Stress Analysis of Bicycle Frame using Different Materials by FEA

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Abstract

The present study deals with the use of a finite element analysis to study the comparative behavior for a standard bicycle frame under a range of measured cases using four different materials such as Steel, Aluminum 6061 T6, Titanium grade 9 and Carbon Fiber. The modeling of the bicycle frame is done using CATIA V5 and the analysis is carried out in ANSYS 16.0. The stress acting within the bicycle are analyzed with respect of frame performance relating to static strength related to load applied. In this study static structural analysis of the bicycle frame is conducted under different load conditions such as static start-up, steady state pedaling, vertical impact, horizontal impact and rear wheel braking in four different materials using ANSYS.

Keywords- Finite Element Analysis (FEA), ANSYS, Mg AZ910, Steel, Al 6061-T6, Titanium G9, Carbon Fiber

I. INTRODUCTION

The structural analysis of the frame is a very important stage in the design process of the bicycle. The finite element method was used to analysis the structural behaviors of bicycle frame. Bicycle frame modeling was done in CATIA V5 software. The analysis of the frame was done using ANSYS 16 software. Sajimsha B et al. [1] carried out the development of new material is based on the need for low weight coupled with high strength and stiffness acting on bicycles. The study aimed to compare different materials for bicycle frame on the basis of less cost and deformation occurring with high strength and performance.

Rajeev et al. [2] carried out an analysis on equivalent (von-Mises) stress analysis for all material alloys for all load cases is performed in ANSYS to make a comparative study and he concluded that aluminum alloys are light weight but are easily deformed. M.V. Pazare et al. [3] deals with the stress analysis of bicycle frame by using Finite Element Method and found that the maximum stress occurs in the top tube of the bicycle frame. Kailas Khutal et al. [4] made an effort in identifying a FE methodology that would reduce the development time and the reliable results can obtained. In this work, two simulation methodologies were studied - linear static analysis considering test rig boundary conditions and fatigue using harmonic analysis. Derek Covill et al. [5] this paper outlines the use of a finite element model to simulate the behaviour for a standard steel bicycle frames under a range of measured load cases. Hence it is concluded that further research is required to understand how tube profiles, selection and load distribution between tubes can be used to influence frame strength, and to analyze the modes of failure for various bicycle designs under typical and extreme usage in order to understand the implications of design on safety.

Derek Covill et al. [6] explained about the parametric Finite Element model of road bicycle frames using beam elements with varying tube profiles. Bharati A. Tayadea et al. [7] carried out a F.E.A. comparison between Falcon Avon bicycle frame, Sunami bicycle frame, Foster bicycle frame and Miss India Hero bicycle frame. From the results of FEA, it is apparent that the stresses induced in the bicycle frame of Falcon Avon is least and the factor of safety is also well above the limit hence the stresses are less than the ultimate strength of the material.. Thus the design of bicycle frame is sturdy. The results are relevant provided the assumptions and boundary conditions are perfect. Akhyar et al. [8] studied the stress and displacement of bike frame with “T” and “I” profiles have been analyzed in this work with simple truss structure design and finite element analysis. Various loading conditions are introduced in this paper such as static start-up, steady state pedaling, vertical loading, horizontal loading, and rear wheel breaking. However, bicycle frame with solid T and I profile design is still quite heavy when compared to standard bicycle frames on the market. The FEA simulation results cleared that there are still many opportunities for optimization of this bike frame design with the aim of to reduce material used. Optimization is needed to reduce material used of the bicycle frame, but the important is still in a safe tolerance and comfort for users.

II. METHODOLOGY

A. Modeling

The frame is the main component. It consists of top tube, head tube, bottom tube, seat tube, seat stay and chain stay to which the wheels and other components are connected. The design parameters are shown in table 1 was obtained from the paper, Sajimsha B et al. [1]. According to the design parameters, a 2D sketch was drawn as shown in figure 1. Then the bicycle frame modeling was done in CATIA V5, as shown in figure 2. The bicycle frame was meshed with tetrahedral shapes and 74916 elements and 146201 nodes respectively. The static structural analysis was done in ANSYS 16.0.

Table 1: Design Parameters of Bicycle Frame

Parameter	*Value*
Seat Tube Angle	*73.5°*
Seat Tube Length	*580mm*
Top Tube Length	*570mm*
Bottom Tube Length	*670mm*
Chain Stay Length	*360mm*
Seat Stay Length	*500mm*

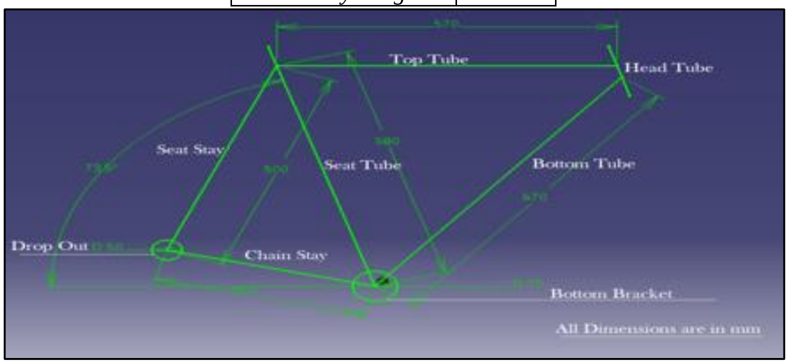


Fig. 1: Sketched model

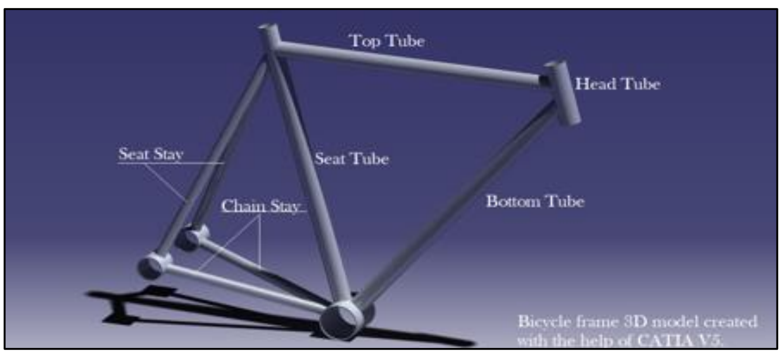


Fig. 2: 3-Dimensional Model of Bicycle Frame

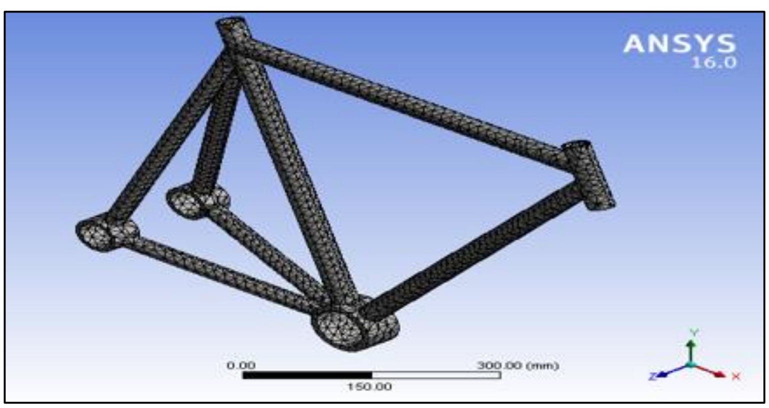


Fig. 3: Bicycle frame with meshing of 5mm

B. Boundary Conditions

The approach involves five boundary conditions that are considered in this effort.

B1. Static Start-up: The rider is on the bicycle applying a load of 700N and 200N on the top of the seat tube and on the bottom bracket respectively as shown in figure 4.

B2. Steady State Pedaling: The cyclist is on the bicycle and applying a force of 1000N and 200N on the bottom bracket and top of the head tube respectively as shown in figure 5.

B3. Vertical Impact: It is represented by multiplying the cyclist’s weight by some amount of G factor. In this case a factor of 2G is taken taking the load to 2250N which is the necessary case when an object falls from an infinitesimal height onto a rigid surface as shown in figure 6.

B4. Horizontal Impact: A load of 2250N is applied to the front dropout horizontally, with the rear dropout’s constraint from any translational motion as shown in figure 7.

B5. Rear Wheel Braking: It is assumed that the tire is skidding and thus rear pitch over is imminent, therefore all forces are concentrated on the rear wheel as shown in figure 8.

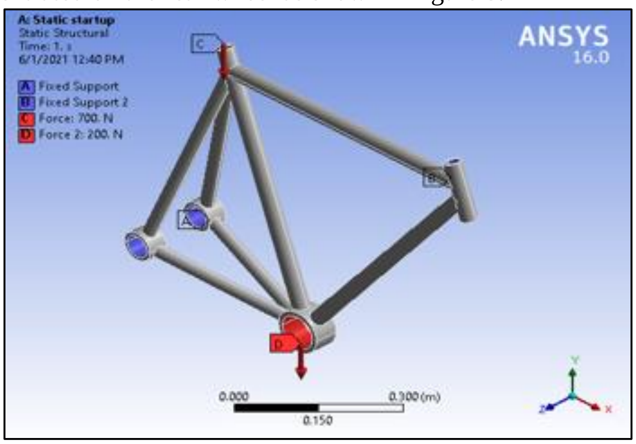


Fig. 4: Static Start-up

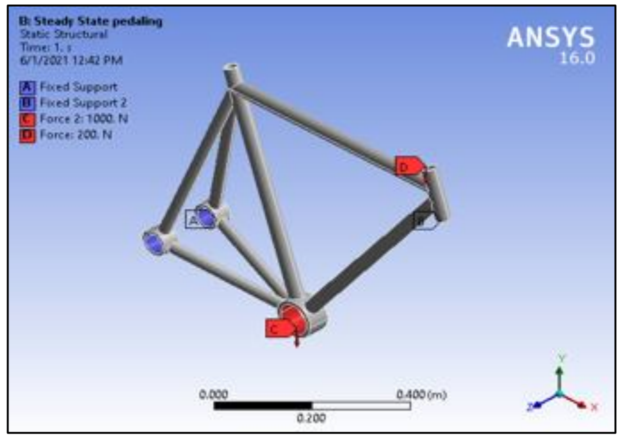


Fig. 5: Steady State Pedaling

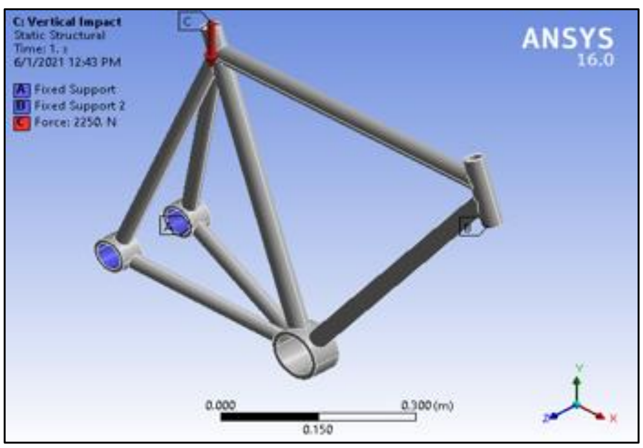


Fig. 6: Vertical Impact

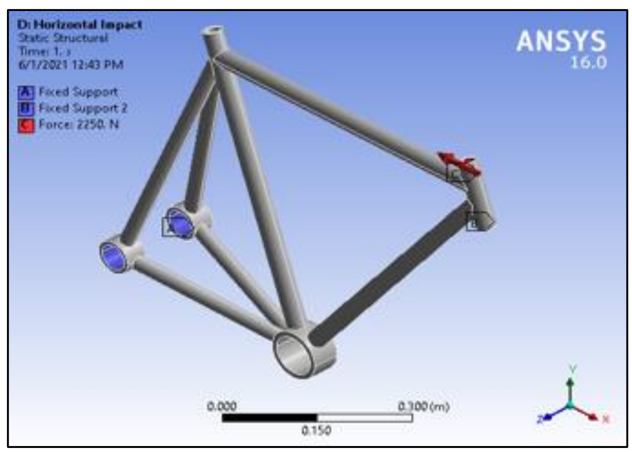


Fig. 7: Horizontal Impact

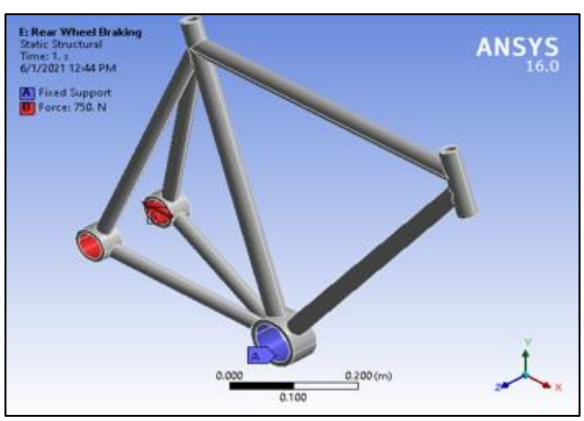


Fig. 8: Rear Wheel Braking

C. Validation

The validation of the present study is carried out using a journal paper by Sajimsha B et al. on Analysis of Mountain Bike Frames by ANSYS [1]. The equivalent (von-Mises) stress found at static start-up from the base paper is 7.4116 MPa and present study is 7.1463 MPa respectively. The total deformation value found at static start-up from the base paper is 0.030416 mm and present study is 0.030587 mm respectively. After examining, it is found that the equivalent (von-Mises) stress and total deformation values obtained from the base paper and from the present study are in close accordance at all given load conditions. Figure 9 and 10 shows the comparison of base paper and present work.

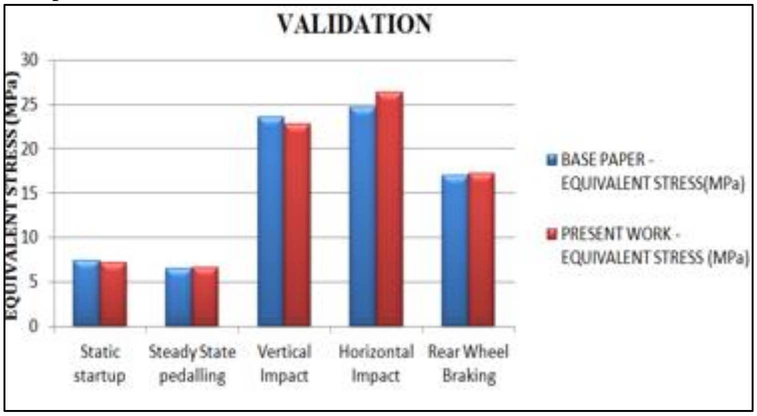


Fig. 9: Comparison of Equivalent Stress (MPa) in base paper and present work

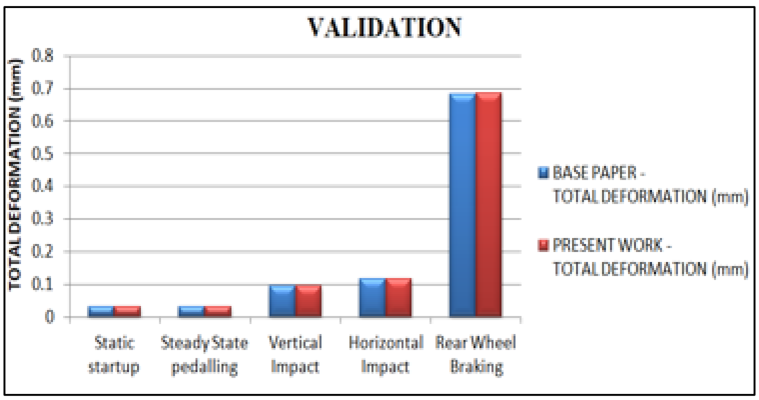


Fig. 10: Comparison of Total Deformation (mm) in base paper and present work

D. Material Properties

There are a wide variety of materials used in bicycle frames. The mechanical properties of the materials used for present bicycle frames study can be seen in Table 2.

Table 2: Mechanical properties of the materials selected

Materials	Modulus of Elasticity (GPa)	Poisson's Ratio	Density (Kg/M^3)
Steel	205	0.29	7800
Aluminum 6061 T-6	72	0.33	2700
Titanium Grade 9	95	0.3	4480
Carbon fiber	415	0.1	1800

III. RESULT AND DISCUSSION

1. Comparison Of Maximum Stress Obtained for Different Cases:

Table 3 and figure 11 shows the maximum values of stresses obtained for the different loading cases for different materials and are compared in order to ascertain the properties of materials to take the impact of the loading.

Table 3: Comparison of Maximum Equivalent (Von- Mises) Stress (MPa) in Different Materials

	Maximum Equivalent(Von-Mises) Stress (Mpa)			
Conditions	Steel	Aluminum 6061 T6	Titanium Grade 9	Carbon Fiber
1.Static Startup	9.8212	10.915	10.896	10.940
2.Steady State Pedalling	6.3773	7.4270	7.3168	8.4552
3.Vertical Impact	31.216	33.722	34.607	34.839
4.Horizontal Impact	28.069	30.364	31.071	33.941
5.Rear Wheel Braking	17.746	17.780	18.022	19.498

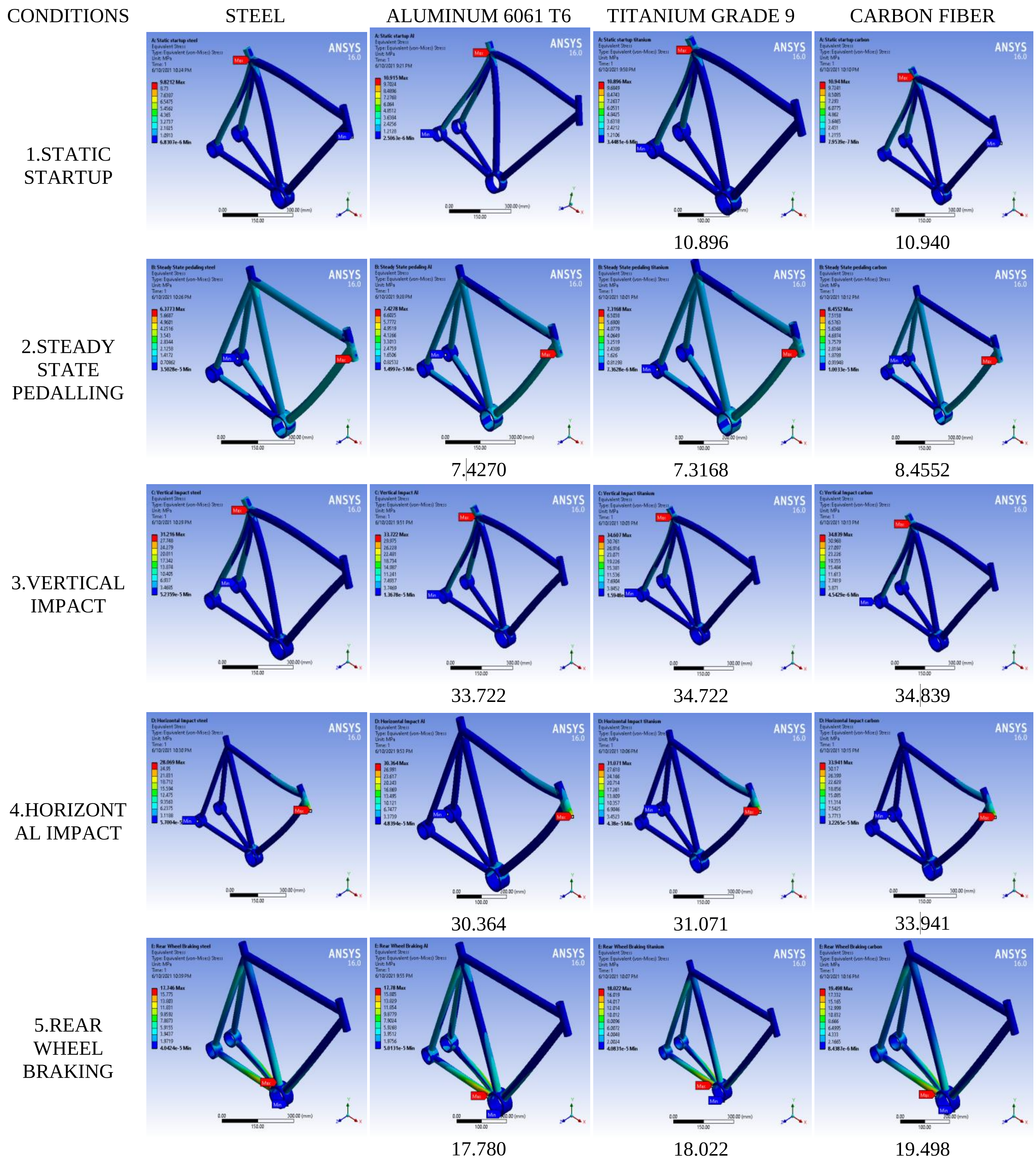


Fig. 11: Maximum Equivalent (von-Mises) Stress (MPa) of Different Materials

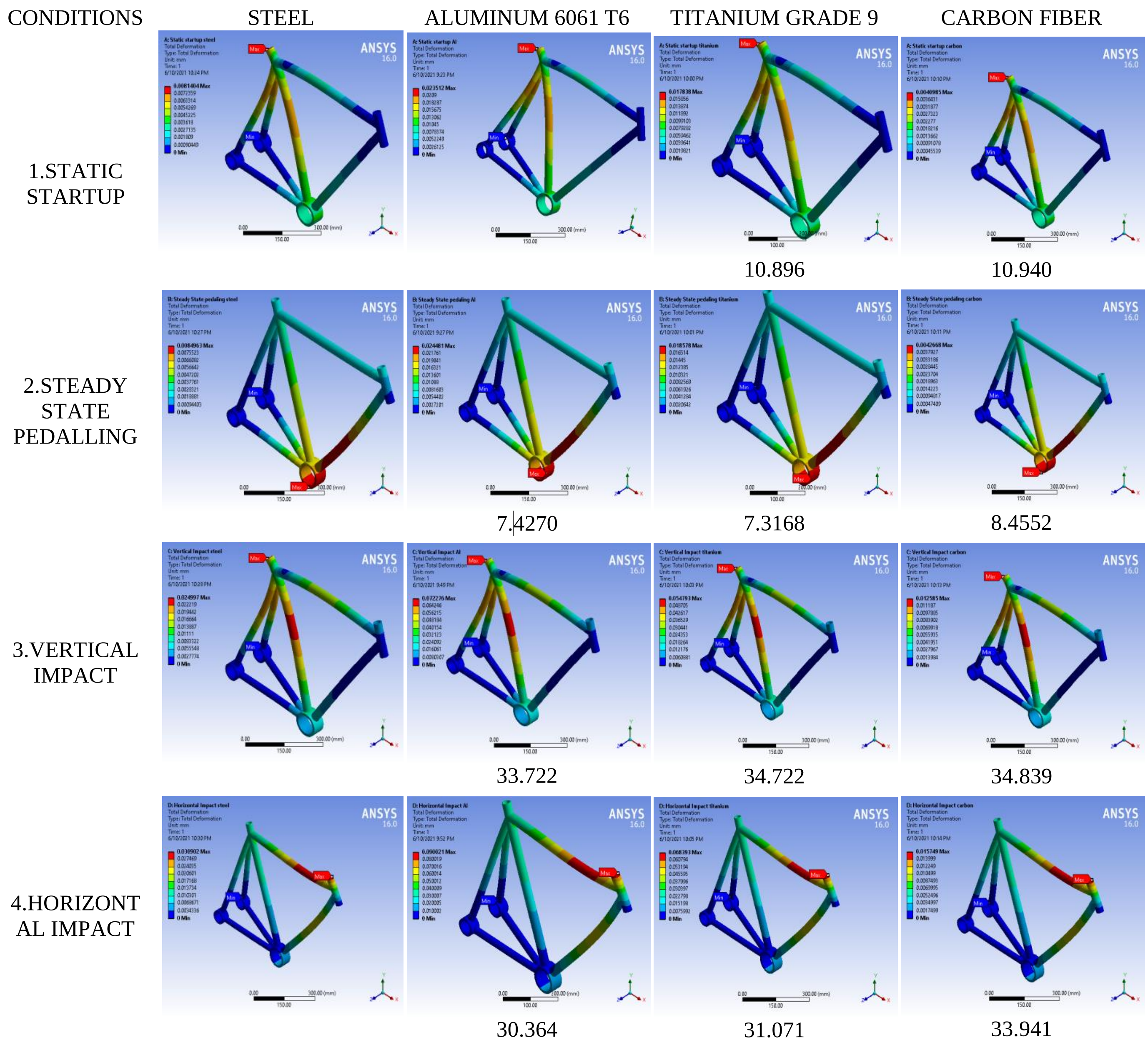
From the table 3 it is clearly evident that carbon fiber has the maximum equivalent stress distribution as compared to the other three materials used and Steel happens to have the lowest values of maximum equivalent stress for static start up, steady state pedaling, vertical impact and horizontal impact loading cases respectively. The increasing order of stress acting can be made out from the figure which is as follows: Steel < Aluminum 6061-T6 < Titanium Grade 9 < Carbon Fiber.

2. Comparison of Maximum Deformation Obtained For Different Cases:

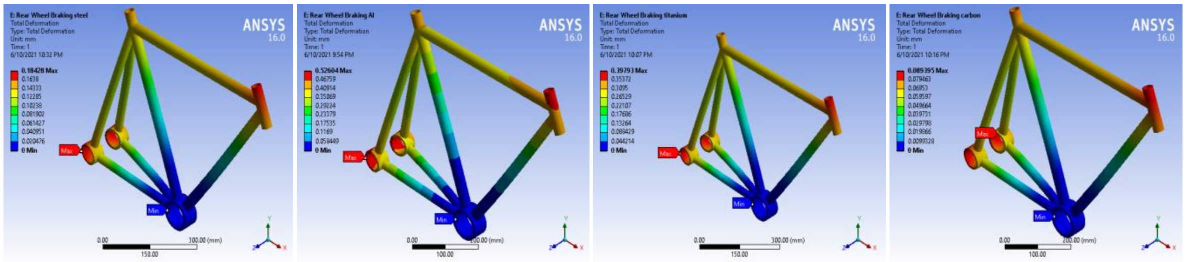
Table 4 and figure 12 shows the maximum values of deformation obtained for the different loading cases for different materials and are compared in order to ascertain the properties of materials to take the impact of the loading.

Table 4: Comparison of Maximum Deformation (mm) in Different Materials

	Maximum Total Deformation (mm)			
Conditions	*Steel*	*Aluminum 6061 T6*	*Titanium Grade 9*	*Carbon Fiber*
1.Static Startup	*0.0081404*	*0.023512*	*0.017838*	*0.0040985*
2.Steady State Pedalling	*0.0084963*	*0.024481*	*0.018578*	*0.0042668*
3.Vertical Impact	*0.024997*	*0.072276*	*0.054793*	*0.012585*
4.Horizontal Impact	*0.030902*	*0.090021*	*0.068393*	*0.015749*
5.Rear Wheel Braking	*0.18428*	*0.52604*	*0.39793*	*0.089395*



5.REAR WHEEL BRAKING



17.780 18.022 19.498

Fig. 12: Maximum Total Deformation (mm) of Different Materials

From the table 4 it is clearly evident that carbon fiber has a less chance of deformation than other three materials used. Aluminum 6061 T6 happens to be the most deformed material for static start up, steady state pedaling, vertical impact and horizontal impact loading cases respectively. Aluminum 6061 T6 is the most deformed alloy for rear wheel braking loading case with a deformation of 0.52604 mm. The increasing order of deformation can be made out from the figure which is as follows: Carbon Fiber < Steel < Titanium Grade 9 < Aluminum 6061-T6.

IV. CONCLUSION

In this present study modeling of the designed bicycle frame was done in CATIA V5 software. The bicycle frame was designed using 4 different materials i.e, Steel, Aluminum 6061 T6, Titanium Grade 9 and Carbon. For these 4 frames, 5 different load cases such as static start up, steady state pedaling, vertical impact and horizontal impact loading are defined in order to make out the equivalent stress and total deformation in each frame. A comparative study was made for the total deformation and equivalent (von-Mises) stress in the members of materials for all load cases with the help of ANSYS 16.0. After the analysis on four materials, Carbon fiber has a less chance of deformation than other three materials used. Aluminum 6061 T6 happens to be the most deformed material. Aluminum 6061 T6 is the most deformed material for rear wheel braking loading case with a deformation of 0.52604 mm. In the case of Equivalent (von-Mises) stress Carbon fiber has the maximum equivalent stress distribution as compared to the other three materials used. Steel happens to have the lowest values of maximum equivalent stress.

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