Finite element and experimental analysis of folding bicycle frame

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Abstract - **Bicycle is considered as a very popular and easily available source of transportation which is very efficient as well as economical among the man powered vehicles. Bicycle Frame is very important structural element on which all other different types of structural elements and accessories are mounted. Due to such importance of frame its structural strength is very much important for safe riding. As all other elements are mounted on the frame with help of different types of fastening methods, different types of loads are directly transferred to it like reaction force from ground, weight of rider, breaking force and force due to peddling action. Till date numbers of innovative ideas were presented for bicycle frame structure, out of these innovations a foldable bicycle frame structure is proposed for this work. The foldable structure of frame provides ease of portability as it is very easily folded to smaller size compared to original size. In this work static structural analysis of folding frame is carried out using both using finite element method and experimental method for two loading condition that are horizontal loading, vertical loading. The loading and boundary conditions were developed in reference with 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. Results of FEA were compared to experimental analysis results.**

keywords - **CAD, FEA, Folding bicycle, frame**

I. INTRODUCTION

A bicycle frame structure is a vital component of a bicycle design. The main role of the frame structure is to transfer the mechanical energy produced to the bicycle rear wheel. All other elements structural elements and accessories of bicycle are mounted or attached to Frame with the help of different fastening methods. As the frame structure is very important element of bicycle design, numbers of innovations were presented throughout the history till date. Numbers of modifications were carried out on frame design such as modification in overall shape of bicycle, design of frame structure, material of frame, etc. 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. In case of bicycle different types of loads are acting on the frame, from the rider, the field and the ground reaction. 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. 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. In this work static structural stress analysis of foldable bicycle frame is carried out using finite element method for two loading conditions like horizontal structural loading, vertical structural loading with reference to ASTM F2711-08 bicycle frame testing standard. Then the experimental analysis is carried out for the same loading and boundary conditions. The results of finite element analysis were compared with results of experimental analysis.

II. LITERATURE REVIEW

Bharati Tayade et.al [1] 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. **Derek Covill et.al [2]** 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. **M.V.Pazare [3]** 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. **Joachim Vanwalleghem et.al [4]** 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 [5]** 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. **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. **Paul Miles et.al [7]** has carried out the experimental analysis of pedal bicycle frame for various types of loads and then the experimental analysis results were directly compared to FEA results. The different loading conditions were static loading, steady pedaling on smooth, mid-grade, and rough pavement, and hard acceleration on level ground and uphill. **Arun Sam Varghese [8]** has done finite element analysis of bicycle frame for composite laminates. Finite element analysis is carried out for two different proposed design for Carbon/Epoxy composite material

III. FINITE ELEMENT ANALYSIS

In finite element analysis the solid model of folding frame is imported to the simulation software and converted to finite element meshed model using solid 186 and solid 92 element types and stress analysis is carried out by applying loading and boundary conditions to this finite element mode. The solid model of bicycle frame was created using CAD software CATIA V5 R16.

1. **Solid modeling and finite element meshing**

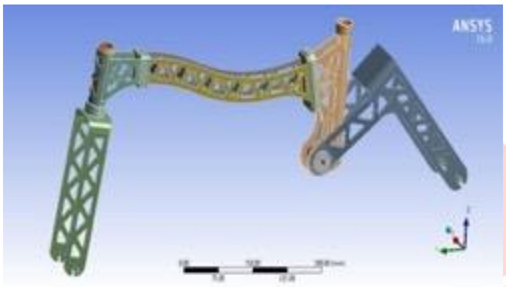


Figure 3.1: Solid model of the folding bicycle frame

Figure 3.2: Meshing of the folding bicycle frame

2. **Loading and boundary conditions for 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.

Loading and Boundary conditions for horizontal loading includes fixed support at rear fork axle cylindrical surface, displacement at front fork axle cylindrical surface and 600N force at front fork axle cylindrical surface.

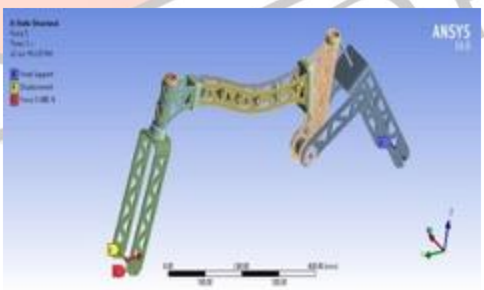


Figure 3.3: Loading and boundary conditions for horizontal loading test

3. **Loading and boundary conditions for 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.

Loading and boundary conditions for vertical loading includes fixed support at rear fork axle cylindrical surface, fixed support at front fork axle cylindrical surface and 800N force on top surface of rear frame seat post position.

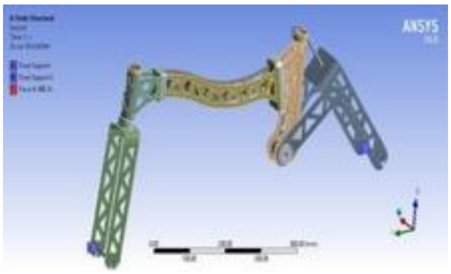


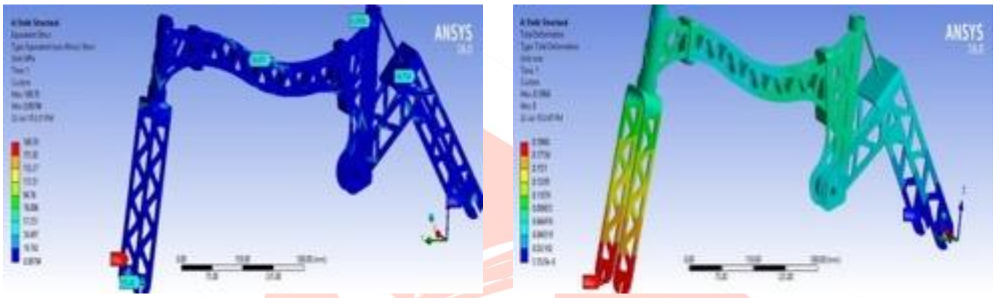
Figure 3.4: Loading and boundary conditions for vertical loading test

4. Bicycle frame material

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.

IV. FINITE ELEMENT ANALYSIS RESULTS

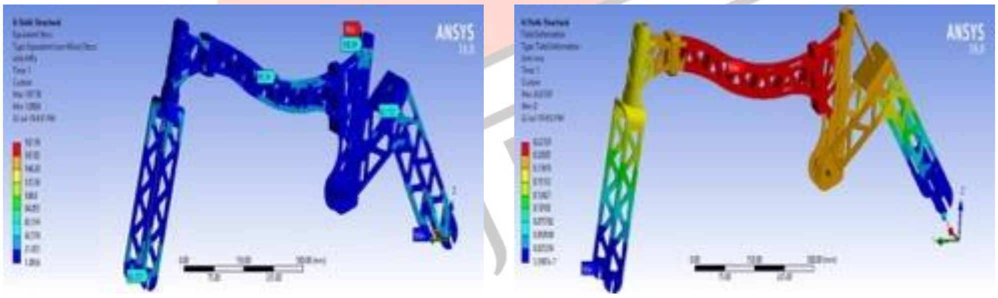
1. Horizontal loading test



(A) (B)

Figure 4.1: (A) Equivalent (von-mises) stress induced in frame (B) Total deformation in frame

2. Vertical loading test



(A) (B)

Figure 4.2: (A) Equivalent (von-mises) stress induced in frame (B) Total deformation in frame

V. EXPERIMENTAL ANALYSIS

1. Elements of Experimental Setup

NI cDAQ 9174 module data acquisition system, labview computer system with labview software, bonded metallic strain gauge, bicycle frame, frame supporting stand.

2. Experimental Testing Setup

Experimental analysis is carried out for both horizontal and vertical loading condition with the help of experimental setup. The four strain gauges were applied at four different locations on frame such as bottom of front and rear fork, top of seat post and center part of frame.

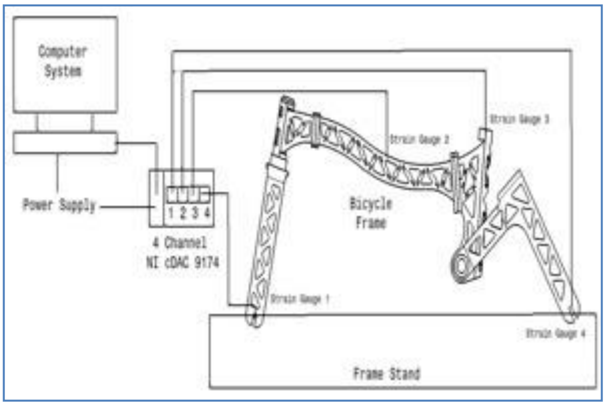


Figure 5.1: Experimental testing setup

3. Vertical loading test

The same loading and boundary condition were applied as finite element analysis, fixed support at both the rear and front fork axel and the 80 kg load at the top face of seat post.

Figure 5.2: Experimental testing setup for vertical loading test

4. Horizontal loading test

The same loading and boundary condition were applied as finite element analysis, the front fork is allowed to slide along frame axis direction, fixed support at the rear axle of rear fork and the 60 kg load to the axel of front fork.

Figure 5.3: Experimental testing setup for horizontal loading test

VI. COMPARISON OF FEA RESULTS WITH EXPERIMENTAL ANALYSIS RESULTS

1. Comparison for horizontal loading test

Table 6.1 Comparison of FEA results with Experimental Results for horizontal loading

Strain gauge location	ANSYS Results		Experimental Results		% Error (Stress)	% Error (Strain)
	Strain	Stress (Mpa)	Strain	Stress (Mpa)		

Front Fork	2.257×10^{-3}	155.41	2.374×10^{-3}	161.67	3.87	4.93
Center Frame	5.54×10^{-4}	38.475	6.094×10^{-4}	41.98	8.35	9.09
Seat Post	1.23×10^{-4}	8.29	1.340×10^{-4}	9.23	10.18	8.21
Rear Frame	2.405×10^{-4}	16.57	2.621×10^{-4}	18.05	8.20	8.24

2. Comparison for vertical loading test

Table 6.2 Comparison of FEA results with Experimental Results for vertical loading

Strain gauge location	ANSYS Results		Experimental Results		% Error (Stress)	% Error (Strain)
	Strain	Stress (Mpa)	Strain	Stress (Mpa)		
Front Fork	9.011×10^{-4}	62.33	9.72	10.07	9.72	10.07
Center Frame	1.248×10^{-3}	85.58	7.25	6.80	7.25	6.80
Seat Post	1.46×10^{-3}	100.89	4.48	4.76	4.48	4.76
Rear Frame	6.11×10^{-4}	42.133	6.45	6.58	6.45	6.58

VII. Conclusion

Finite element analysis was carried out for foldable bicycle frame for two loading conditions such as horizontal loading and vertical loading. The finite element analysis result showed that the equivalent stress, strain and the total deformation in frame for both loading condition are within the allowable limits. Also the results of finite element analysis were compared with results of experimental analysis which showed that FEA gives the approximate but most probable solutions.

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