

Static Structural Analysis of Foldable Frame for Bicycle using Finite Element Method

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Abstract - Bicycle is very economical and efficient way of conveyance among the man powered vehicles. Frame is especially vital component of bicycle as all other elements are mounted on it. Different types of loads such as weight of rider, breaking force and the reaction from ground are directly transferred to it. Consequently the structural strength of frame is very much important for safe riding. In this work foldable frame is proposed out of numbers of innovative designs for the same. The conventional shape of frame structure is modified to new proposed form to serve folding function. The foldable structure of frame makes it portable and occupies little place as it can fold to smaller size than its original size. This work deals with structural analysis of folding frame using finite element method. The stress analysis is done for three different loading conditions like horizontal loading, vertical loading and impact loading with reference to ASTM F2711-08 bicycle frame testing standard. The 3D modeling of frame is modeled using CAD software CATIA V5 and analysis is carried out in finite element analysis software ANSYS 16.0. Results show that the highest stress occurs at front and rear fork part of frame structure which is finalized as failure locations in the frame.

Key Words: CAD, FEA, ANSYS, Folding bicycle, frame

1. INTRODUCTION

A frame is very important key component of a bicycle structure, on this component all other accessories like wheel and handle bar are mounted. The main function of the frame is to transfer the produced mechanical energy by the rider to the rear wheel. In case of bicycle different types of loads are acting on the frame, from the rider, the field and the ground reaction. Throughout the history of bicycle design, there have been continuous changes and improvements in design of cycle frame on technologies. Most improvements through the years have been done in modifications to the mechanisms layout on the bicycle. This includes overall structural shape of the Cycle, design of a frame structure, and material improvements. The design of foldable frame bicycle is not unfamiliar looking by any kind. However, there are slight differences in the structural shape of a foldable bicycle frame if compared to its conventional counterpart. Size, shape and weight of folding bicycle made it relatively easy to carry it from one place to another place considering need of portability. Since frames are a critical component from safety point of view, design of the frame structure and the material used for frame for foldable bicycle must have very steady and consistent structural strength under different conditions

of load. Stress throughout a bicycle frame varies under different loads. A certain part of frame will experience different stresses when the bike is static than it will when the bike is being pedaled. Various loads acting to the frame cause these stresses. The load due to weight of cyclist on the seat, loads and vibrations produced from road and the force that cyclist exerts on the pedals, all have an effect on the state of stress of the frame. During earlier days the trial and error technique is used for design optimization of frame but this method does not provide the relevant result and the intuition made is not of necessity all time correct so there is need of software that provide a way to get direct and appropriate result. This ultimately saves the cost and time of manufacturer. The solution is provided by Finite Element Analysis technique (FEA). FEA is a computational method used to obtain fairly accurate solutions of boundary value problems in engineering. This work deals with static structural stress analysis of folding bicycle frame using finite element method. The stress analysis is carried out for loading conditions like horizontal structural loading, vertical structural loading and impact loading with reference to ASTM F2711-08 bicycle frame testing standard. **Derek Covill et.al [1]** has discussed analysis of bicycle frame with the finite element analysis. He has done the finite element model using beam type element to characterize a typical road bicycle frame and carry out FEA of frame. This finite element model subjected to two standard loading conditions to understand the vertical conformity and lateral stiffness characteristics of presented bicycle frames structure and evaluate these characteristics to a better solution in these conditions. **Bharati Tayade et.al [2]** has discussed the FEA of various designs of bicycle frame. This analysis is done by taking into account conditions like static start up, steady state paddling, vertical impact, horizontal impact, rear wheel braking etc. the results of analysis gives the stress, strain, factor of safety of bicycle frame. **Joachim Vanwallegem et.al [3]** this study includes the advance of a multi-directional testing technique for stiffness of bicycle as high stiffness of bicycle frame is found to be important for professional bicycle riders because it allows for maximal momentum and reduce energy loss due to bicycle frame compliance. In this method load in its main components is subdivided in two parts (both force and torque) and measuring the resultant frame deflection allows to conclude about the directional stiffness of the frame. **M.A. Maleque et.al [4]** this study includes development of the method of material selection and selection of the best material for the application of folding bicycle frame. Two methods are presented for the material selection, like cost per unit

property and digital logic methods. In a method of cost per unit property, only strength is considered but in digital logic method, many properties such as yield strength, tensile strength and young's modulus were considered for material selection. **M.V.Pazare [5]** this study includes the study of analysis of stresses induced in bicycle frame using finite element technique and its assessment with theoretical stress analysis. In theoretical analysis the frame is projected as truss like structure and the stresses induced in different components of frame determined for various condition of loading like, vertical impact, horizontal impact, rear wheel braking. Also Finite Element Analysis is done for same boundary and load conditions. The results of FEA and theoretical analysis are compared to each other to find out the relation between them. **Aparna Deshpande [6]** has discussed that structural design of frame and the weight optimization are the very important aspects for the optimization of bicycle performance. In this study modal analysis is carried for composite material for the optimization of design of frame structure using FEA.

2. FINITE ELEMENT ANALYSIS

2.1 Horizontal Loading Test

This test includes loading the frame at the bottom of the front fork along the y-axis with a pre-determined load. The rear dropouts of the frame are constrained in all directions and front dropouts are allowed for transverse movement only along the axis of frame.

In ANSYS the boundary and loading conditions for horizontal test are fixed support at rear fork axle cylindrical surface, displacement allowed to move only along frame axis (y direction) on front fork axle cylindrical surface and 600N force at front fork axle cylindrical surface along frame axis (y direction)

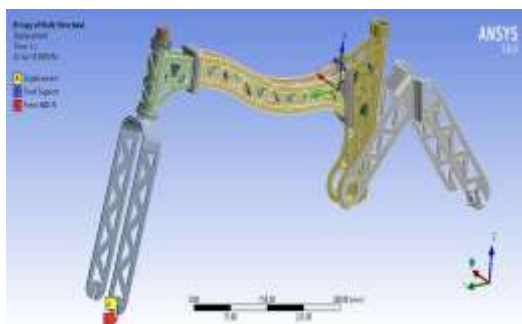


Fig -1: Constraints and load applied for horizontal loading

2.2 Vertical Loading Test

This test includes loading a frame in vertical direction just on the seat post surface with a pre-determined load and the rear and front dropouts are constrained.

In ANSYS the boundary and loading conditions for vertical test are fixed support at both rear and front fork axle

cylindrical surface and 800N force on top surface of rear frame seat post position

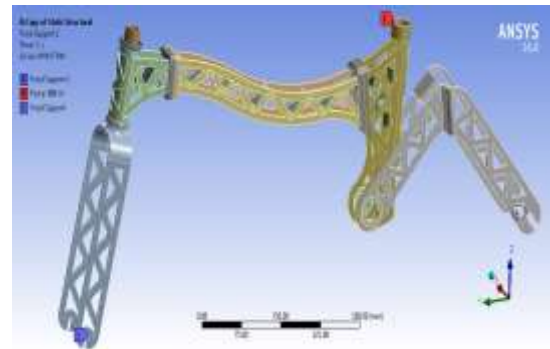


Fig -2: Constraints and load applied for vertical loading

2.3 Impact Loading Test

In this test bicycle frame placed vertically with a 22.5 kg striker on a front fork of the bicycle frame. The frame is rigidly mounted at the rear axle, and the front axle is allowed to roll. This test simulates an impact occurring on the front fork of the bicycle.

In ANSYS the boundary and loading conditions for impact test are fixed support at rear fork axle cylindrical surface, displacement allowed to move only along frame axis (y direction) on front fork axle cylindrical surface and 140 mm/s velocity to the dead weight of 22.5kg (This dead weight will impact on the face of front fork when dropped from 1m height.)

Velocity calculation for dead weight

We know,

$$\text{Potential Energy} = \text{Kinetic Energy}$$

$$mgh = 1/2mv^2$$

$$v = \sqrt{2gh}$$

As the dead weight is to be dropped from height of 1 meter,

$$v = \sqrt{2 \times 9.8 \times 1000}$$

$$v = 140 \text{ mm/s.}$$

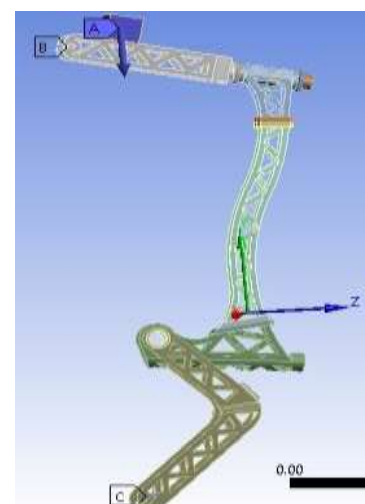


Fig -3: Constraints and load applied for impact loading

3. MATERIAL FOR FRAME

There are a wide variety of materials used in bicycle frames. Bike frames were originally made from wood, but modern frames are made primarily from aluminum, steel, titanium and carbon fiber. The materials used for mountain bicycle frames have a wide range of mechanical properties as shown in following table

Table -1: Mechanical properties of common bicycle frame materials

	Modulus of Elasticity (GPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Density (kg/m ³)	Cost (USD per kg)
Aluminum - 6061-T6	72	193-290	241-320	2,700	\$2.42
Aluminum - 7005-T6	72	290	350	2,780	\$2.87
Steel - 4130	205	800-1,000	650	7,800	\$0.95
Titanium - Grade 9	91-95	483-620	621-750	4,480	\$57.40
Carbon Fiber	275-415	Varies	Varies	1,800	Varies

The 6061 aluminum alloy

The 6061 aluminum alloy is an alloy frequently used for a wide variety of applications. This material is used for bicycle frames, aircraft structures, automotive parts, and much more. The two most important elements in alloying in 6061 are silicon and magnesium. The important mechanical properties for comparing bike frame materials include the material's density, ultimate tensile strength, weldability and cost.

4. RESULTS

4.1 Horizontal Loading Test

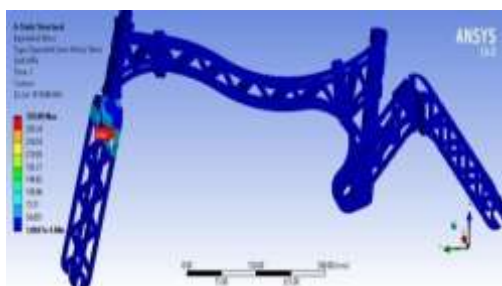


Fig -4: Equivalent stress (von misses) induced in frame for horizontal loading

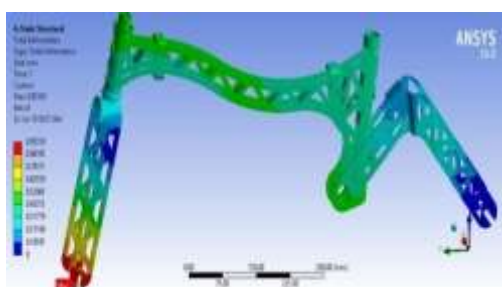


Fig -5: Total deformation in frame for horizontal loading

4.2 Vertical Loading Test

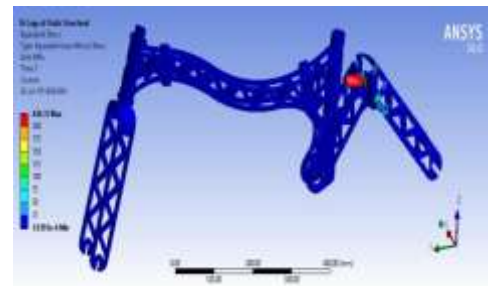


Fig -6: Equivalent stress (von misses) induced in frame for vertical loading

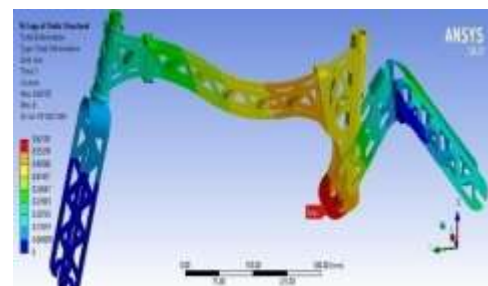


Fig -7: Total deformation in frame for vertical loading

4.3 Impact Loading Test

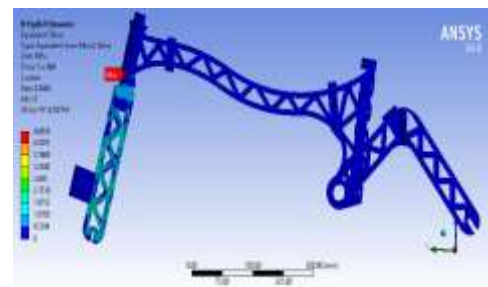


Fig -8: Equivalent stress (von misses) induced in frame for impact loading

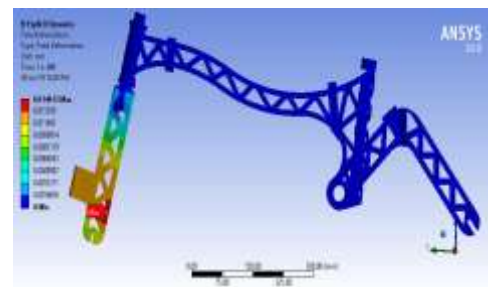


Fig -9: Total deformation in frame for impact loading

4.1 Result discussion

From static structural analysis for horizontal structural test it is found that maximum stress induced and total deformation in frame is at front fork. Hence front fork is remarked as first failure location of bicycle frame. From static structural analysis for vertical structural test it is found that maximum equivalent stress induced and total deformation in frame is at rear fork. Hence rear fork is remarked as second failure location of bicycle frame.

Table -2: FEA results

Loading Condition	Equivalent Stress (MPa)	Total Deformation (mm)
Horizontal Loading	329.89	0.9533
Vertical Loading	430.37	0.6218
Impact Loading	4.8456	0.01497

5. CONCLUSION

Static structural analysis of foldable bicycle frame is carried for the three loading condition in ANSYS. From the results of FEA, it is found that the maximum stress for horizontal loading condition is found at front fork of frame and for vertical loading condition is found at rear fork. Hence from these results front fork and rear fork are finalised as failure locations which can be considered as locations for further design optimisation.

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