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Finite Element Analysis of Bamboo Bicycle Frame

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Original Research Article

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Abstract

This work looked into the finite element analysis of Bamboo frame bicycle using commonly used Computer Aided Design softwares. A solid model of the frame was created and a finite element analysis (FEA) was conducted using the ASTM standard as a guide, with appropriate mechanical properties for various sections of the bike and the joining welds. A maximum weight of 120kg was used for the weight and seat analysis, from the analysis performed, the most fragile area was identified as being the tubes near the bottom bracket, extra carbon fiber wrapping during assembly is recommended during production for the frame. Due to the nature of Nigeria's (developing country) road, we simulated a pothole situation using a horizontal force of 1000N to the front tire. The analysis showed that the highest stress would occur nearest to the point of impact with the pothole.

Keywords: Finite element, analysis, bamboo.

1 Introduction

Bamboos are the fastest growing plants in the world having growth up to 60 cm or more in a day. Bamboos belong to grass family and are columnar rather than tapering in nature. Bamboos have social, South East Asia and are used extensively for building materials, food source and as a

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highly versatile raw product. The bamboos have good bending strength and flexibility. The height of bamboo plant goes up to 40 m and it still withstands the wind pressure. The advantage of bamboo is- it is cheap, flexible, tough, high tensile, light weight material than the other materials like steel and can be used in various building works. Bamboo has various advantages over the other construction material and it is needed that it should be widely used in construction [1].

The last fifteen years has seen a dramatic growth in the variety of bamboo products [2]. In view of its proprieties, bamboo continues to be used for the production of new products. The multi-functional ranges of bamboo uses have shown that it may prove beneficial as a valuable and sustainable natural resource [3]. More recently, bamboo had been reported to have more than 1,500 documented industrial applications, ranging from medicine to nutrition and from toys to aircraft [4]. Bamboo's appearance, strength and hardness combined with its rapid growth rate and capacity for sustainable harvesting makes it an attractive substitute in various industrial sectors. These have created opportunities for bamboo development. In economies such as in China, bamboo has reduced dependence on solid wood, while in less strong economies; there are emerging new opportunities for bamboo products that are targeted for rural development and poverty reduction [2]. Investigation of Bamboo as a viable material for construction material [5-6], composite etc. [7-9], has been on-going for years.

In recent years the need for an eco-friendly means of transportation that is affordable to all sectors of developing countries has become more apparent [10]. Using the Ashby chart, it can be seen that Bamboo can serve as a good replacement to Steel frame bicycle and composite bicycle. Bamboo is a natural composite material longitudinally reinforced by strong fibers. It is a good replacement to steel or composite frame bicycles because it is cheap and fast growing as well as easy to process other properties such as lightness, stiffness and strength of about 40kN/cm^2 [10]

The finite element analysis (FEA) is a very powerful analysis tool, which can be applied to a range of engineering problem. The finite element modeling process allowed for discrediting the intricate geometries into small fundamental volumes called finite element. It is then possible to write the governing equations and material properties for these elements. These equations are then assembled by taking proper care of results that describe the behavior of the original complex body being analyzed. Application of FEA is no limited to mechanical system alone but to range of engineering problem such as stress analysis, dynamic analysis, and deformation studies fluid flow analysis, heat flow analysis and other. With the FEA software it is possible to try a number of alternative designs before actually going for a prototype manufacture. The use of FEA tools can convert the geometry into discretized element and calculating various properties for each element such as geometry, material properties, constraint and loading. This forms the input for the analysis. It also can generate the finite element mesh by making a suitable approximation to the geometry. Then it can calculate the nodes and element properties and allowed the material properties to be specified.

Forrest Dwyer et al. [11], looked at the Material and Design Optimization for an Aluminum Bike Frame. They investigated the fatigue life and failures of aluminum bicycle frames using Finite Element Analysis and physical testing. The objective of this research is the analysis of Bamboo frame bicycle using the Finite Element Analysis method, to investigate the likely areas of failure of the bicycle. The analysis will help to reduce the cost of material wastage, man hour wastage during the production of the bamboo bicycle and spot the areas that need more attention, and the Bamboo bicycle will serve as alternative to conventional bicycle and as an eco-friendly material.

2 Methodology

Bamboo frame bicycle of hollow bamboo tubing was built [10], as shown in Fig. 1. Having an outside diameter of 25mm and a wall thickness of 2mm for the main part of the frame, for the rear forks, the tubing is 12mm outside diameter and 1mm wall thickness. A detail of the joint joining is described in [10]. The softwares used for running this Finite Element Analysis were Pro/Mechanica, Comsol Multiphysics and Autodesk Inventor.

3 Results and Discussion

Modem bicycle frame is shown in Fig. 2, while common bicycle frame made from aluminum, steel, titanium and carbon fiber are shown in Fig. 3.

Fig. 1. The Bamboo frame bicycle [8]

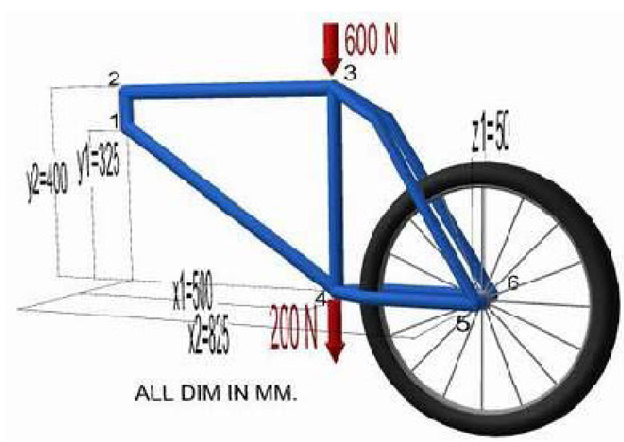

Fig. 2. The Modelled bamboo frame bicycle

Fig. 3. Common bicycle frame materials

Fig. 4 below, shows the stages involved in the design of the Bamboo frame bicycle used for this FEA.

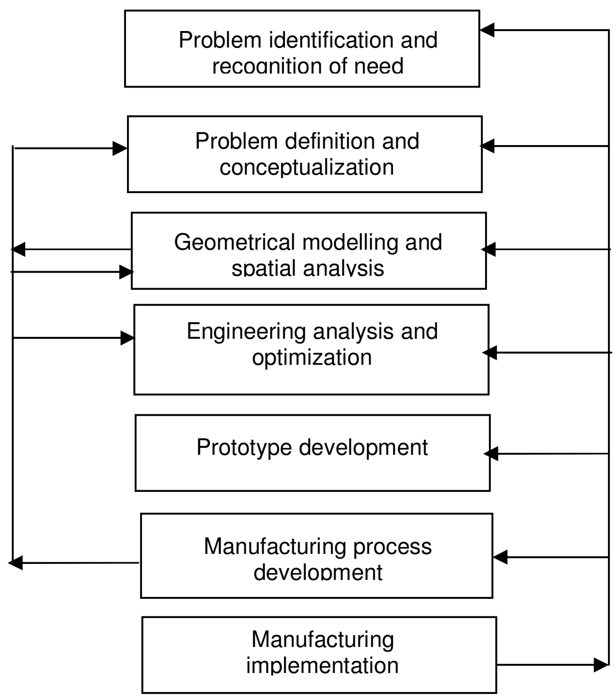

Fig. 4. Stages in the design process

A solid model of the frame was created and a finite element analysis (FEA) was conducted using the ASTM F2711-08 [12], standard as a guide, with appropriate mechanical properties for various sections of the bike and the joining welds.

Mesh Analysis: shown in Fig. 5, Using *Average Element size* of 0.100, *minimum element size* of 0.200, *grading factor* of 1.500 and *maximum turn angle* of 60degree as the mesh setting, while

0.750 was used as the *h refinement threshold* with a *stop criteria* of 10.00% for the convergence setting, the following were achieved as shown in Fig. 8.

3.1 Seat and Weight Analysis

Fig. 6 shows the seat analysis to show the capacity of the load that the Bamboo bicycle can carry. A force of 600N was used coinciding to weight of 60Kg the anthropometric data for female users. The analysis reveals that the frame can carry that weight comfortably without failure. While Fig. 7 shows the analysis for a rider having a weight of 120Kg. the safety factor was at maximum at 0.4098ksi. This shows that the Bamboo frame bicycle will be able to carry up to 120Kg comfortably. Figs. 9-18, shows the various seat and weight analysis, while Table 1 shows result summary of the analysis.

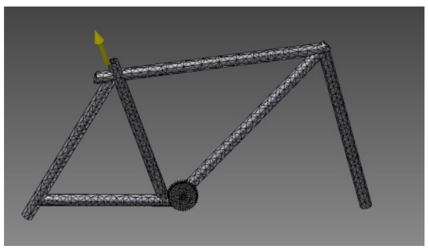

Fig. 5. Mesh analysis

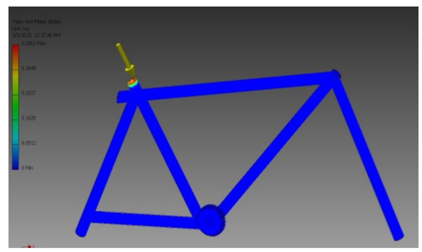

Fig. 6. 600N force simulation on the seat and weight analysis

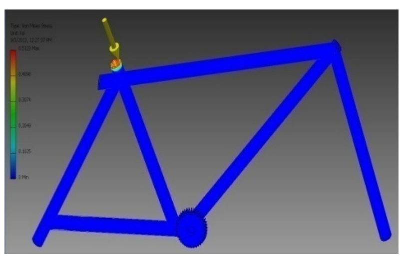

Fig. 7. 1200N force simulation on the seat

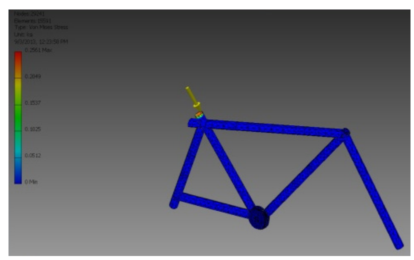

Fig. 8a. Mesh analysis of the seat and weight analysis

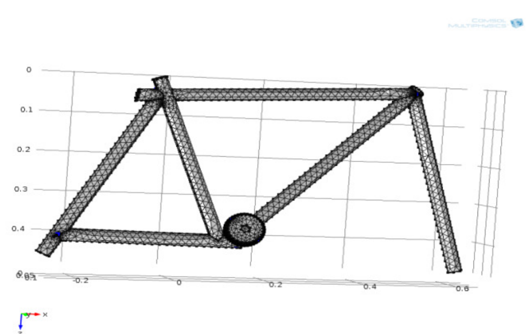

Fig. 8b. Comsol mesh with 16 iteration and depth of 8

Table 1. Result Summary for the Seat and Weight analysis

Name	Minimum	Maximum
Volume	73.6871 in^3	
Mass	6.39448 kg	
Von Mises Stress	0 ksi	0.511912 ksi
1st Principal Stress	-0.071001 ksi	0.266957 ksi
3rd Principal Stress	-0.580374 ksi	0.0019337 ksi
Displacement	0 in	0.0000041898 in
Safety Factor	15 ul	15 ul
Stress XX	-0.300033 ksi	0.200878 ksi
Stress XY	-0.126744 ksi	0.14048 ksi
Stress XZ	-0.256844 ksi	0.144247 ksi
Stress YY	-0.27285 ksi	0.0770246 ksi
Stress YZ	-0.252966 ksi	0.252353 ksi
Stress ZZ	-0.544814 ksi	0.0871963 ksi
X Displacement	-0.0000000610298 in	0.00000235541 in
Y Displacement	-0.00000137134 in	0.00000149638 in
Z Displacement	-0.00000011342 in	0.00000407106 in
Equivalent Strain	0 ul	0.0000148522 ul
1st Principal Strain	-0.00000000000254773 ul	0.0000119239 ul
3rd Principal Strain	-0.0000159078 ul	0 ul
Strain XX	-0.00000467891 ul	0.0000091757 ul
Strain XY	-0.00000540965 ul	0.00000599595 ul
Strain XZ	-0.0000109626 ul	0.00000615673 ul
Strain YY	-0.00000313691 ul	0.00000767745 ul
Strain YZ	-0.0000107971 ul	0.0000107709 ul
Strain ZZ	-0.00001439 ul	0.00000413412 ul

Seat and Weight analysis:

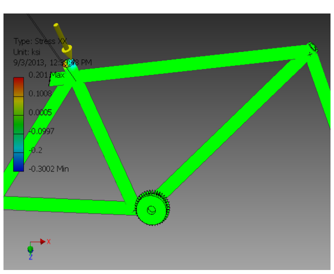

Fig. 9. Stress xx

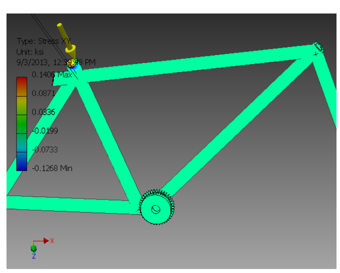

Fig. 10. Stress XY

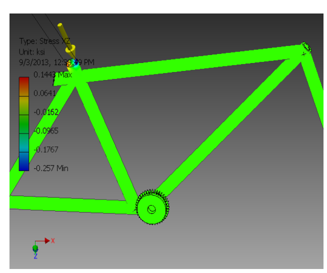

Fig. 11. Stress XZ

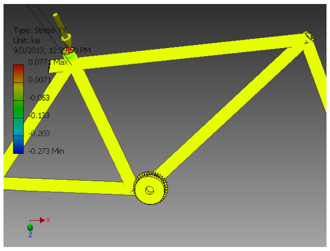

Fig. 12. Stress YY

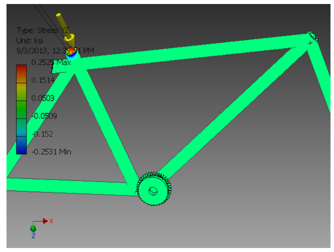

Fig. 13. Stress YZ

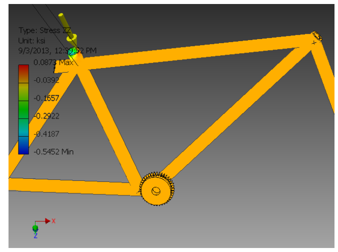

Fig. 14. Stress ZZ

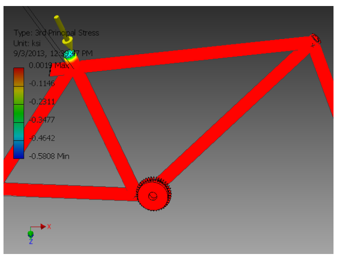

Fig. 15. 3rd Principal Stress

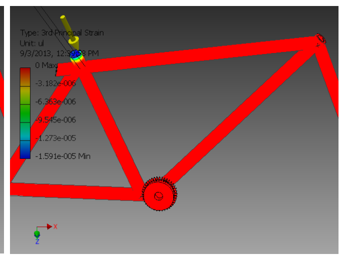

Fig. 16. 3rd Principal strain

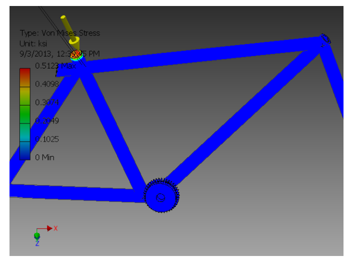

Fig. 17. Von Mises Stress result

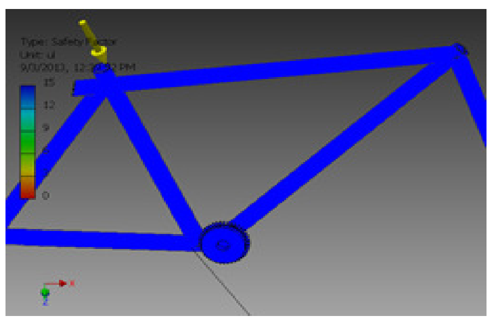

Fig. 18. Safety factor

3.1.1 Pothole simulation

Due to the nature of Nigeria's (developing country) road, we simulated a pothole situation. This was done by assigning a horizontal force of 1000N to the front tire of the bicycle. The analysis as shown in Figs. 19-34, reveal that the highest stress would occur nearest to the point of impact with the pothole. Result summary for the pothole simulation result are shown in Table 2

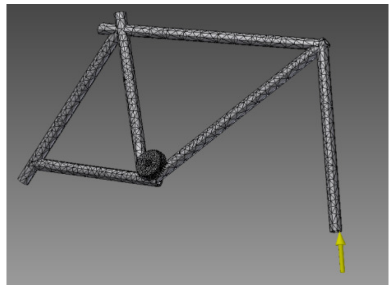

Fig. 19. Mesh analysis of the pothole simulation

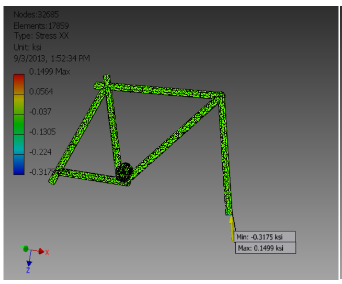

Fig. 20. Stress xx

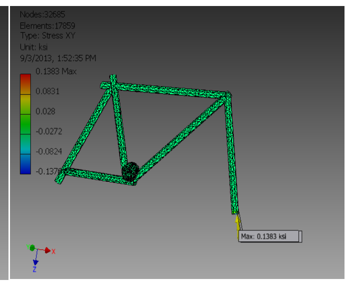

Fig. 21. Stress XY

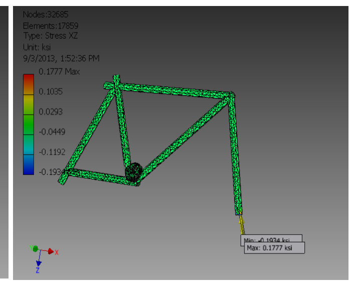

Fig. 22. Stress XZ

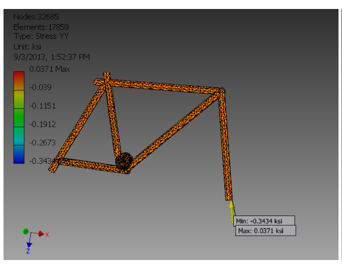

Fig. 23. Stress YY

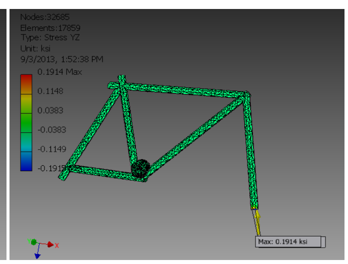

Fig. 24. Stress YZ

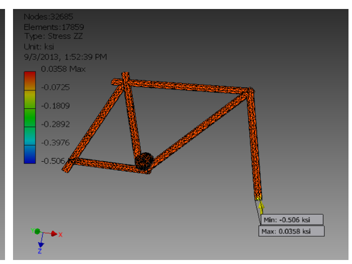

Fig. 25. Stress ZZ

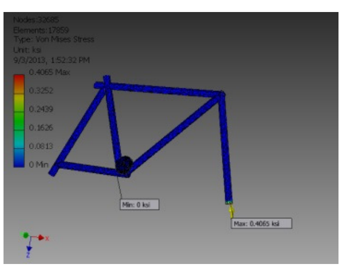

Fig. 26. Von mises Stress

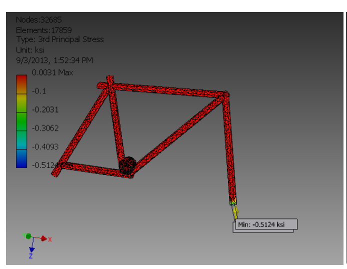

Fig. 27. 3rd principal stress

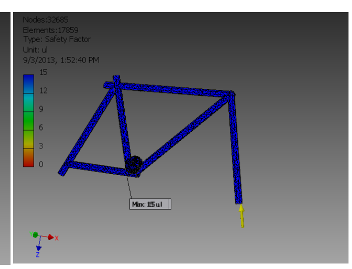

Fig. 28. Safety factor

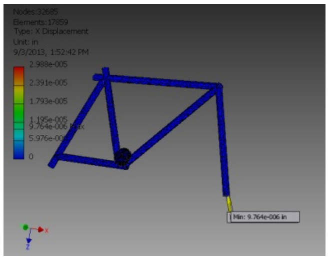

Fig. 29. X Displacement

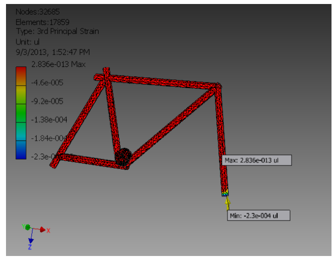

Fig. 30. 3rd principal strain

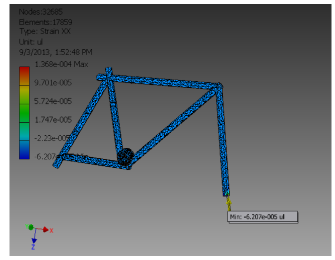

Fig. 31. Strain XX

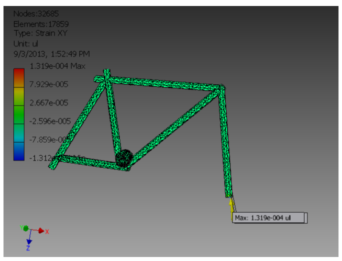

Fig. 32. Strain XY

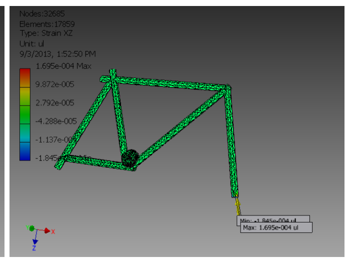

Fig. 33. Strain XZ

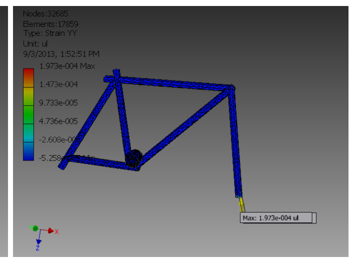

Fig. 34. strain YY

Table 2. Result Summary for the Pothole simulation result

Name	Minimum	Maximum
Volume	73.6871 in^3	
Mass	5.26236 lb	
Von Mises Stress	0 ksi	0.406216 ksi
1st Principal Stress	-0.120724 ksi	0.267518 ksi
3rd Principal Stress	-0.512019 ksi	0.00309255 ksi
Displacement	0 in	0.0000705289 in
Safety Factor	15 ul	15 ul
Stress XX	-0.317253 ksi	0.149822 ksi
Stress XY	-0.137459 ksi	0.138201 ksi
Stress XZ	-0.193253 ksi	0.177583 ksi
Stress YY	-0.343186 ksi	0.0370859 ksi
Stress YZ	-0.191329 ksi	0.191282 ksi
Stress ZZ	-0.505619 ksi	0.0358148 ksi
X Displacement	-0.000029882 in	0.00000976375 in
Y Displacement	-0.0000293315 in	0.0000285493 in
Z Displacement	-0.0000645889 in	0.00000147155 in
Equivalent Strain	0 ul	0.000261954 ul
1st Principal Strain	-0.00000000000536421 ul	0.000221023 ul
3rd Principal Strain	-0.000230011 ul	0.00000000000028357 ul
Strain XX	-0.0000620697 ul	0.000136776 ul
Strain XY	-0.000131212 ul	0.000131921 ul
Strain XZ	-0.000184471 ul	0.000169513 ul
Strain YY	-0.0000525759 ul	0.000197265 ul
Strain YZ	-0.000182634 ul	0.000182589 ul
Strain ZZ	-0.000223901 ul	0.0000368285 ul

3.1.2 Rear wheel pothole analysis

A vertical load on the rear side of the bicycle simulation reveals the above result (shown in the Figs. 35 and 36 below). This can be done by simulating the back wheel hitting down into a hole or landing on this area. The analysis showed a large displacement on the area connected to the dropouts. This is vital in the design of a very strong dropout that would be stable even under large displacements. Result summary for rear wheel pothole analysis are shown in table 3, while bottom bracket motion while pedaling is shown in Fig. 37.

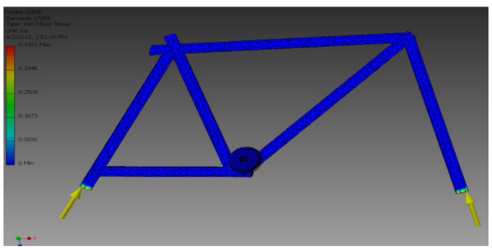

Fig. 35. Mesh analysis of Rear wheel pothole analysis

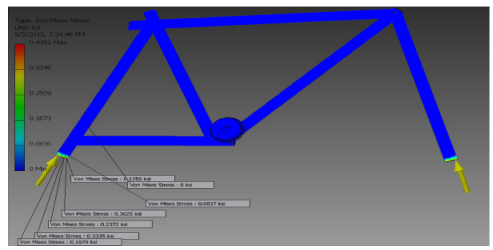

Fig. 36. FEA of the Rear Wheel Pothole simulation

Table 3. Result Summary for the Rear Wheel Pothole simulation result

Name	Minimum	Maximum
Volume	73.6871 in^3	
Mass	5.26236 lb	
Von Mises Stress	0 ksi	0.417944 ksi
1st Principal Stress	-0.120766 ksi	0.303424 ksi
3rd Principal Stress	-0.511955 ksi	0.00310057 ksi
Displacement	0 in	0.0000706701 in
Safety Factor	15 ul	15 ul
Stress XX	-0.357338 ksi	0.253749 ksi
Stress XY	-0.137452 ksi	0.138205 ksi
Stress XZ	-0.193262 ksi	0.200212 ksi
Stress YY	-0.343229 ksi	0.0459863 ksi
Stress YZ	-0.19133 ksi	0.191292 ksi
Stress ZZ	-0.505554 ksi	0.243581 ksi
X Displacement	-0.0000298773 in	0.0000456959 in
Y Displacement	-0.0000293318 in	0.0000318615 in
Z Displacement	-0.0000645893 in	0.0000014719 in
Equivalent Strain	0 ul	0.000266096 ul
1st Principal Strain	-0.000000000000292815 ul	0.000239063 ul
3rd Principal Strain	-0.000230004 ul	0.00000000000192527 ul
Strain XX	-0.000156122 ul	0.000191556 ul
Strain XY	-0.000131205 ul	0.000131924 ul
Strain XZ	-0.00018448 ul	0.000191113 ul
Strain YY	-0.0000525808 ul	0.000197274 ul
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Strain ZZ	-0.000223894 ul	0.000181939 ul

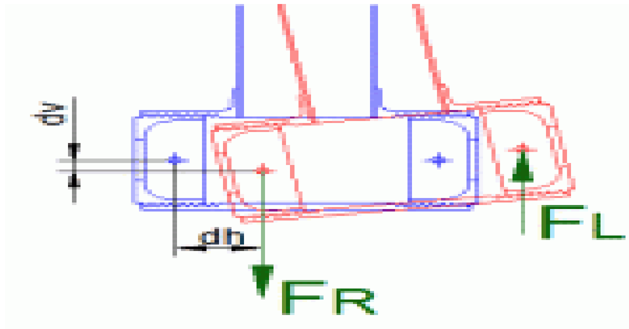

Fig. 37. Bottom Bracket Motion while Pedaling

4 Conclusion

From the analysis performed and shown, the most fragile area was identified as being the tubes near the bottom bracket, extra carbon fiber wrapping during assembly is recommended during production for the frame. For the pothole, wrap the carbon fiber farther down on these tubes for additional reinforcement. The seat analysis also revealed that the Bamboo frame bicycle can carry a weight of 120Kg comfortably without failing.

Competing Interests

Authors have declared that no competing interests exist.

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