Finite Element Analysis of All Terrain Bike [ATB]

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Abstract- *Now a day, pollution is increasing due to so much use of vehicles and fuel cost increasing day by day so use of bicycle is considered to be a great alternative. India is largest bicycle producer next to the China. This is because the bicycle (All terrain bike or ATB) is both environment and people friendly. Considering the rising fuels cost and pollution, the bikes are considered ideal. These can be maintained at low costs. Their inception Pedal cycle has provided society with a source of transportation, exercise, recreation and sport. New pedal cycle frames are generally motivated by mass and/or stiffness considerations and usually incorporate the use of good performance engineering statistics. Indeed, competitive bicycling has promoted the use of different advanced and improved structural materials including non-ferrous alloys (e.g. primarily alloys of aluminum and titanium) and reinforced polymers (e.g. carbon and graphite reinforced epoxies). The need for low weight coupled with good strength and stiffness has led to continuing trail and evolution of high efficient materials for racing bicycles The solution to the pertaining issue is to switch to the most genuine and a proven tool of structure of engineering; the Finite Element Analysis Method (FEA).*

Keywords — : *All Terrain bike frame, Static start up, Steady state pedaling, vertical impact, Horizontal impact, Rear wheel braking***.**

I. INTRODUCTION

The modeling for the frame started with development of several concepts for the performance of the frame. Once a concept was selected and sketch specific designs that would utilize the concept decided on previously. A diamond frame was selected to be designed as it was the most primary frame to be analyzed. For that a diamond framed bicycle model from a standard bicycle size geometry chart was selected. From that a size for a person with a height of 5 feet 10.75 inches a frame was constructed.

Figure 1:- Tubing diagram of the bike frame

II. FINITE ELEMENT ANALYSIS OF BICYCLE FRAME USING ANSYS

To verify the analytical result of stresses for pedal cycle frame it is compared with FEA analysis. The isseu to be modeled is shown in the following figure 2 (a simple pedal bycle frame). The frame is to be built of 5 different alloys of pipes having an outside and inside diameter of 33mm and 29mm and a wall thickness of 2mm for head pipe, top pipe, and seat tube and down tube. The outside and inside diameter for chain stay and seat stay are 23mm and 21mm respectively.

The material properties of the alloys are depicted. For this analysis a mesh size of 5mm is taken as it converge the most with the results obtained by the theoretical analysis shown in figure 2.

Figure 2:- Bike frame with meshing of 5mm

III. LOADING AND CONSTRAINTS ON BIKE FRAME

The applied loads and constraints are as follows:-

Figure 3:- Static start up

Figure 4:- Steady state pedaling

Figure 5:- Vertical impact

Figure 6:- Vertical impact

Figure 7:- Horizontal impact

IV. NATURAL FREQUENCY

One of the most common failure modes of bicycle frames is due to high cycle fatigue. The resonant frequency developed due to frame vibration cause the frame failure due to fatigue. The frame vibration characteristics are determined by the natural frequencies and the corresponding modes of shapes.

During free Oscillation, the aim of model analysis is to determine the frequencies and natural mode of shapes. To execute this analysis, it is very common to use finite element analysis method (FEM) because, similar to other methods and calculations using FEM, the arbitrary shapes and results are considerable for the object being analyzed. Sometimes, the only wanted modes are the lowest frequencies; they can be the most important modes at which the object will oscillate, dominating all the higher frequency modes.

It is also possible to determine natural frequencies and mode shapes by test a physical object (Experimental Model). That is called an Experimental Model testing. On the basis of results of Experimental Model testing, Finite element method can be accurate to find out, if the hypothesis made were precise (e.g. material belongings can be correct and boundary conditions may be make or become different).

A mode of Vibration is characterized by a modal frequency and a mode shape, and is numbered according to the number of half waves in the vibration. Each maner is entirely independent of all other modes. Thus different frequencies and different mode shapes in all modes.

Vibration refers to mechanical to and fro motion about an equilibrium point. The oscillations may be periodic (repeat in discipline) or random (not in discipline). Free vibration (no forces considered) occurs when a mechanical system is set off with an initial input disbursing forces and then allowed to vibrate freely. The mechanical arrangement will then oscillate at one or more of its "natural frequency" at high amplitude and damp down to zero amplitude.

Forced vibration is when a cyclic force or motion is applied to a mechanical system in particular time duration. In forced vibration the frequency of the vibration, is equal to the frequency of the applied motion, with order of magnitude being dependent on applied motion and the actual mechanical system.

V. RESULTS AND DISCUSSIONS

Theoretical Stresses on Members

As there are three different alloys, so we have to make three different tables in order to present the resultant stress in different loading cases for all alloys.

1. Chromoly 4130

Load case	Normal Stresses (x-axis) in members (MPa)				
	Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	3.62	0	5.91	1.37	0
Steady state pedaling	6.52	1.12	8.93	3.76	1.28
Vertical impact	10.83	1.95	15.71	7.52	1.83
Horizontal impact	6.68	5.65	0	0	0
Rear wheel braking	0	0	0	12.59	16.81

Table 1:- Theoretical comparison of stresses on members

2. Titanium-3Al-2.5V

Load case	Normal Stresses (x-axis) in members (Mpa)				
	Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	3.21	0	5.83	0.88	0
Steady state pedaling	3.53	0	6.59	0.86	0
Vertical impact	6.51	0	11.85	4.01	0
Horizontal impact	7.71	7.06	0	0	0
Rear wheel braking	0	0	0	13.13	17.28

Table 2:- Theoretical comparison of stresses on members

3. Titanium-6Al-4V

Load case	Normal Stresses (x-axis) in members (MPa)				
	Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	5.56	0	7.91	3.61	0
Steady state pedaling	6.41	1.13	8.97	4.25	0.97
Vertical impact	10.95	0	15.37	7.11	0
Horizontal impact	6.97	6.83	0	0	0
Rear wheel braking	0	0	0	12.16	16.51

Table 3:- Theoretical comparison of stresses on members

Finite Element Analysis Results by ANSYS

The FEM results by ANSYS will be different for different alloys. The results obtained by ANSYS are illustrated below

1. **Chromoly-4130**
2.

Load case	Normal Stresses (x-axis) in members (Mpa)				
	Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	3.58	0	5.68	1.47	0
Steady state pedaling	6.53	1.36	8.72	4.33	1.52
Vertical impact	11.07	2.05	15.02	7.13	2.05
Horizontal impact	6.83	5.34	0	0	0
Rear wheel braking	0	0	0	12.77	16.92

Table 4:- Comparison of stresses on members

Figure 8:- Static start up

Figure 9:- Steady state pedalling

Figure 10:- Vertical impact

Figure 11:- Horizontal impact

Figure 12:- Rear wheel braking

3. Titanium-3Al-2.5V

Load case	**Normal Stresses (x-axis) in members (MPa)**				
	Top tube (AB)	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	3.3	0	5.65	0.93	0
Steady state pedaling	3.64	0.12	6.26	1.02	0.12
Vertical impact	6.62	0	11.33	4.12	0
Horizontal impact	7.64	6.82	0	0	0
Rear wheel braking	0	0	0	13.2	17.5

Table 5:- Comparison of stresses on members

Figure 13:- Static start up

Figure 14:- Steady state pedaling

Figure 15:- Vertical impact

Figure 16:- Horizontal impact

Figure 17:- Rear wheel braking

3. Titanium-6Al-4V

	Normal Stresses (x-axis) in members (Mpa)				
Load case	**Top tube (AB)**	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	5.611	0	7.59	3.622	0
Steady state pedaling	6.65	1.71	8.82	4.4	1.69
Vertical impact	11.22	0	15.19	7.24	0
Horizontal impact	7.27	7.27	0	0	0
Rear wheel braking	0	0	0	12.54	16.83

Table 6:- Comparison of stresses on members

Figure 18:- Static start up

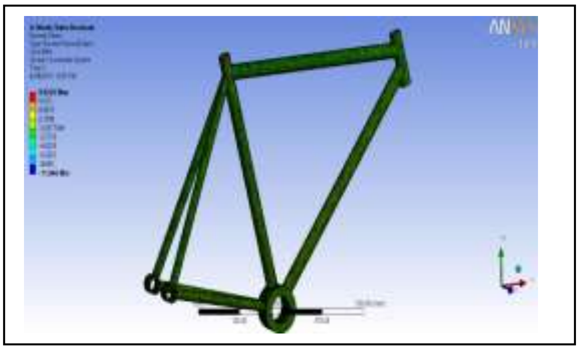

Figure 19:- Steady state pedalling

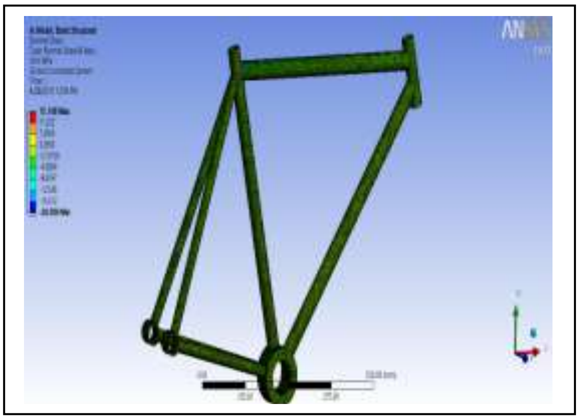

Figure 20:- Vertical impact

Figure 21:- Horizontal impact

Figure 22:- Rear wheel braking

VALIDATION OF FINITE ELEMENT ANALYSIS

On comparison of theoretical (analytical) results obtained by Finite Element Formulation and the result obtained by Finite Element Analysis in ANSYS drives us to the conclusion that the difference in results is varying from 0% to 42.6 % (Chapter 6.3.1 – 6.3.5) but the average variation is under 5 % which validates the loading case calculations performed by ANSYS.

The variation is larger at times due to the meshing quality difference between ANSYS and the meshing quality used for analytical calculations. Meshing in ANSYS was so adjusted to converge best with the results of the analytical process.

The 5 alloys used have varied difference on same loading conditions but they are mostly at par with its analytical results. In some cases with lower stress obtained the difference has been quite large at a level of 40% which is evident as the difference shoots up exponentially for smaller values with same difference in absolute nature as that of larger stress values.

In the truss analysis, the assumption was made that all of the frame components were two-force members and that these members were attached at hinge joints that cannot apply any moments. The assumption was held that the material being dealt with was linear elastic and isotropic. Looking at the FEA results, it is observed that the stress distribution was not truly uniform across the cross section of the tube. This invalidates our truss analysis since two-force members can only have uniform stress across the cross section of the component.

For the difference calculation purpose the maximum stress obtained in the member in FEA analysis was compared with that of analytical analysis. In FEA the stress across the cross section was not uniform this is the true case in real life conditions. But for validation purpose it was assumed that the stress is uniform and the maximum stress along the members in FEA was compared with analytical results.

Equivalent (Von–Mises) Stress Analysis for Bike Frames

Equivalent (von-Mises) stress analysis for the 5 alloys is done in ANSYS applying the different loading conditions with a meshing of 5mm.

Chromoly-4130

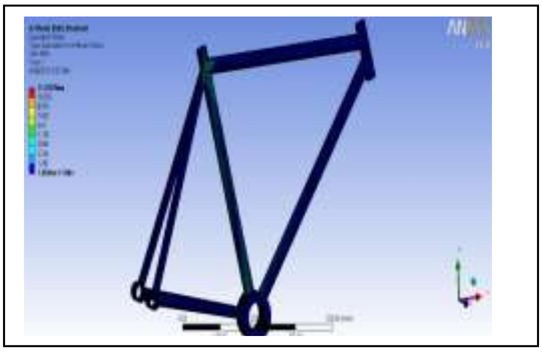

Figure 23:- Equivalent stress, Static start up

Figure 24:- Equivalent stress, Steady state pedaling

Figure 25:- Equivalent stress, Vertical impact

Figure 26:- Equivalent stress, Horizontal impact

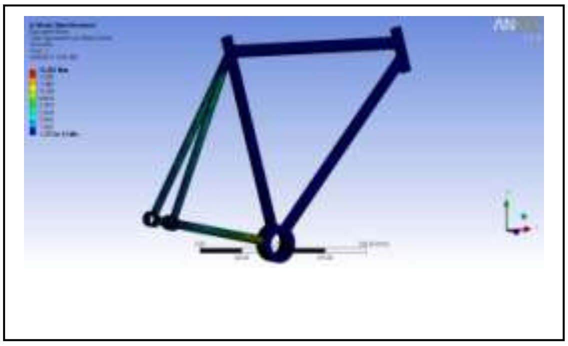

Figure 27:- Equivalent stress, Rear wheel braking

Load case	Equivalent (von-Mises) Stress in members (MPa) Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	10.25	6.41	11.53	8.97	1.28
Steady state pedaling	10.6	6.62	11.92	9.27	1.32
Vertical impact	20.51	12.82	23.07	17.94	2.56
Horizontal impact	32.18	28.6	0	0	0
Rear wheel braking	0	0	0	13.58	15.28

Table 7:- Comparison of equivalent stresses on members

Titanium-3Al-2.5V

Figure 28:- Equivalent stress, Static start up

Figure 29:- Equivalent stress, Steady state pedaling

Figure 30:- Equivalent stress, Vertical impact

Figure 31:- Equivalent stress, Horizontal impact

Figure 32:- Equivalent stress, Rear wheel braking

Load case	Equivalent (von-Mises) Stress in members (MPa) Top tube (AB)	Down tube (AD)	Seat tube (BD)	Seat stays (BC)	Chain stays (CD)
Static start up	20.53	0	23.1	17.96	0
Steady state pedaling	20.98	0	23.6	18.35	0
Vertical impact	41.03	0	46.16	35.9	0
Horizontal impact	29.07	25.84	0	0	0
Rear wheel braking	0	0	0	14.5	16.31

Table 8:-Comparison of equivalent stresses on members

Titanium-6Al-4V

Figure 33:- Equivalent stress, Static start up

Figure 34:- Equivalent stress, Steady state pedaling

Figure 35:- Equivalent stress, Vertical impact

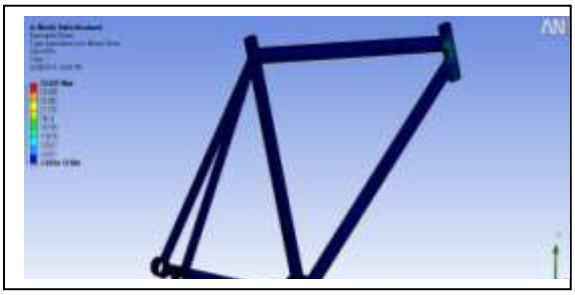

Figure 36:- Equivalent stress, Horizontal impact

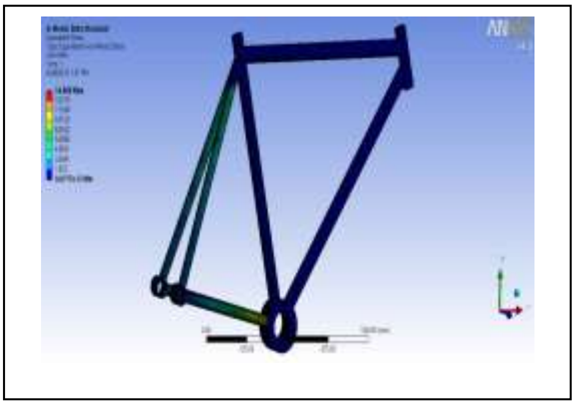

Figure 37:- Equivalent stress, Rear wheel braking

	Equivalent (von-Mises) Stress in members (MPa)				
Load case	**Top tube (AB)**	**Down tube (AD)**	**Seat tube (BD)**	**Seat stays (BC)**	**Chain stays (CD)**
Static start up	10.42	5.21	11.72	9.12	1.3
Steady state pedaling	10.76	5.38	12.11	9.41	1.34
Vertical impact	20.85	10.42	23.45	18.24	2.6
Horizontal impact	32.63	29	0	0	0
Rear wheel braking	0	0	0	13.21	14.86

Table 9:- Comparison of equivalent stresses on members

Comparison of Maximum Stress Obtained For Different Cases

The maximum values of stresses obtained for the different application of load cases for different alloys are compared in order to ascertain the properties of material alloy to take the impact of the loading. The yellow colour depicts the alloy having the maximum stress and blue colour depicts the alloy having minimum stress for a given condition (Table 10).

	Maximum stress obtained for different cases (Mpa)				
ALLOYS	**Static start up**	**Steady state pedaling**	**Vertical impact**	**Horizontal impact**	**Rear wheel braking**
Chromoly -4130	11.53	11.92	23.07	32.18	15.28
Titanium-3Al-2.5V	23.1	23.6	46.16	29.07	16.31
Titanium-6Al-4V	11.72	12.11	23.45	32.63	14.86

Table 10:- Comparison of maximum stress (MPa) obtained for different cases

Comparison of Maximum Deformation Obtained For Different Cases

The maximum values of deformation obtained for the different application of load cases for different alloys are compared in order to ascertain the properties of material alloy to take the impact of the loading. The more the deformation the more the material alloy is susceptible to failure. Yellow colour depicts maximum deformation and blue colour depicts minimum deformation for a given condition among the alloys (Table 10).

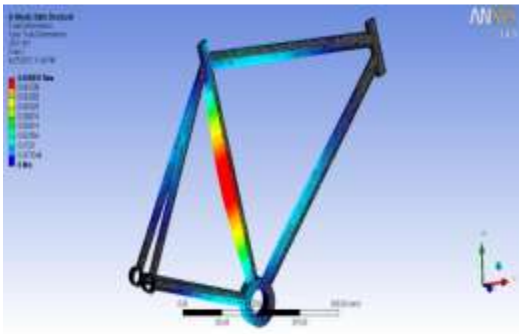

Figure 38:- Static start up (maximum deformation), Aluminum 7005-T

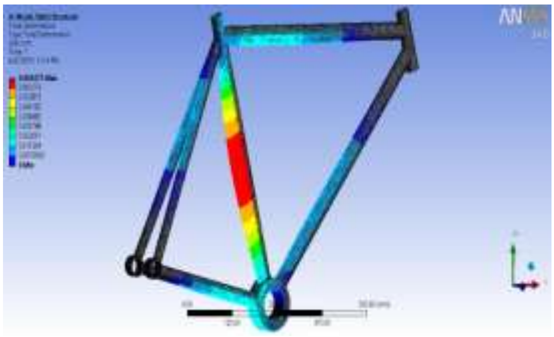

Figure 39:- Steady state pedaling (maximum deformation), Aluminum 7005-T

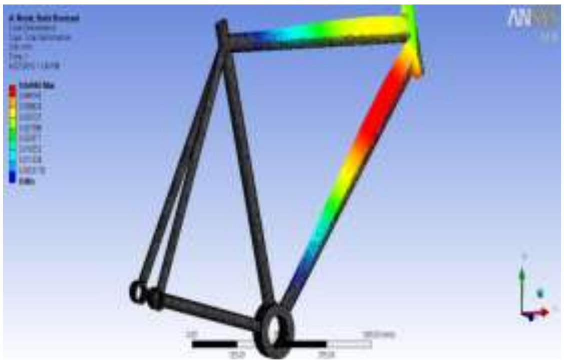

Figure 40: -Vertical impact (maximum deformation), Aluminum 7005-T

Figure 41:- Horizontal impact (maximum deformation), Aluminum 7005-T

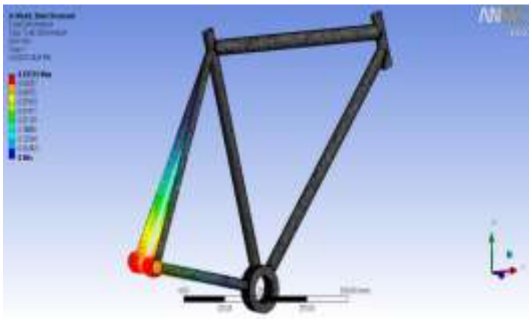

Figure 42:- Rear wheel braking (maximum deformation), Aluminum 6061-T

With reference to the reference number 1 and comparing it with our result.

ALLOYS	**Maximum deformation obtained for different cases (mm)**				
	Static start up	**Steady state pedaling**	**Vertical impact**	**Horizontal impact**	**Rear wheel braking**
Aluminum 6061-T	0.023	0.024	0.047	0.049	0.56
Aluminum 7005-T	0.068	0.069	0.137	0.05	0.54
Chromoly-4130	0.024	0.023	0.046	0.016	0.184
Titanium-3Al-2.5V	0.016	0.017	0.033	0.035	0.388
Titanium-6Al-4V	0.042	0.043	0.085	0.03	0.341

Table 11:- Comparison of maximum deformation (mm) obtained for different cases:

- Aluminum 7005-T happens to be the most deformed alloy with a distortion of 0.068, 0.069, 0.137 and 0.05 mm for static start up, steady state pedaling, vertical impact and horizontal impact loading cases respectively.
- Aluminum 6061-T is the most deformed composite for rear wheel braking loading case with a deformation of 0.56 mm.
- The maximum deformation happens for the rear wheel braking case where a force of 750 N is applied on the dropouts which clearly impacts seat stays and chain stays.

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