5. Maximum Von misses stress of frame with 1 mm thickness, for (a) vertical force, (b) pedalling force.

Table 3. Simulation results for frame city bike with 1 mm thickness using Titanium material

| Parameters                  | Vertical Force | Pedaling Force |
|-----------------------------|----------------|----------------|
| Static Factor of Safety     | 1.682          | 8.001          |
| Maximum Von Mises Stress    | 297.3          | 62.49          |
| Fatigue Factor of Safety    | 5.233          | 27.83          |
| Life minimum (cycles)       | 10,000,000     | 10,000,000     |
| Frame mass (kg)             | 3.92           |                |

4. Conclusions
This article discusses the fatigue simulation of a city bike frame with titanium material. The results of the fatigue test simulation with both types of loading, namely pedalling and vertical forces, indicate that the titanium material with 1.2 mm thickness is overdesigned. Therefore, it is necessary to modify the bicycle frame by reducing the thickness of the frame to 1 mm on each tube. The safety value of the resulting fatigue simulation shows a decrease due to the reduction in thickness, however it still safe in terms of the material strength limit. The resulting bicycle frame after being modified is lighter, where the initial mass was 6.79 kg and reduce to 3.92 kg.

5. References
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