Numerical Study on Materials and Design Optimization of a Bicycle Frame

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Abstract—Strength has been gaining importance in the design of bicycle frame. Composite materials which are composed of reinforced fibers and plastics matrix have high strength-to-weight and stiffness-to-weight ratios. They have unique advantages over monolithic materials, such as high strength, high stiffness, long fatigue life, low density, corrosion resistance, wear resistance, and environmental stability.

Therefore the objective of this project is to study the strength comparison of composites (HT Graphite epoxy, S-Glass Epoxy) with Aluminum for both circular and elliptical cross-section of the frame member. The design of bicycle frame is modeled in Solid works software and the static analysis is done in ANSYS. The load is applied on frame as Static start up. With the help of results likewise Von-Misses stress, Von-Misses strain and Total Deformation, the best cross-sectional member with good material property of the frame is identified.

Keywords—HT Graphite epoxy, S-glass epoxy, Bicycle frame, Optimization.

I. INTRODUCTION

Throughout the history of cycling, there have been constant improvements in design of cycle frame on technologies. Most improvements through the years have been modifications to layout of the mechanisms on the bicycle. This includes overall shape of the Cycle, design of a frame structure, and material improvements.

A bicycle frame is the main component of a bicycle, onto which wheels and other components are fitted. Strength has been gaining importance in the design of bicycle frame. Composite materials which are composed of reinforced fibers and plastics matrix have high strength-to-weight and stiffness-to-weight ratios. They have unique advantages over monolithic materials, such as high strength, high stiffness, long fatigue life, low density, corrosion resistance, wear resistance, and environmental stability.

Due to above characteristics, the laminated fiber-reinforced composite materials such as HT Graphite Epoxy composites are widely applied in aircraft, aerospace, military, automotive, marine, and sports structures.

II. LITERATURE SURVEY

Mr. M.V. Pazare and Prof .S.D. Khamankar conducted a stress analysis of bicycle frame by using Finite Element Method. The analysis is carried out in Ansys, The F.E.A. results are compared with theoretical results. They have chosen the material of the frame as Aluminum T 6061. They concluded that the stresses produced by theoretically and by Finite Element method are identical. The stresses produced from Static start up, Horizontal impact, Vertical impact, and Rear wheel braking are compared. Both theoretical and Finite element results are less than yield strength in tension i.e.(Syt = 290 MPa) for the material selected.

Sagar Pardeshi, Pankaj Desle published a IJIRSET journal on Design and Development of Effective Low Weight Racing Bicycle Frame, in this they studied about the dependency of the performance is directly proportionate to weight of the cycle and frame structural design, Optimization of weight and structure of the frame is the best scope of optimizing the overall performance of the racing cycle, A monologue design is advisable in racing utility hence we are targeting towards composite design and how its frame can be optimizes by using static and dynamic FEA Analysis .using the knowledge from literature review, we can know how the CAD model is prepared. The results found that the maximum stress is induced in top tube which is less than the yield strength of mild steel. So there is also scope to reduce the weight of the frame by considering the current stresses obtained.

M.A. Maleque and S. Dyuti published a paper on Material selection of Bicycle frame using Cost per unit property and Digital logic methods. In this paper they have selected the best material based in two methods, the initial screening of the material is done by ASHBY's chart. Multiple properties such as tensile strength, yield strength, young's modulus, toughness and density were considered for the optimum selection of the materials. The best material they found is kevlar fiber reinforced polymer (KFRP).

L. Castejón, A. Miravete, J. Ullod, E. Larrodé done a research on Composite monocoque frame for a mountain bicycle: Testing and calculation, which shows the way in which a monocoque frame of a mountain bicycle made of carbon fiber and Kevlar laminate, a poliurethane foam core and different metallic stiffeners were analyzed. The study was performed in two parts, namely, a first part in which the bicycle was tested considering several static and dynamic cases and a second part carried out by using the F.E.M., from which vibration frequencies and modes were obtained, as well as the foam optimization to be used in the core. It was also possible to compare the results obtained in both parts.

C**.** T. Sun and K. J.Yoon Conducted an experiment on Graphite Epoxy in Composite Materials Laboratory at School of Aeronautics and Astronautics, Purdue University and published a report on the properties of Graphite epoxy composite material at different temperatures. The results include the strength, elastic modulus, Shear modulus, strain and poisons ratio for the specimen.

Justin Reina published an experimental report on Structural analysis on Bicycle frame using finite element techniques. This experiment in general provided great insight into the functionality, implementation and ultimate accuracy of the FE method. While this experiment limited analysis to simple frame structures, its consistency in predicting discrepancies between experimental and modeled results in addition to the discrepancies between actual models provided strong support of the general accuracy of the FE method.

Finite Element Analysis:

In the design of many modern devices and equipment**,** the finite element method has become a tool for the many successful products that we have come to use daily. In this study, the analysis of a bicycle frame is carried out by finite element method. Historically, intuition and trial-and-error in physical prototyping testing processes have played important roles in coming out with the evolution of a bicycle frame.

However, using such a physical trial-and-error design procedure is costly and time consuming, and has its limitations, especially when new materials are introduced and when new applications or demands are placed on the structure. Hence, there is the need to use the finite element tool to help the designer come up with reliable properties in the design to meet the demands expected by the consumers. Using the finite element method to perform a virtual prototyping instead of a physical prototyping can save lots of cost, time and effort.

There will be number of factors to be considered when it comes to designing a bicycle frame. For example, factors like the weight of the frame, the maximum load on the frame, the impact toughness of the frame, and so on. In a finite element analysis, one would require information on the material properties, the boundary conditions and the loading conditions. The loading conditions on a bicycle can be extremely complex. In this study we consider a loading condition of a static start-up is applied to the bicycle.

III. PROCESS METHODOLOGY

For the present study, the strength comparison of composites (HT Graphite epoxy, S-Glass Epoxy) with Aluminum for both circular and elliptical cross-section of the frame member is carried in ANSYS Software.

Although the prominent cross sectional model for bicycles have been tubular, mainly hollow, our design method includes circular and elliptical cross-section. Adopting rounded contours instead of cornered edges was conceived and utilized due to the transverse effects it has on the applied stresses. Under an applied load, a frame with cornered edges would institute stress concentrations at the edges, lowering its ultimate strength and weakening the structure. Rounded perimeters help to disperse any applied load along the cross section eliminating any stress concentrations and stress raisers. This decision also incorporates the safety and comfort of the prospective rider. Organic, rounded edges will provide a higher level of assurance and amenity rather than an abrupt angle

3.1. Material Selection:

As per the material survey the best suited material is the aluminium alloy which is commonly used. Then composite materials like HT Graphite epoxy, S-Glass Epoxy are preferred due to its low density and compatible yield strength. These materials were chosen for designing frame and comparing its results. Thus this paper focuses on optimizing bicycle frame with different materials. Table1 and table2 indicates the material properties considered.

Table- 3.1: sectional view of rectangular stacked microchannel

Material	Modulus of elasticity(GPa)	Ultimate Tensile Strength(MPa)	Yield Strength (MPa)	Density (kg/m^3)	Cost per kg in Rs
Aluminium Alloy 6061T6	68.9	310	276	2800	350
S glass-epox(Composite)	90	3750	3450	2630	90
HT Graphite – Epoxy (Composite)	221	3600	2000	1750	150

3.2. Design Parameters of a Model:

The following are the parameters that are considered for the design of Bicycle frame.

3.2.1General Dimensions of Bicycle Frame

Table 3.2: Dimensions of Bicycle frame.

Parameter	Values	
	Length (mm)	Angle
Length of head tube	120	---
Length of seat tube	382	---
Length of top tube	500	---
Head tube angle	----	77^0
Seat tube angle	----	77^0
Seat stays	440	---
Chain stays	325	---

3.2.2 General Dimensions for Hallow Circular Cross-section:

Table 3.3: Dimensions of Circular Cross-section.

Parameters	Values	
	Inner dia (mm)	Outer dia (mm)
Head Tube	21	25
Seat Tube	21	25
Top Tube	21	25
Seat Stays	12	16
Chain Stays	12	16

3.2.3 General Dimensions for Hallow Elliptical Cross-Section:

Table 3.4: Dimensions of elliptical cross-section

Parameters	Values	
	Minor axis (mm)	Major axis (mm)
Head Tube	18.6	25
Seat Tube	18.6	25
Top Tube	18.6	25
Seat Stays	12	16
Chain Stays	12	16

Wall thickness will be 2 mm for both hallow circular and elliptical cross-section frame members.

3.3. Designing of the Model:

Required CAD was developed using SOLIDWORKS modeling software. The cad geometry has basic requirement for Head tube, top tube, bottom tube, chain stays, seat stays, bottom bracket shell and the two triangles commonly says diamond frame. This is the model of the bicycle frame. A bicycle frame is the main component of a bicycle, onto which wheels and other components are fitted.

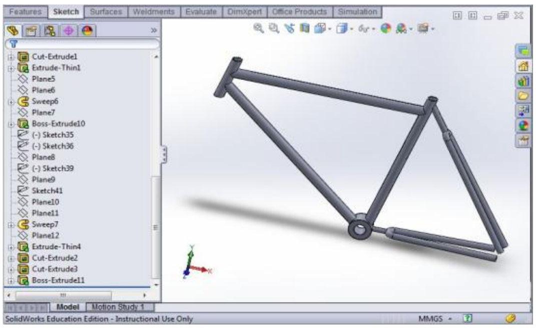

Fig.3.1 Design model with seat stays **(Circular Cross-section).**

IV. FINITE ELEMENT ANALYSIS

The finite element method represents an extension of the matrix method for the analysis of framed structures to the analysis of the continuum structures. The method is extremely powerful as it helps to accurately analyze structures with complex geometrical properties and loading conditions.

ANASYS R14.5 is self-contained general purpose finite element program that provides a complete solution to design problems. It consists of powerful design capabilities like full parametric solid modeling, design optimization and auto meshing, which gives engineers full control over their analysis.

4.1 Various Steps involved during analysis in ANSYS are:

Table 4.1: Stages of Ansys.

PRE-PROCESSOR PHASE	SOLUTION PHASE
Geometry definitions	Element matrix formation
Mesh generation	Overall matrix triangulation
Materials definition	Wave front
Constraint definition	Displacement, Stress, etc.,
Load definition	Calculations

4.2 Meshed model of Bicycle Frame (Circular Cross-Section):

The figure shows circular cross section frame with fine mesh.

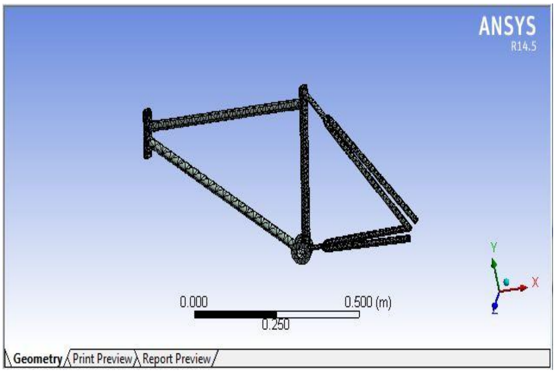

Fig. 4.2 Mesh view of circular cross section frame

4.3 Assigning Loads:

The following figures shows how the fixed supports are provided and how the loading of 900N is applied by static start up method on the bicycle frame.

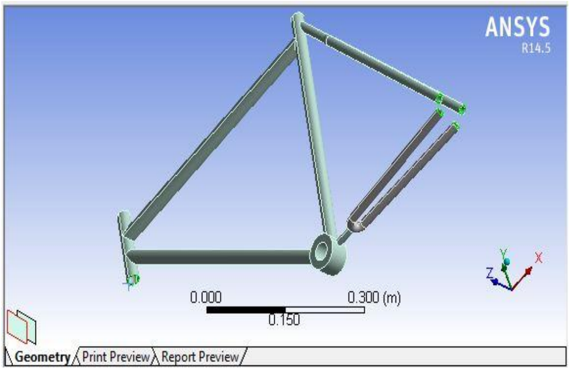

Fig. 4.3 Fixed supports

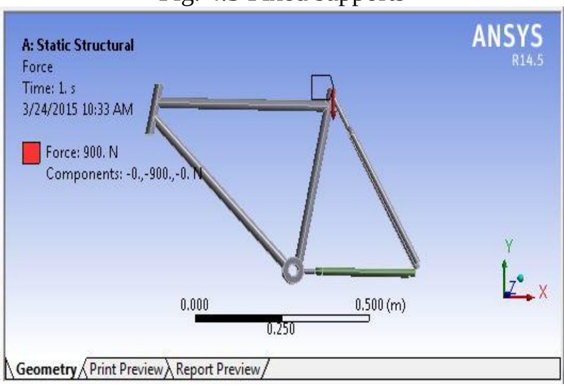

Fig. 4.4: Loading on frame

V. RESULTS AND DISCUSIONS

After completion of pre-processing steps in ANSYS (Meshing, Loading etc.,) the user should allow the solver to complete the analysis. After the completion of analysis the following results (Deformation, Strain & Stress) were obtained.

To examine stress and strain, it was assumed that 900N person as a maximum weight was placed on the seat. The loading of 900N is applied by static start up method on the bicycle frame. We fixed the bottom of both head stack and chain stays. Under these conditions static structural simulation was executed. Mainly we focused on three aspects: equivalent stress (Von-Mises stress), equivalent elastic strain (Von-Mises strain) and total deformation (Maximum displacement). After simulating the bicycle, we compared this yield stress of Aluminium 6061-T6 with HT Graphite Epoxy and S-Glass Epoxy for a possibility of low Maximum Von-Mises stress. All the figures shown below include maximum points of stress, strain and displacement values.

5.1 Stress Analysis:

Once the pre-processing stage of analysis in Ansys R14.5 for static structural analysis was completed (geometry definition, material definition, mesh generation, loading and defining constraints), then during the solving of our problem there will be a formation of element matrix for stress analysis and the calculations takes place, so that the following equivalent stresses results were obtained for different material in both circular cross-section and elliptical cross-section frame member as shown in figure 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6.

5.1.1 Circular Cross-Section:

Maximum Von-Mises stress for Aluminium 6061-T6 is 1.5896e7 Pa.

Maximum Von-Mises stress for HT Graphite Epoxy is 1.6251e7 Pa.

Maximum Von-Mises stress for S-Glass Epoxy is 1.6332e7 Pa

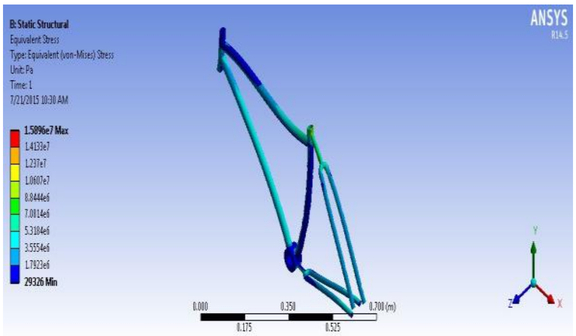

Fig. 5.1: Stress (Aluminium 6061-T6)

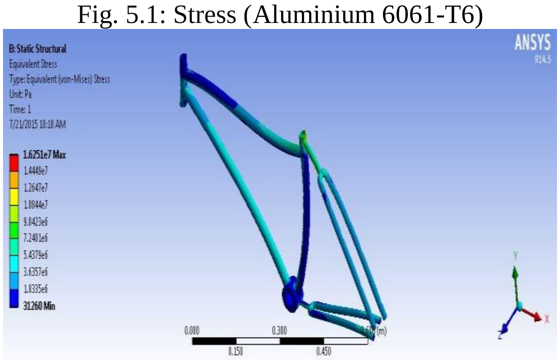

Fig. 5.2: Stress (HT Graphite Epoxy)

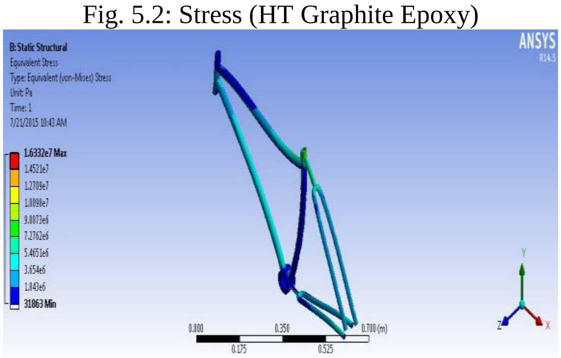

Fig. 5.3: Stress (S-Glass Epoxy).

5.1.2 Elliptical Cross-Section:

Maximum Von-Mises stress for Aluminium 6061-T6 is 3.8132e7 Pa.

Maximum Von-Mises stress for HT Graphite Epoxy is 3.8362e7 Pa.

Maximum Von-Mises stress for S-Glass Epoxy is

3.8443e7 Pa

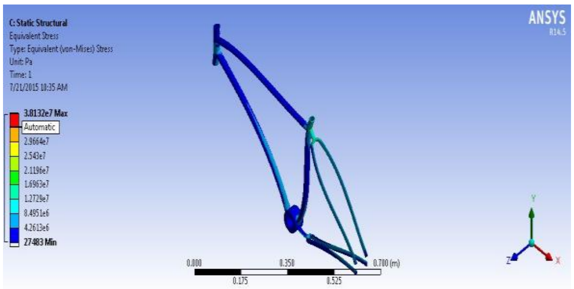

Fig. 5.4: Stress (Aluminium 6061-T6)

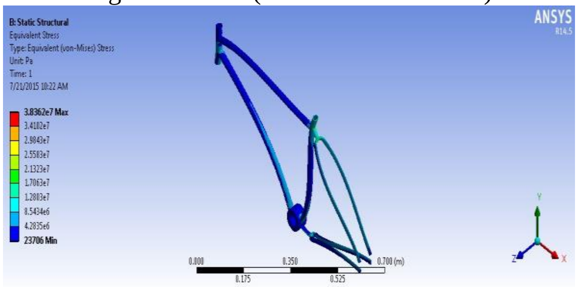

Fig. 5.5: Stress (HT Graphite Epoxy).

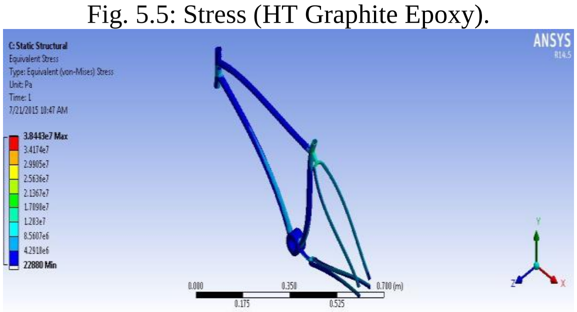

Fig. 5.6: Stress (S-Glass Epoxy).

5.2 Strain Analysis:

After the pre-processing stage of analysis in Ansys R14.5 for static structural analysis was completed (geometry definition, material definition, mesh generation, loading and defining constraints), then during the solving of our problem there will be a formation of element matrix and Overall matrix triangulation for strain analysis and the calculations takes place, so that the following maximum strain values were obtained for different material in both circular cross-section and elliptical cross-section frame member as shown in figure 5.7, 5.8, 5.9, 5.10, 5.11 and 5.12.

5.2.1 Circular Cross-Section:

Maximum Von-Mises strain for Aluminium 6061-T6 is 0.00023094 Pa.

Maximum Von-Mises strain for HT Graphite Epoxy is 7.3595e-5 Pa.

Maximum Von-Mises strain for S-Glass Epoxy is 0.00018162 Pa

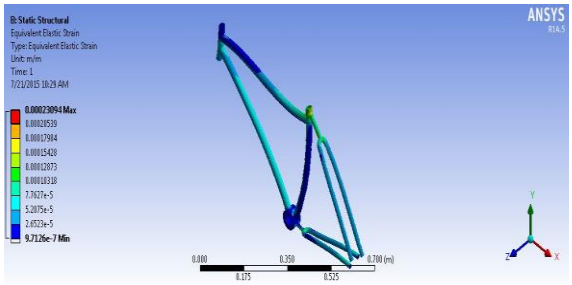

Fig Fig. 5.7: Stress (Aluminium 6061-T6)

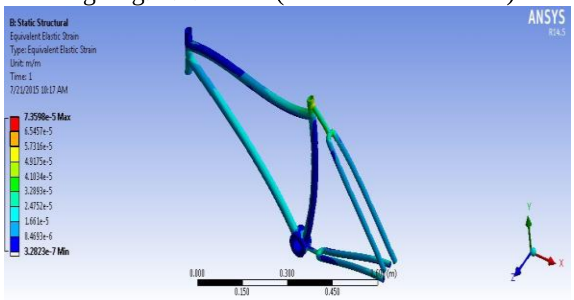

Fig. 5.8: Stress (HT Graphite Epoxy).

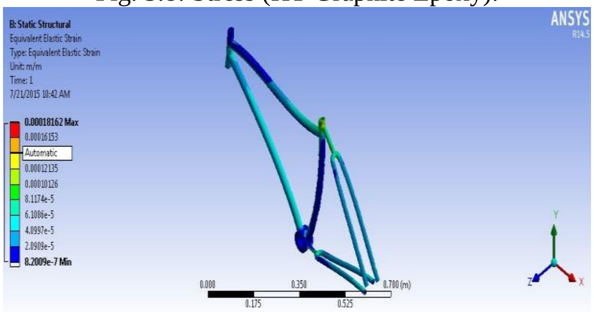

Fig. 5.9: Stress (S-Glass Epoxy).

5.2.2 Elliptical Cross-Section:

Maximum Von-Mises strain for Aluminium 6061-T6 is 0.00066072 Pa.

Maximum Von-Mises strain for HT Graphite Epoxy is 0.00020857 Pa.

Maximum Von-Mises strain for S-Glass Epoxy is 0.00051439 Pa.

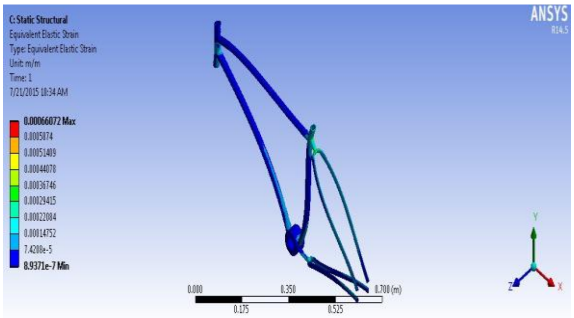

Fig. 5.10: Stress (Aluminium 6061-T6)

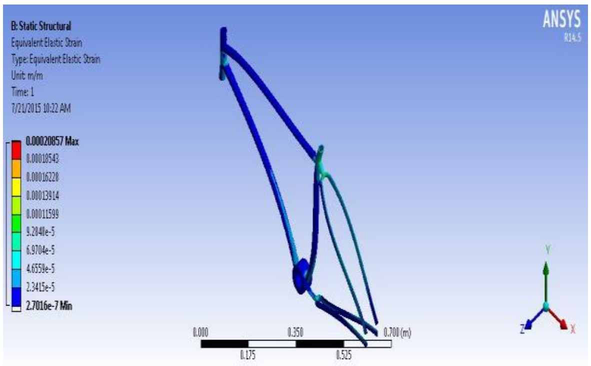

Fig. 5.11: Stress (HT Graphite Epoxy)

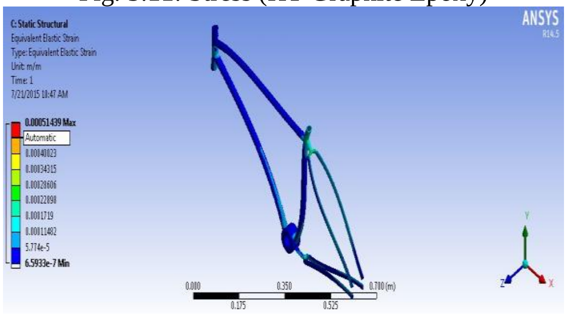

Fig. 5.12: Stress (S-Glass Epoxy).

5.3 Displacement Analysis:

After the pre-processing stage of analysis in Ansys R14.5 for static structural analysis was completed (geometry definition, material definition, mesh generation, loading and defining constraints), then during the solving of our problem there will be a formation of element matrix, Overall matrix triangulation and Wave front in the frame member to obtain total deformation and the calculations takes place, then the following overall deformation in the frame members are obtained for different material in both circular cross-section and elliptical cross-section frame member as shown in figure 5.13, 5.14, 5.15, 5.16, 5.17 and 5.18.

5.3.1 Circular Cross-Section:

Maximum displacement for Aluminium 6061-T6 is 9.1385e-5 mm.
Maximum displacement for HT Graphite Epoxy is 2.8539e-5 mm.
Maximum displacement for S-Glass Epoxy is 6.2309e-5 mm

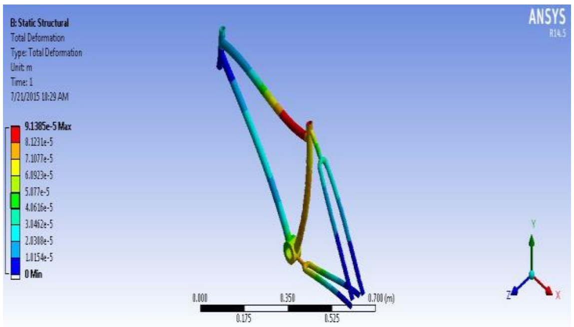

Fig. 5.13: Stress (Aluminium 6061-T6)

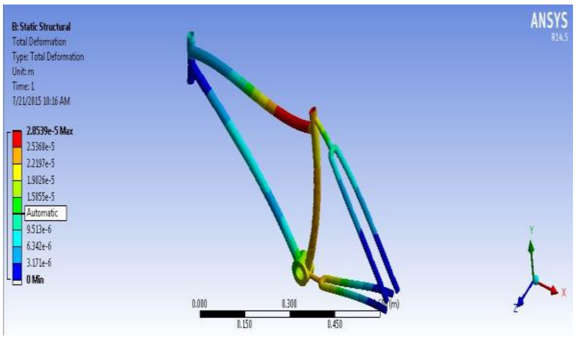

Fig. 5.14: Stress (HT Graphite Epoxy).

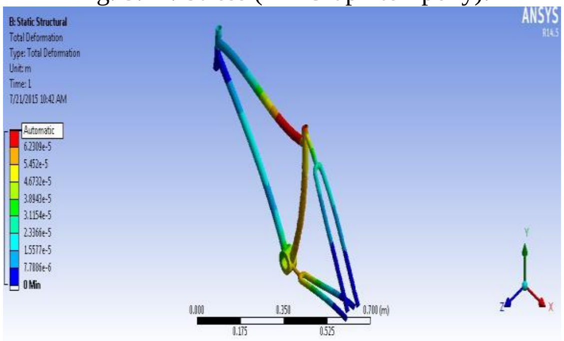

Fig. 5.15: Stress (S-Glass Epoxy).

5.3.2 Elliptical Cross-Section:

Maximum displacement for Aluminium 6061-T6 is 0.00015066 mm.

Maximum displacement for HT Graphite Epoxy is

4.7279e-5 mm.

Maximum displacement for S-Glass Epoxy is 0.0001033 mm.

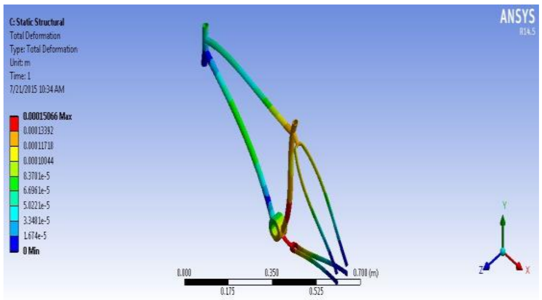

Fig. 5.16: Stress (Aluminium 6061-T6)

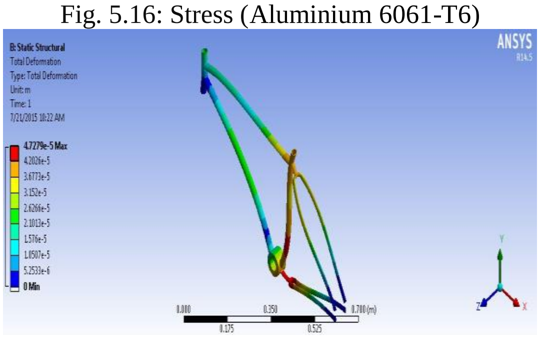

Fig. 5.17: Stress (HT Graphite Epoxy).

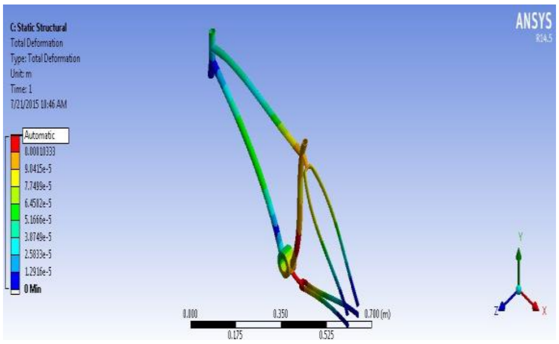

Fig. 5.18: Stress (S-Glass Epoxy).

5.3 DISCUSSION

5.3.1 Comparison of Aluminium Alloy6061-T6 with HT Graphite epoxy and S-Glass Epoxy (Circular cross-section):

Table 5.1: Comparison of stress, strain and deformation for Circular cross-section frame member

S. No.	Particular		Circular cross section		
	Result		Aluminium Alloy6061-T6	HT Graphite Epoxy	S-Glass Epoxy
1	VON -MISES STRESS(Pa)	Max	1.5896e7	1.6251e7	1.6332e7
2	VON MISES STRAIN(Pa)	Max	0.00023094	7.3595e-5	0.00018162
3	TOTAL DEFORMATION (mm)	Max	6.2309e-5	2.8539e-5	9.1385e-5

5.3.2 Comparison of Aluminium Alloy6061-T6 with HT Graphite epoxy and S-Glass Epoxy (Elliptical cross-section):

Table 5.2: Comparison of stress, strain and deformation for Elliptical cross-section frame member

S. No.	Particular		Elliptical Cross section		
	Result		Aluminium Alloy6061-T6	Graphite Epoxy	S-Glass Epoxy
1	VON -MISES STRESS(Pa)	Max	3.8132e7	3.8362e7	3.8443e7
2	VON MISES STRAIN	Max	0.00020857	0.00066072	0.00051439
3	TOTAL DEFORMATION (mm)	Max	0.00015066	4.7279e-5	0.0001033

VI. CONCLUSION:

From the Results and Discussion which are tabulated in the above table 5.1 and 5.2, composites (HT Graphite epoxy and S-Glass Epoxy) can be used as Bicycle frame material because of better results (stress, strain & displacement) when compared with Aluminium Alloy6061-T6.

- The maximum Von-Mises stress for circular cross-section is 1.6332e7 Pa.
- The maximum Von-Mises stress for elliptical cross-section is 3.8443e7 Pa
- The maximum Von-Mises strain for circular cross-section is 7.3595e-5.
- The maximum Von-Mises strain for elliptical cross-section is 0.00066072.
- The Total Deformation obtained in circular cross-section is 9.1385e-5mm.
- The Total Deformation obtained in elliptical cross-section is 4.7279e-5 mm.

Therefore, for the bicycle frame the Circular cross section is more preferable than Elliptical cross-section because of high strength withstanding ability. Then in the two composite materials (HT Graphite epoxy and S-Glass Epoxy) S-Glass Epoxy can be preferred when compared to HT Graphite Epoxy because of less cost and reasonably high strength than HT Graphite Epoxy.

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