DESIGN, OPTIMIZATION AND STRUCTURAL ANALYSIS OF BICYCLE CHASSIS

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Abstract - *The bicycle frame has been undergoing many changes and advancements these days. The chassis frame has to be able to cope with different criterias including the strength, weight, cost and apt shape. The best chassis is the one that could have an overall performance in the above mentioned criterias. So our project takes into account the above mentioned factors. This project aims to design an optimised bicycle chassis using topological optimization and analysis using different materials.*

Keywords: *Topological optimization, creo, finite element analysis.*

1.INTRODUCTION

Bicycles are a popular and clean mode of personal transportation for short distances in cities due to many social and environmental changes in recent years. Frame is the main structure of a bicycle on which various accessories are mounted. The bicycle chassis has been undergoing many changes and advancements these days. The chassis has to be able to cope with different criteria including the strength, weight, cost and apt shape. The best chassis is the one that could have an overall performance in the above mentioned criteria. So our project takes into account the above mentioned factors. First step is shape analysis which is done through Ansys tool Topological Optimization and FEA. Topology optimization (TO) is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints the goal of maximizing the performance of the system. That means volume removal in the area where very less materials are concentrated, thereby reducing the cost and weight. After that optimized shape is drawn in CREO software considering the standard codes. The design was made to undergo the structural analysis after the load calculation. The material optimization is the final step, the conventional material is aluminum alloy or steel alloy but our studies have proved the best material in terms of strength and stiffness is CFRP (Carbon Fibre Reinforced Plastic). So the FEA results also proves that our study is same i.e. CFRP is better material. This project aims to design an optimized bicycle chassis using topological optimization and analysis using different materials.

2. METHODOLOGY

1. Study of Triangularisation of Chassis
2. Dimensional Analysis
3. Initial Geometry Formation
4. Load Calculation
5. Static analysis { Deformation and stress)
6. Topological Optimization
7. Final Geometry Formation.
8. Static Structural analysis.
9. Material Analysis.

2.1 Initial geometry

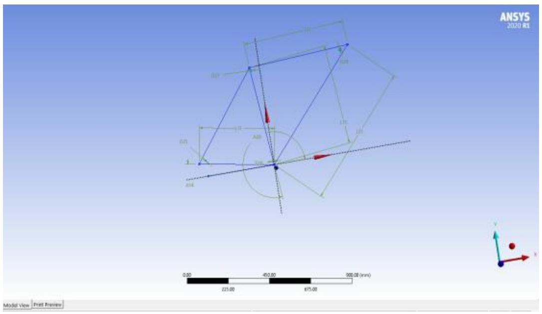


Fig 1- Initial geometry of a bicycle chassis

2.2 Load calculation

Forces are calculated at the different points and fixed supports are provided at the respective locations.
Force are calculated considering the load of the passenger to be 75 kg. F = 75*9.81= 716 N
Load at the handle bar = 506 N
At the Pedal section (falling from the top).
$V^2= u^2+2as$, u=0 we get ,
$V^2= 2*9.81*3.1 = 60.822$ m2/s2
V=7.92 m/s
Acceleration at the ground,
v = u+at, sub u=0, v=7.92 m/s, t=.1sec
a=(v-u)/t = (7.92-0)/.1 = 79.2 m/s^2
Force = ma = 75 * 79.2 = 5946 N
At the Bottom portion the Cylindrical Support is provided.

2.3 Material selection and their properties

Mass of the chassis; m= density*volume=d*A*L
Area; A=m/(d*L)
Stress, σ=F/A ; σ=F/(m/dL) ; σ= FL(d/m)
which means that mass is proportional to density by stress. To minimise mass, we have to
maximize the ratio of stress/ density. This criteria is used to select material from design chart.

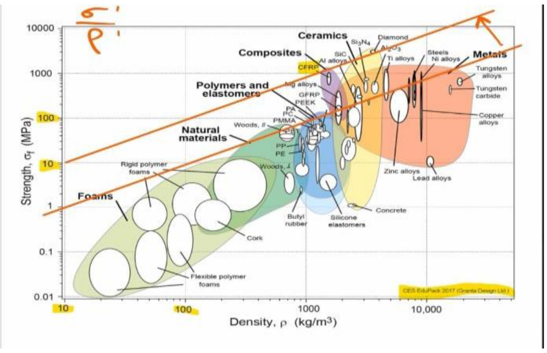


Fig 2- Strength vs density

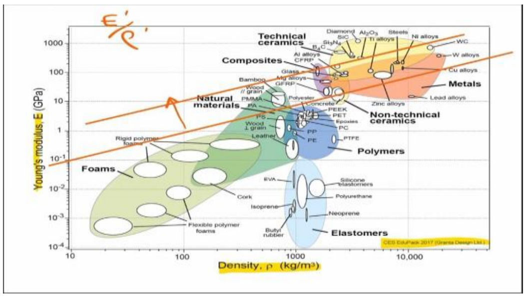


Fig 3- Young's modulus vs density

2.3.1 Aluminium alloy

Table 1- Mechanical properties of a Aluminium Alloy

Young's modulus	68300 MPa
Poisson's Ratio	0.33
Bulk Modulus	66961 MPa
Shear Modulus	25677 MPa
Ultimate tensile strength	313 MPa
Yield tensile strength	259 MPa

2.3.2 Structural steel

Table 2- Mechanical properties of a structural steel

Young's modulus	2e+05 MPa
Poisson's Ratio	0.3
Bulk Modulus	1.6667e+05 MPa
Shear Modulus	76923 MPa
Compressive ultimate strength	0 Mpa
Compressive yield strength	250 MPa

2.3.3 Carbon fibre reinforced polymer

Table 3- Mechanical properties of a CFRP

Young's Modulus X direction	3.95e+05 MPa
Young's modulus Y direction	6000 MPa
Young's modulus Z direction	6000 MPa
Poisson's Ratio XY	0.2
Poisson's Ratio YZ	0.4
Poisson's Ratio XZ	0.2
Shear Modulus XY	8000 MPa
Shear Modulus YZ	2142.9 MPa
Shear Modulus XZ	8000 MPa

3. TOPOLOGICAL OPTIMIZATION

Optimization is the iterative process for finding a design that maximizes or minimizes the objective by searching the design space. Topology optimization (TO) is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system.
ANSYS topology optimization can be used to find the maximum stiffness, the minimum volume and maximum natural frequency of the structure.The steps involved in the topological optimization are;

1. Initial modelling
2. Meshing
3. Boundary conditions
4. Performing topology optimization
5. Design of optimized model

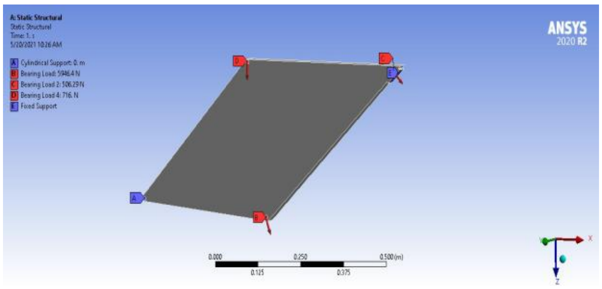


Fig 4- Applying load on a plate.

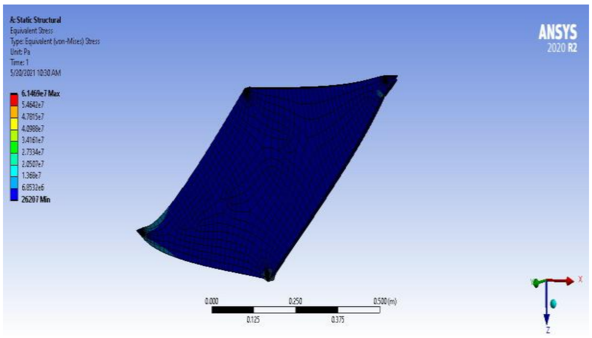


Fig 5- Von-mises stress distribution of a plate

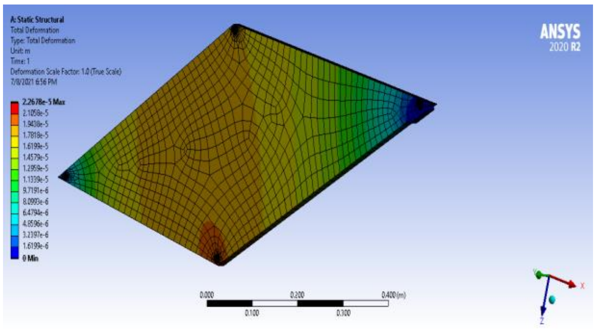


Fig 5- Total deformation of a plate

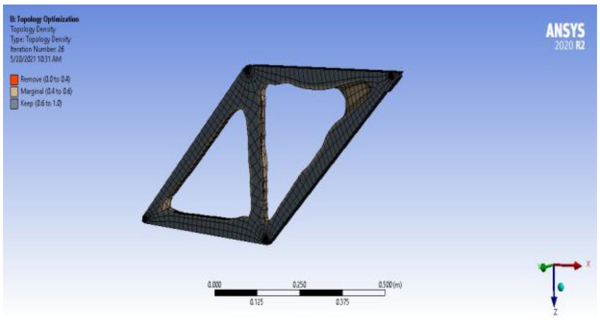
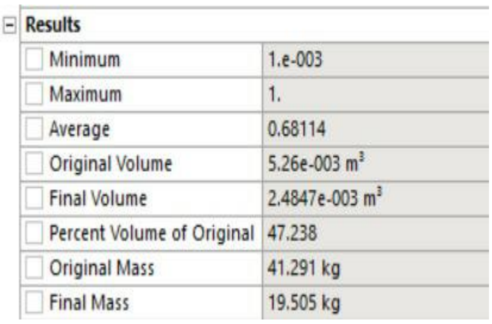


Fig 6- Frame generated by topology optimization

Table 4- Details of topological optimization



⊟ Results	
☐ Minimum	1.e-003
☐ Maximum	1.
☐ Average	0.68114
☐ Original Volume	5.26e-003 m^3
☐ Final Volume	2.4847e-003 m^3
☐ Percent Volume of Original	47.238
☐ Original Mass	41.291 kg
☐ Final Mass	19.505 kg

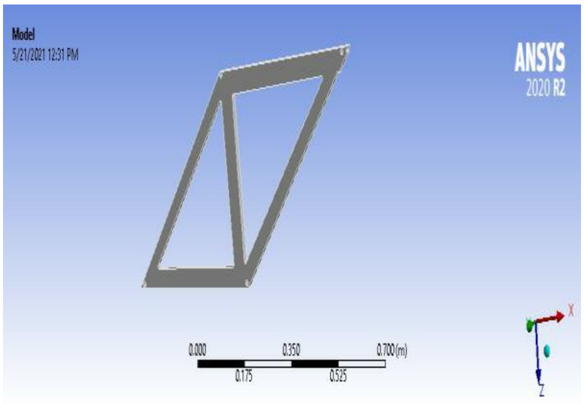


Fig 7- Frame cut to form optimized chassis

4. DESIGN OF BICYCLE CHASSIS BASED ON TOPOLOGICAL OPTIMIZATION

The bicycle chassis modeling was done in CREO software. The main dimension of the bicycle chassis consists of many tubes. Frames are required to be strong, stiff and light. The main parts of the bicycle chassis can be divided into top tube, seat tube, head tube, downtube, chain stay and seat stay.

Table 4- Specification of bicycle chassis

Part	Length (mm)	Diameter (mm)
Seat stay	417	17
Chain stay	494	17
Top tube	500	40
Head tube	120	42
Down tube	620	34
Seat tube	423	42

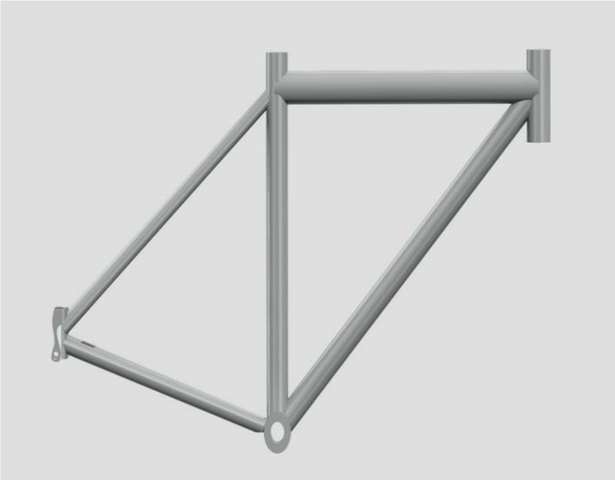


Fig 8- 2D view of Bicycle chassis.

5. FINITE ELEMENT ANALYSIS

5.1 MESHING (PRE-PROCESSING)

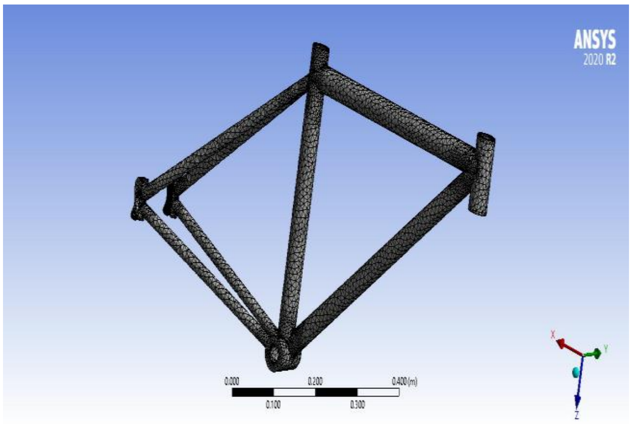


Fig 9- Meshing of a Bicycle chassis

Table 5- Meshing details

Nodes	134744
Element	55030

5.2 BOUNDARY CONDITION

- Load at handlebar =716 N
- Load at seat post = 506 N
- Load at pedal section = 5946 N
- One fixed support and two cylindrical support.

5.3 ANALYSIS RESULT (POST-PROCESSING)

5.3.1 ANALYSIS USING ALUMINIUM ALLOY AS CHASSIS MATERIAL

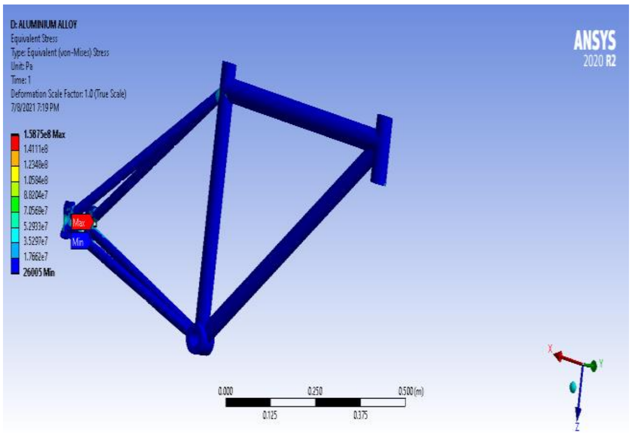


Fig 10- Von-Mises stress distribution of Aluminium Alloy

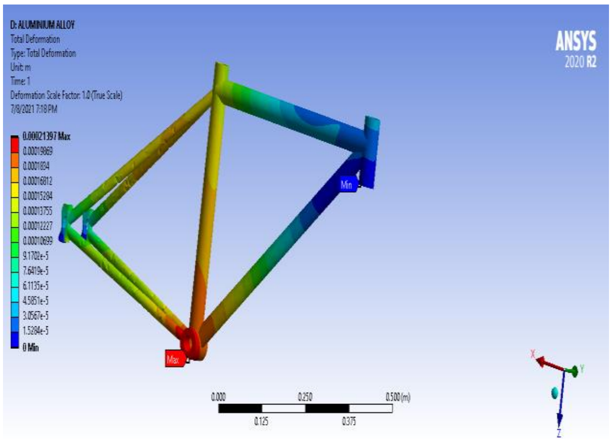


Fig 11- Total deformation of Aluminium alloy

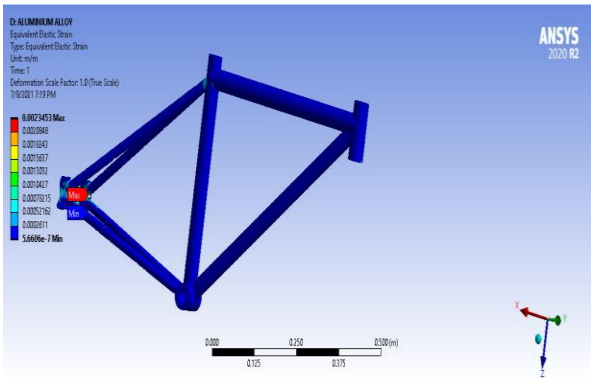


Fig 12- Equivalent Elastic Strain of a Aluminium alloy

5.3.2 ANALYSIS USING STRUCTURAL STEEL AS CHASSIS MATERIAL

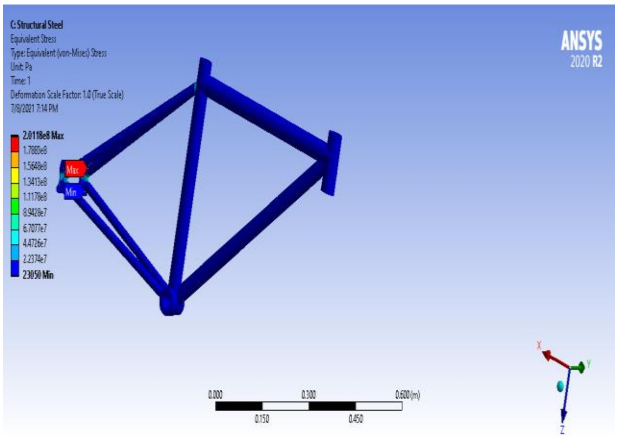


Fig 13- Von-Mises stress distribution of Structural steel

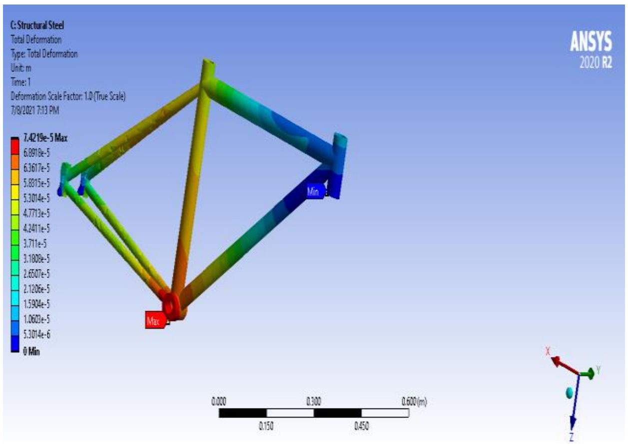


Fig 14- Total deformation of Structural steel

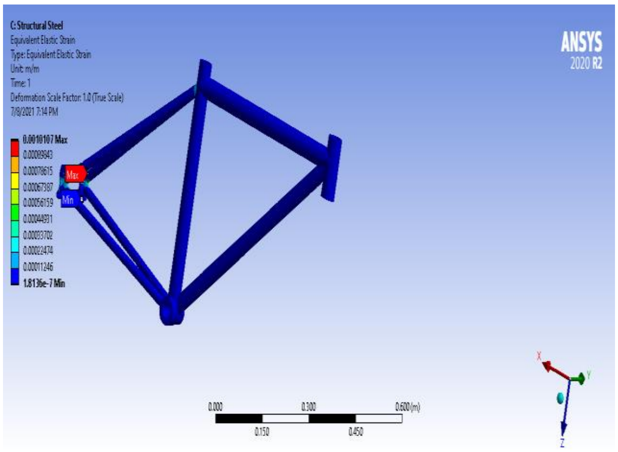


Fig 15- Equivalent Elastic Strain of a Structural steel

5.3.3 ANALYSIS USING CFRP AS CHASSIS MATERIAL

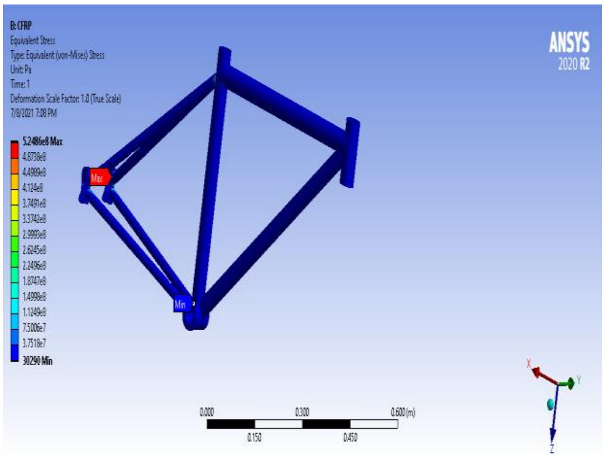


Fig 16- Von-Mises stress distribution of CFRP

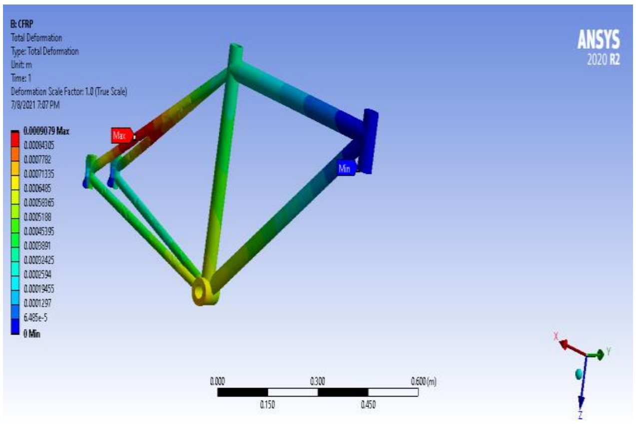


Fig 17- Total deformation of CFRP

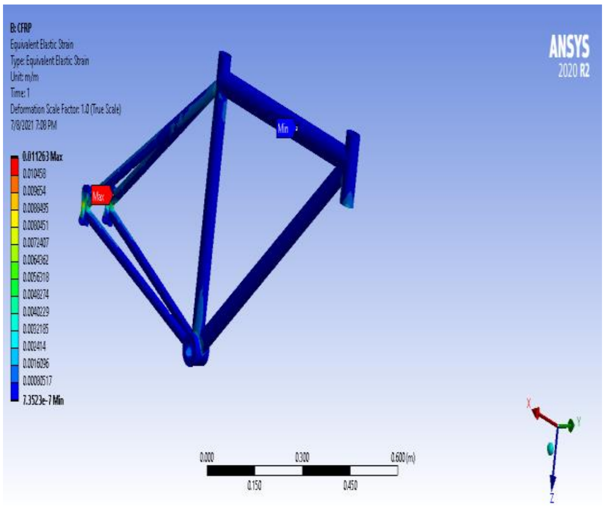


Fig 18- Equivalent Elastic Strain of a CFRP.

5.4 ANALYSIS RESULT (COMPARISON)

5.4.1 Comparison of stress

Table 6- comparison of stress

Material	Stress
Aluminium alloy	1.59e+08
Structural steel	2.01e+08
CFRP	5.25e+08

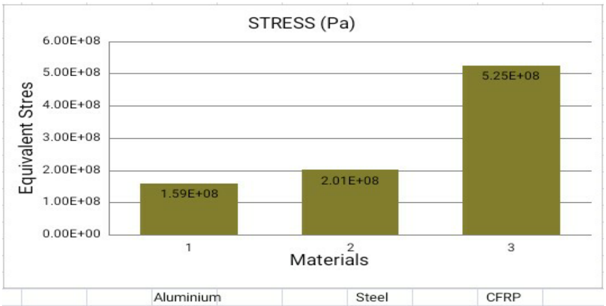


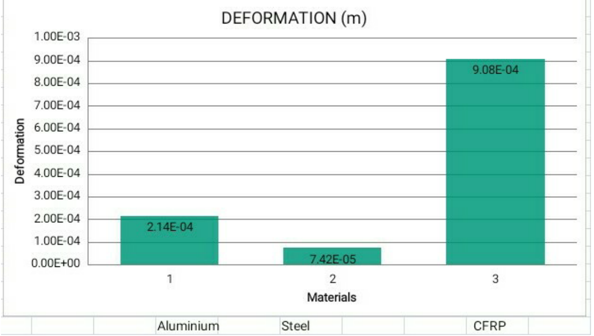
Chart 1- Bar Graph shows comparison of Stress.

5.4.2 Comparison of deformation

Table 7- comparison of deformation

Material	Deformation
Aluminium alloy	2.14e-04
Structural steel	7.42e-05
CFRP	9.08e-04

Chart 2- Bar Graph shows comparison of deformation.



5.4.3 Comparison of elastic strain

Table 8- comparison of elastic strain

Material	Elastic strain
Aluminium alloy	2.35e-03
Structural steel	1.01e-03
CFRP	1.13e-02

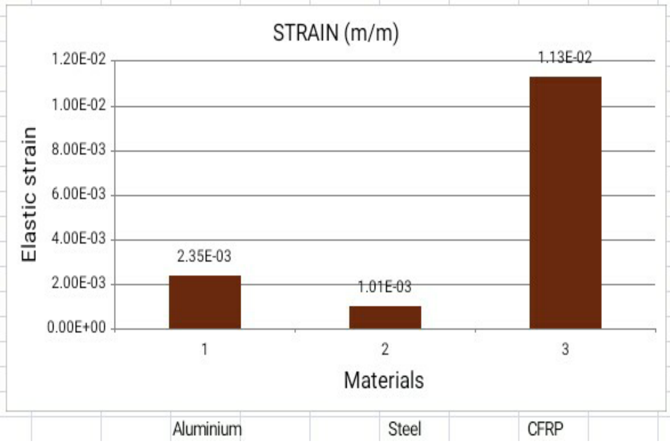


Chart 3- Bar Graph shows comparison of elastic strain

7. CONCLUSIONS

In the present the finite element analysis of a Bicycle chassis was carried out using ANSYS software using various boundary conditions FEA results based on stress (Von Mises), deformation and equivalent elastic strain on different materials. This project aims to design an optimised bicycle chassis using topological optimization and analysis using different materials like Aluminium alloy, Structural steel and Carbon fibre reinforced polymer. A more optimized and cost effective bicycle chassis was obtained. The most suitable material for the chassis is selected by utilizing equations and design charts. The Aluminium alloy was found to have least deformation stress values out of three material taken here

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