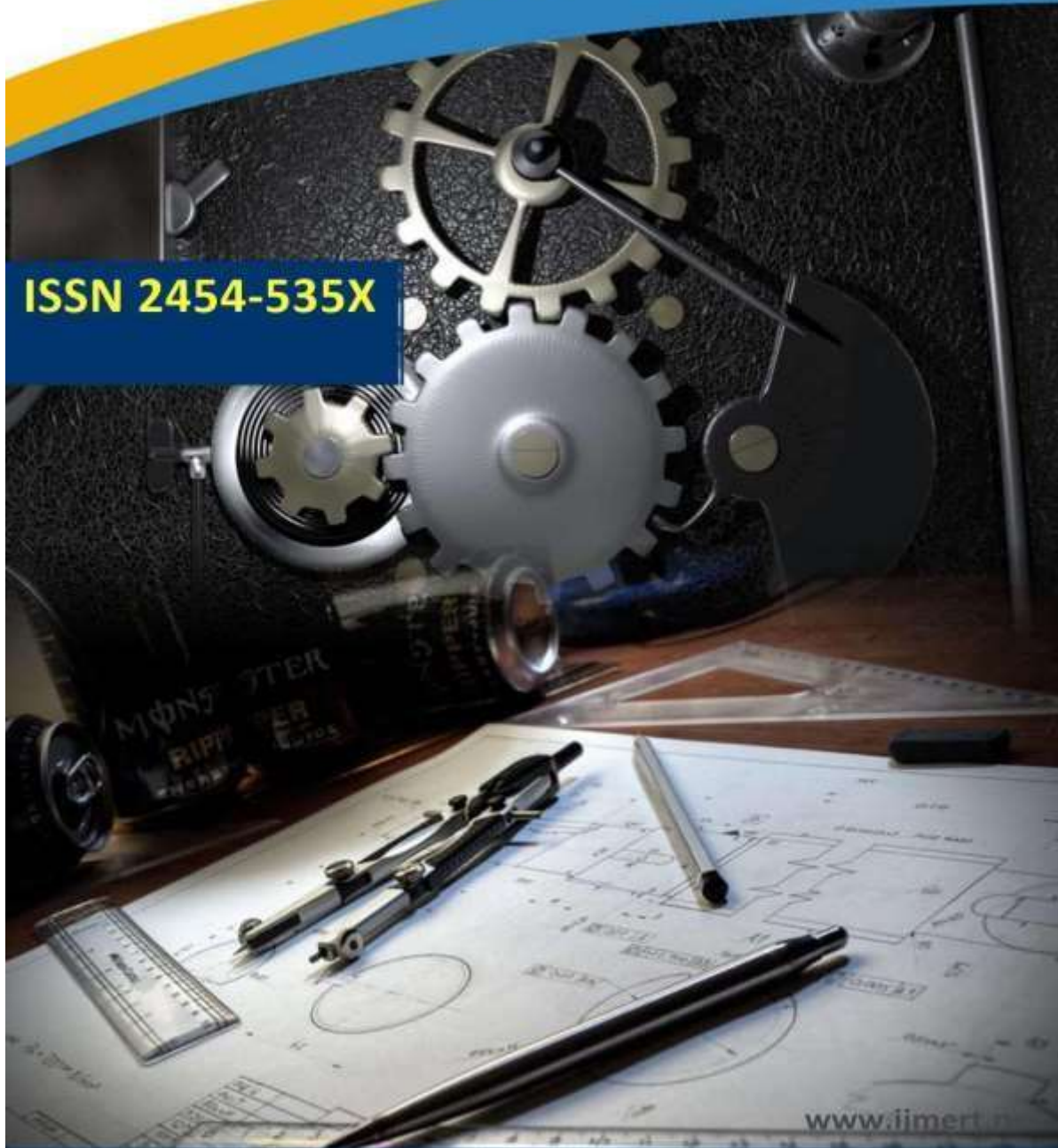




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Design and structural analysis of the bicycle frame by using different materials

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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 and AISI 1020 for circular cross-section and square cross section of the frame member. The design of bicycle frame is modelled in catia 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, Fatigue the best material and the best frame is identified.

Keywords— Aluminum 6061-T6, AISI 1020, HT Graphite epoxy, S-glass epoxy, Bicycle frame, Optimization.

INTRODUCTION

1.1 INTRODUCTION TO SUSPENSION FRAME:

The motorcycle chassis consists of the frame, suspension, wheels and brakes. Each of these components is described briefly below. Frame Motorcycles have a frame made of steel, aluminium or an alloy. The frame consists mostly of hollow tubes and serves as a skeleton on which components like the gearbox and engine are mounted. The frame also serves as a support for the suspension system, a collection of springs and shock absorbers that helps keep the wheels in contact with the road and cushions the rider from bumps and jolts. Wheels Motorcycle wheels are generally aluminium or steel rims with spokes, although some models introduced since the 1970s offer cast wheels. Cast wheels allow the bikes to use tubeless tires, which, unlike traditional pneumatic tires, don't have an inner tube to hold the compressed air.

The front and rear wheels on a motorcycle each have a brake. The rider activates the front brake with a hand lever on the right grip, the rear brake with the right foot pedal. Drum brakes were common until the 1970s, but most motorcycles today rely on the superior performance of disc brake.



Figure 1 BICYCLE FRAME

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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.

1.2 REAR FRAME

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,

1.3 FUNCTIONS OF THE FRAME

1. To carry load of the passengers or goods carried in the body.
2. To support the load of the body, chains, pedal, carriage, handle gears box etc.,
3. To with stand the forces caused due to the sudden braking or in movement
4. To with stand the stresses caused due to the bad road condition.
5. To with stand centrifugal force while cornering.

I. PROJECT OVER VIEW

2.1 PROCESS METHODOLOGY:

For the present study, the strength comparison of composites (HT Graphite epoxy, S-Glass Epoxy) with AISI 1020, Aluminum for square and circular 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 square and circular 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

2.2 PROBLEM IDENTIFICATION:

Weight reduction is now the main issue in now a days. Because if the weight of the vehicle increases the muscle power also increases. At the same time as the weight of the vehicle increases the cost also increases which becomes a major issue while purchasing an automobile. For example if we take Bicycle frame of. It is manufactured with Structural Steel, AL 6061-T6. Steel structures exposed to air and water, such as bridges are susceptible to corrosion. In conditions of repeated stress and more temperatures it can suffer fatigue and cracks. These are the main problems of steel and these are

compensated by inducing composite materials. A composite material is defined as a material composed of two or more materials combined on a macroscopic scale by mechanical and chemical bonds. Unique characteristic of many fibre reinforced composites is their high internal damping capacity. This leads to better vibration energy absorption within the material and results in reduced noise transmission to neighbouring structures. Many composite materials offer a combination of strength and modulus that are either comparable to or better than any traditional metallic metals. Because of their low specific gravities, the strength to weight-ratio and modulus to weight-ratios of these composite materials are markedly superior to those of metallic materials. The fatigue strength to weight ratios as well as fatigue damage tolerances of many composite laminates are excellent. For these reasons, fiber composites have emerged as a major class of structural material and are either used or being considered as substitutions for metals in many weight-critical components in aerospace, automotive and other industries.

High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort.

2.3 Various loads acting on the frame:

1. Short duration Load – While crossing a broken patch.
2. Momentary duration Load – While taking a curve.
3. Impact Loads – Due to the collision of the Bicycle
4. Inertia Load – While applying brakes.
5. Static Loads – Loads due to frame parts.
6. Over Loads – Beyond Design capacity.

2.4 MATERIAL SELECTION:

As per the material survey the best suited material is the aluminium alloy ,AISI 1020 carbon steel 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 1 MATERIAL PROPERTIES

Material	Modulus of elasticity (GPa)	Ultimate tensile strength (Mpa)	Yield strength (Mpa)	Density (kg/m ³)	Cost per kg in Rs
Aluminium Alloy 6061-T6	68.9	310	276	2800	350
s-glass epoxy(composite)	90	3750	3450	2630	90
HT-graphite epoxy(composite)	221	3600	2000	1750	150
AISI 1020	186	420	350	7870	135

2.5 DESIGN PARAMETERS OF A MODEL:The following are the parameters that are considered for the design of Bicycle frame.

Table 2 Dimensions of Bicycle frame Circular and square

Parameters	Values	
	Length (mm)	Angle
Length of head tube	115	—
Length of seat tube	360	—
Length of top tube	460	—
Head tube angle	—	77°
Seat tube angle	—	77°
Seat stays	430	—
Chain stays	320	—

Table 3 Dimensions for Hallow Circular and Square Cross-section

Parameters	Values	
	Inner dia (mm)	Outer dia
Length of head tube	20	24
Length of seat tube	20	24
Length of top tube	20	24
Seat stays	10	14
Chain stays	10	14

II. DESIGNING OF THE MODEL

Required CAD was developed using CATIA modeling software As per the geometry dimensions 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.

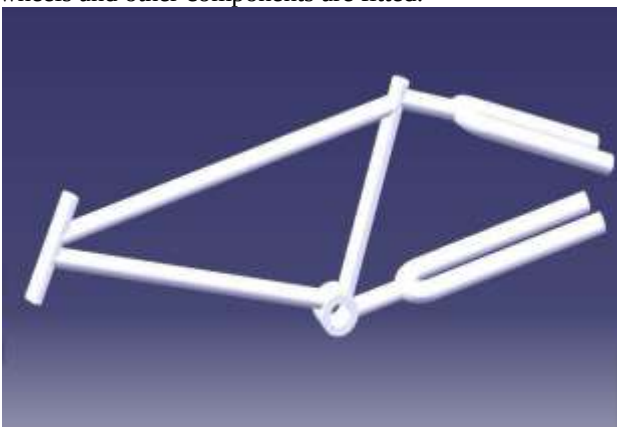


Figure 2: BICYCLE FRAME CIRCULAR IN CATIA WORK BENCH

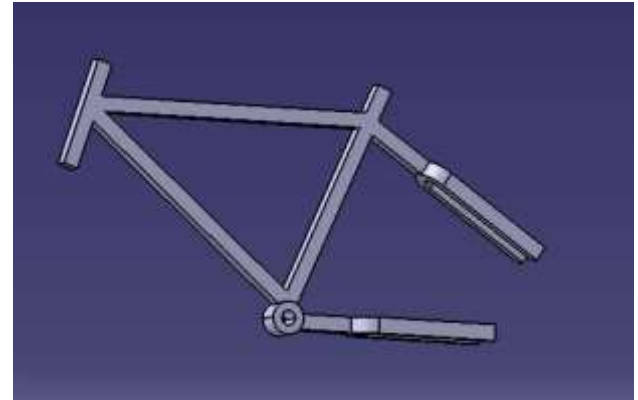


Figure 3: BICYCLE FRAME SQUARE IN CATIA WORK BENCH

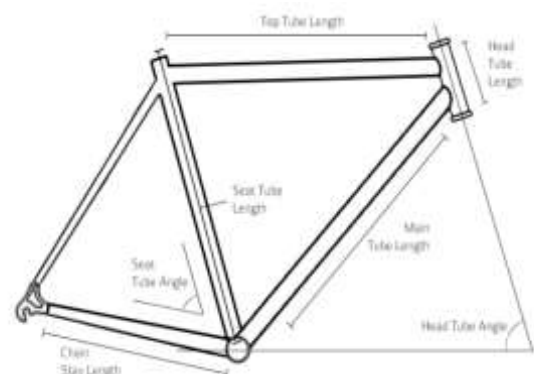


Figure 4: FRAME NOMINCLATURE

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

The figure shows circular cross section frame with fine mesh.

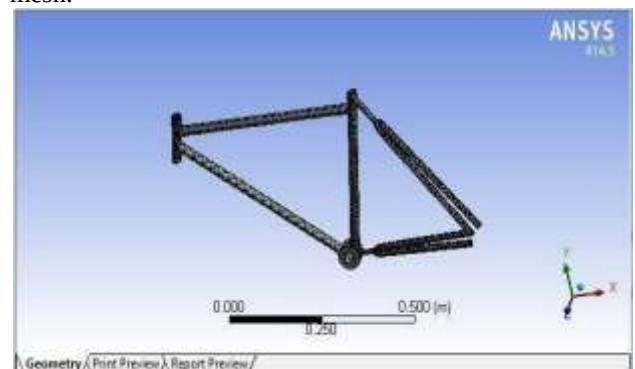


FIGURE 5: MESHED MODEL

3.2 TESTING METHODS, BOUNDARY AND LOADING CONDITIONS

The bicycle frame is subjected to frontal loading test and vertical loading test. The boundary and loading conditions are taken from the past references. From the Finite element analysis the normal and shear stress of each ply under the vertical loading, is obtained. The frame is fixed at the front and rear ends. For the vertical loading test, loads are applied on the head part, seat part, and bottom bracket part. Handle load of 230 N

(23.45Kg), Seat load of 1000 N (101.9Kg) and Peddle load of 300 N (30 Kg) are applied here. The total vertical load is 155 kg. The frame is fixed at rear tube ends and front tube ends.

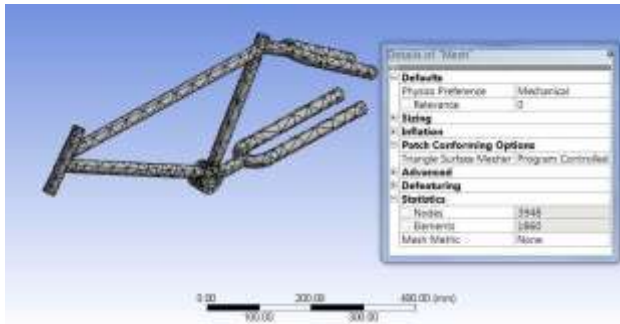


Figure 6: Circular Mesh body

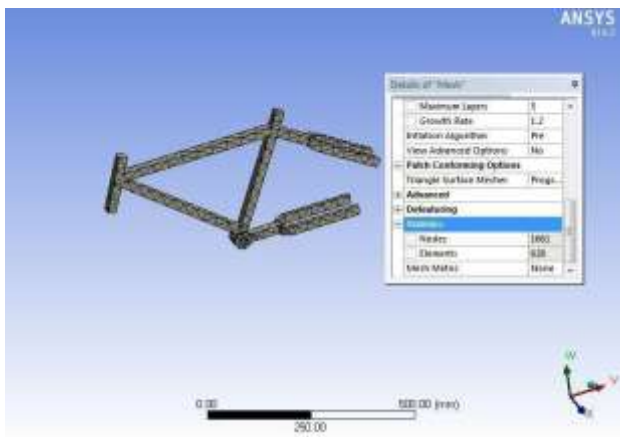


Figure 7: Square Mesh body



Figure 8: Fixed supports vertical loading on circular section

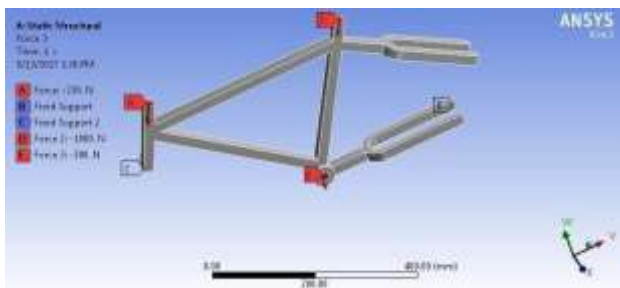


Figure 9: Fixed supports vertical loading on square section

III. RESULTS AND DISCUSSIONS

4.1 RESULTS

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, Shear stress & Stress, Fatigue) were obtained.

To examine Deformation, Shear stress & Stress, Fatigue, two sections circular and Square it was assumed that

900N person as a maximum weight was placed on the seat. The frame is fixed at the front and rear ends. For the vertical loading test, loads are applied on the head part, seat part, and bottom bracket part. Handle load of 230 N (23.45Kg), Seat load of 1000 N (101.9Kg) and Peddle load of 300 N (30 Kg) are applied here. The total vertical load is 155 kg. The frame is fixed at rear tube ends and front tube ends.

Under these conditions static structural simulation was executed. Mainly we focused on three aspects: equivalent stress (Von-Mises stress), (shear stress), total deformation (Maximum displacement) & Fatigue (safety factor) After simulating the bicycle, we compared this yield stress of AISIS 1020, 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, Shear stress and displacement values.

4.2 STRESS ANALYSIS CIRCULAR CROSS-SECTION:

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 circular cross-section frame member as shown in below figures.

4.2.1 Circular Cross-Section:

Maximum Von-Mises stress for Aluminium 6061-T6 is 15.049 MPa. Maximum Von-Mises stress for HT Graphite Epoxy is 14.075 MPa. Maximum Von-Mises stress for S-Glass Epoxy is 15.761MPa. Maximum Von-Mises stress for AISI 1020 STEEL is 12.331MPa.

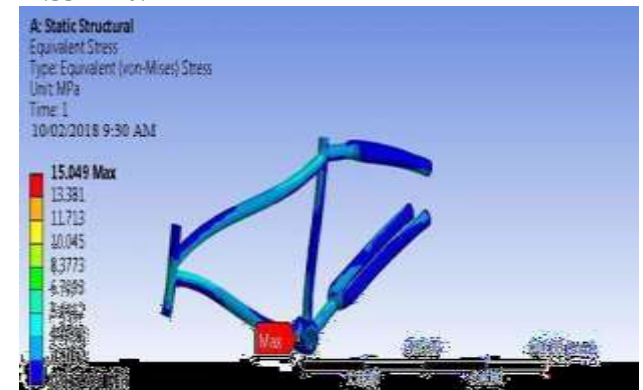


Figure 10: Stress (Aluminium 6061-T6)

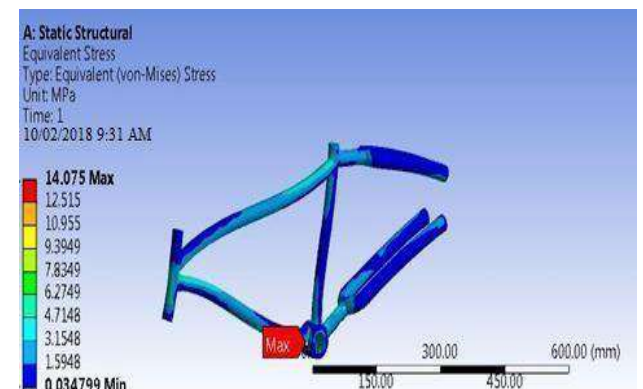


Figure 11: Stress (HT Graphite Epoxy)

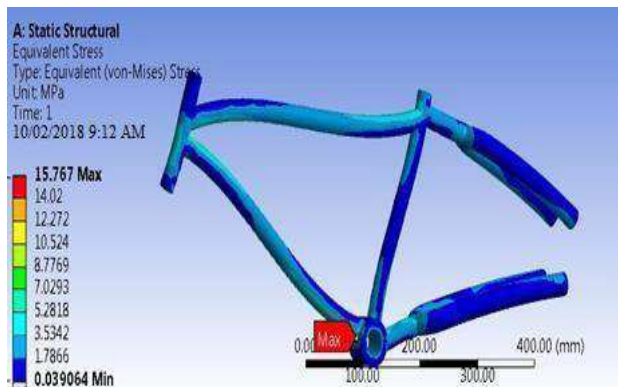


Figure 12: Stress (S-Glass Epoxy).



Figure 13: Stress (AISI 1020 STEEL).

4.3 DISPLACEMENT ANALYSIS CIRCULAR CROSS-SECTION:

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 circular cross-section frame member as shown in below figures

4.3.1 Circular Cross-Section:

Maximum displacement for Aluminium 6061-T6 is 0.0255 mm. Maximum displacement for HT Graphite Epoxy is 0.0238 mm. Maximum displacement for S-Glass Epoxy is 0.0267 mm Maximum displacement for AISI 1020 STEEL is 0.0208 mm

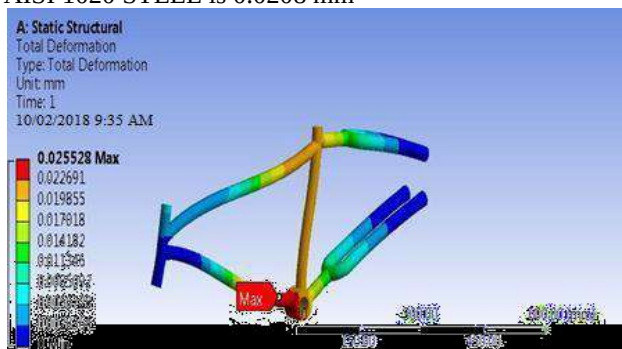


Figure 14: Deformation (Aluminium 6061-T6)

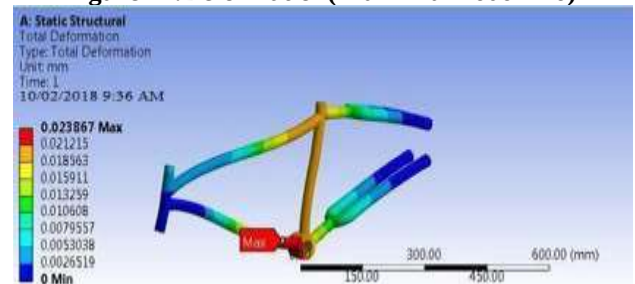


Figure 15: deformation (HT Graphite Epoxy).

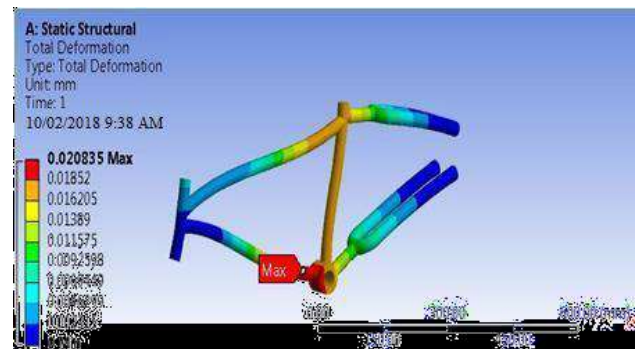


Figure 16: deformation (AISI 1020 STEEL).

4.4 SHEAR STRESS 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 shear stress and the calculations takes place, then the following overall shear stress in the frame members are obtained for different material in circular cross-section and frame member as shown in below figures

7.4.1 Circular Cross-Section:

Maximum shear stress for Aluminium 6061-T6 is 8.437 Mpa Maximum shear stress for HT Graphite Epoxy is 7.891 Mpa. Maximum shear stress for S-Glass Epoxy is 8.840 Mpa Maximum shear stress for AISI 1020 STEEL is 6.914 Mpa

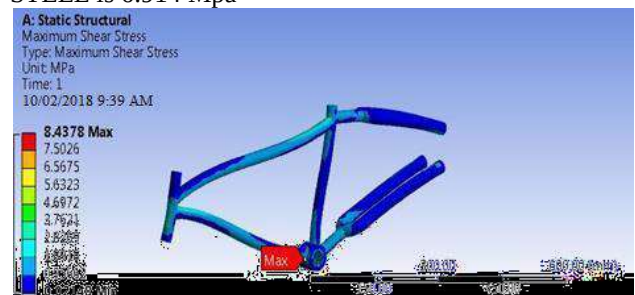


Figure 17: Shear stress (aluminium 6061-T6).

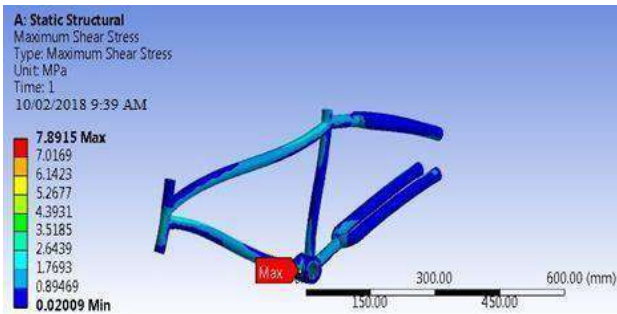


Figure 18: Shear stress (HT Graphite Epoxy).



Figure 19: Shear stress (S-Glass Epoxy).

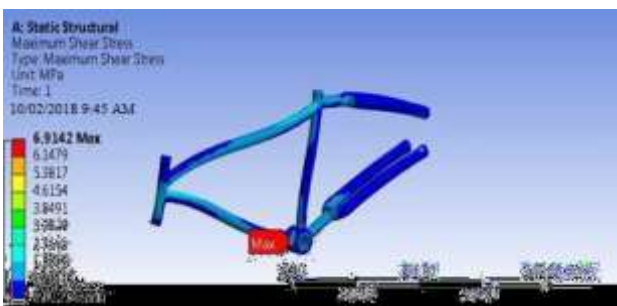


Figure 20: Shear stress (AISI 1020 STEEL).

4.5 CIRCULAR CROSS SECTION FITAGUE (SAFETY FACTOR):

It also known as (and used interchangeably with) **safety factor (SF)**, is a term describing the load carrying capacity of a system beyond the expected or actual loads. Essentially, the factor of safety is how much stronger the system is than it usually needs to be for an intended load. Safety factors are often calculated using detailed analysis because comprehensive testing is impractical on many projects, such as bridges and buildings, but the structure's ability to carry load must be determined to a reasonable accuracy. Many systems are purposefully built much stronger than needed for normal usage to allow for emergency situations, unexpected loads, misuse, or degradation (reliability).

4.5.1 Circular Cross-Section:

Safety factor for Aluminium 6061-T6 is 4.692 Safety factor for HT Graphite Epoxy is 4.680 Safety factor for S-Glass Epoxy is 4.551 Safety factor for AISI 1020 STEEL is 5.664



Figure 21: Safety factor (Aluminium 6061-T6)

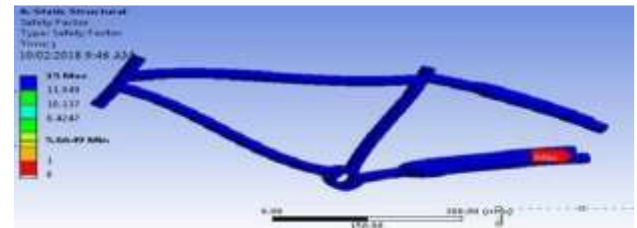


Figure 22: Safety factor for AISI 1020 STEEL

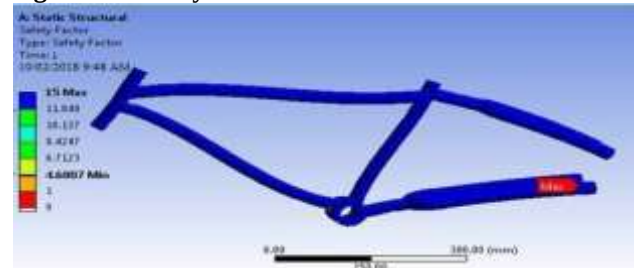


Figure 23: Safety factor for HT-Graphite

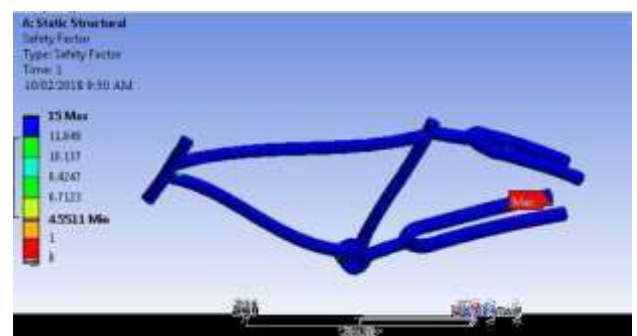


Figure 24: Safety factor for S-Glass

Epoxy 4.5.2 Displacement Analysis Square Cross-Section:

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 square cross-section frame member as shown in below figures

4.5.3 Square Cross-Section:

Maximum displacement for AISI 1020 STEEL is 0.022 mm Maximum displacement for HT Graphite Epoxy is 0.024 mm. Maximum displacement for Aluminium 6061-T6 is 0.026mm. Maximum displacement for S-Glass Epoxy is 0.027 mm

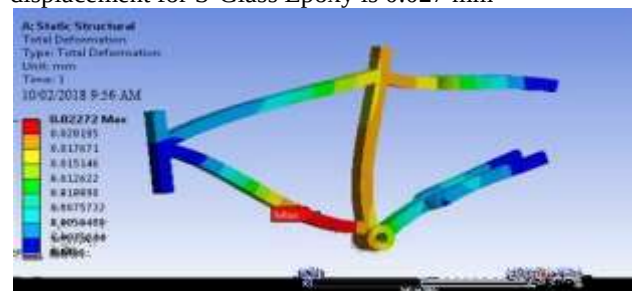


Figure 25: Total deformation AISI 1020 material

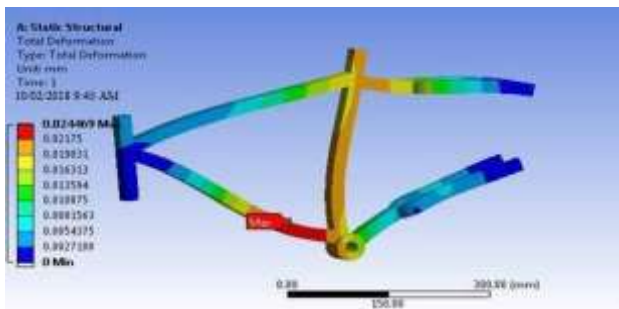


Figure 26: Total deformation HT-Graphite material

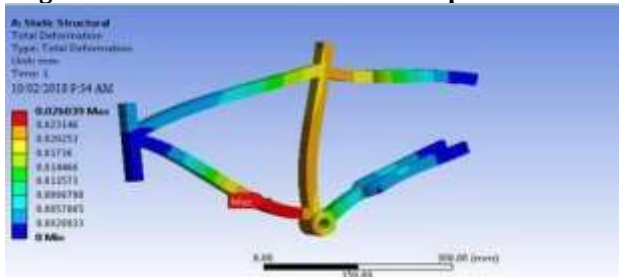


Figure 27: Total deformation Al-6061-T6

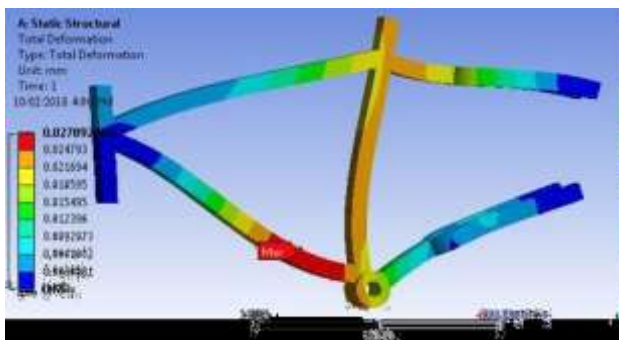


Figure 28: Total deformation S-glass epoxy

4.5.4 Stress Analysis Square Cross-Section:

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 Square cross-section frame member as shown in below figures.

4.5.5 Square Cross-Section:

Maximum Von-Mises stress for AISI 1020 STEEL is 7.976 MPa. Maximum Von-Mises stress for HT Graphite Epoxy is 8.519 MPa. Maximum Von-Mises stress for Aluminium 6061-T6 is 9.021MPa. Maximum Von-Mises stress for S-Glass Epoxy is 9.715 MPa.

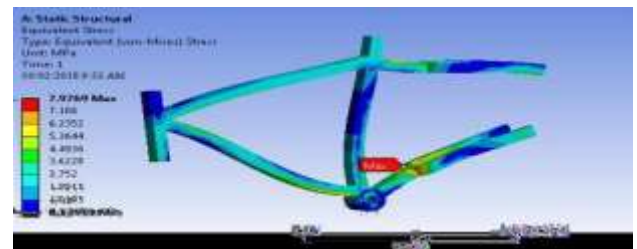


Figure 29: Von-Mises stress AISI 1020

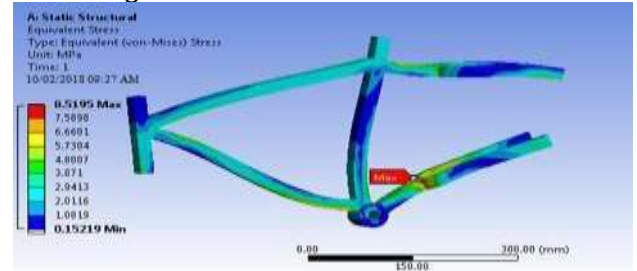


Figure 30: Von-Mises stress HTGraphite epoxy

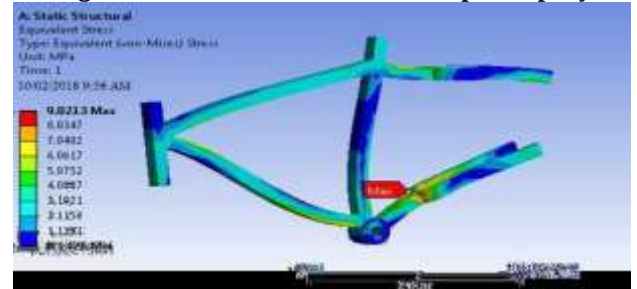


Figure 31: Von-Mises Stress Al-6061MATERIAL

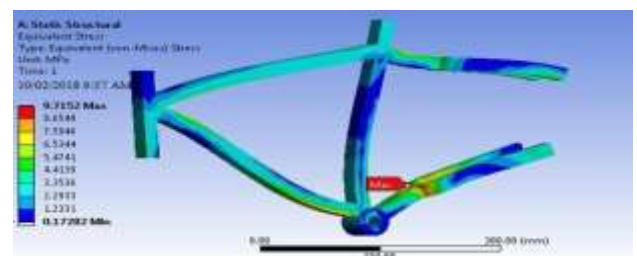


Figure 32: VONMISES STRESS S-GLASS EPOXY MATERIAL

4.6 SHEAR STRESS 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 shear stress and the calculations takes place, then the following overall shear stress in the frame members are obtained for different material in Square cross-section and frame member as shown in below figures

4.6.1 Square Cross-Section:

Maximum shear stress for AISI 1020 STEEL is 4.065 Mpa Maximum shear stress for HT Graphite Epoxy is 4.342 Mpa. Maximum shear stress for Aluminium

6061-T6 is 4.598 Mpa Maximum shear stress for S-Glass Epoxy is 4.951 Mpa

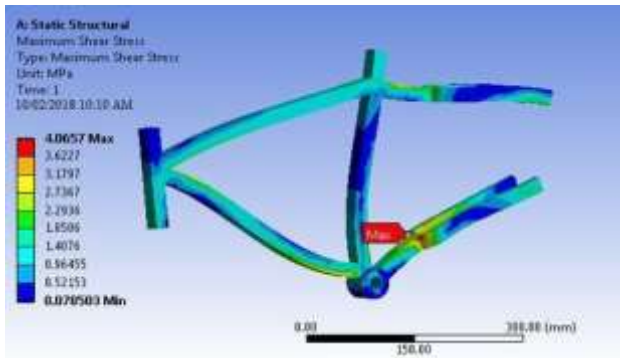


Figure 33: Shear stress on AISI 1020

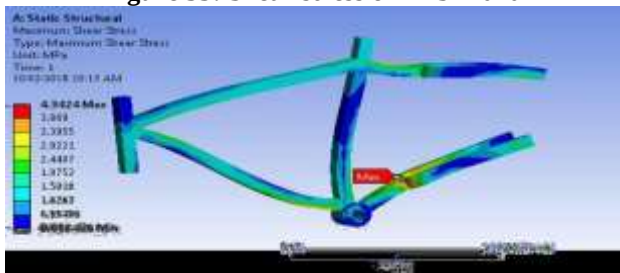


Figure 34: Shear stress on HT-Graphite

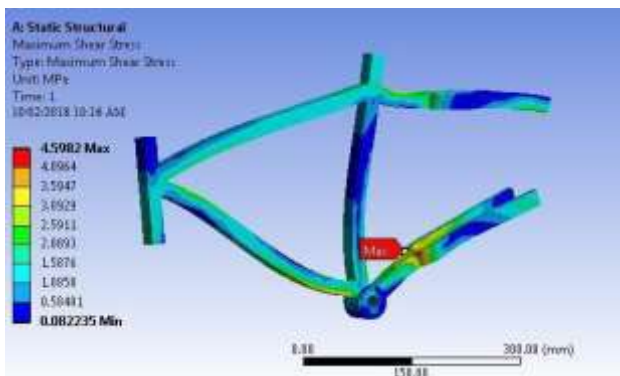


Figure 35: Shear stress on AL-6061-T6

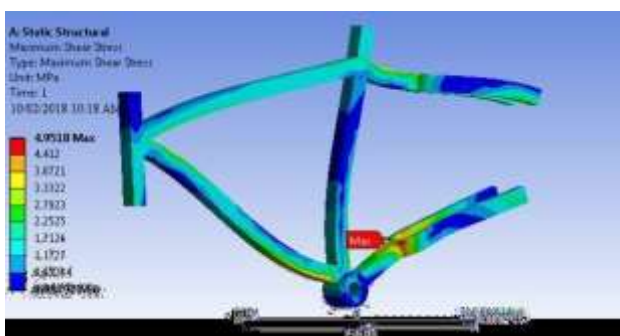


Figure 36: Shear stress S-glass epoxy

4.6.2 Square Cross-Section:

Safety factor for AISI 1020 STEEL is 12.037
Safety factor for HT Graphite Epoxy is 11.135
Safety factor for Aluminium 6061-T6 is 10.348
Safety factor for S-Glass Epoxy is 5.747

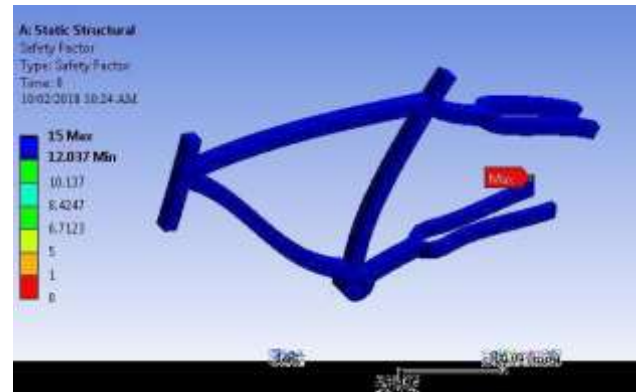


Figure 37: Safety factor for AISI 1020 STEEL

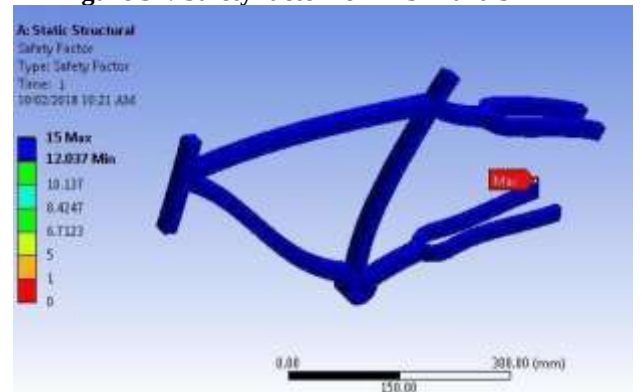


Figure 38: Safety factor for HT-Graphite



Figure 39: Safety factor for S-Glass Epoxy

Table 5 Square - cross section results

S.No	particular		Square - cross section			
			Aluminium Alloy 6061-T6	HT-Graphite Epoxy	S-GLASS EPOXY	AISI 1020 STEEL
1	Von-mises stress(Mpa)	Max	9.021	8.519	9.715	7.976
2	Total deformation(mm)	Max	0.026	0.024	0.027	0.022
3	Shear stress(Mpa)	Max	4.598	4.342	4.951	4.065
4	Safety factor	Min	10.348	11.135	5.747	12.037

4.7 CIRCULAR CROSS-SECTION GRAPHS:

4.7.1 Von-mises Stress Graph: The Von-mises Stress comparison Graphs between four Different materials

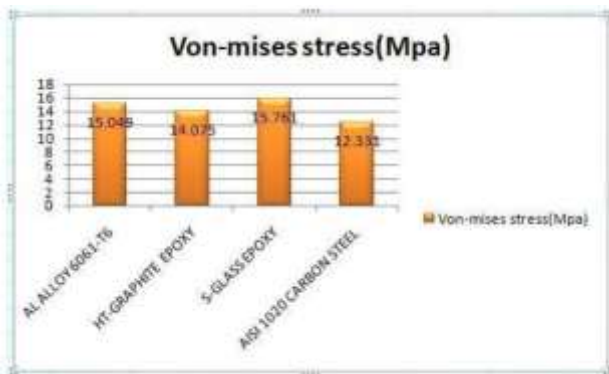


Figure 40: Von-mises Stress Graph

4.7.2 Total deformation Graph : The total deformation comparison Graphs between four Different materials

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have low stress compared to other two materials

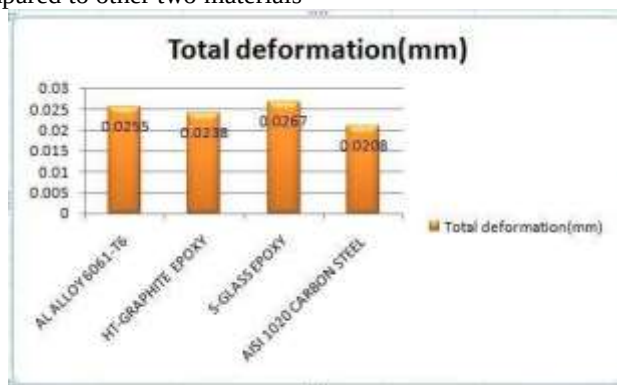


Figure 41: Total deformation graph

4.7.3 Shear stress graph: The shear Stress comparison Graphs between four Different materials

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have low deformation compared to other two materials

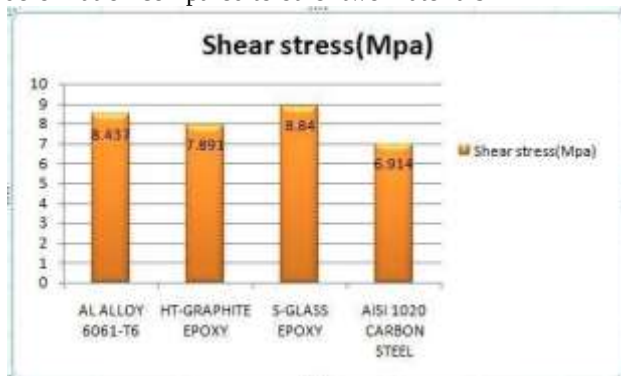


Figure 42: Shear stress graph

4.7.4 Safety factor graph: The safety factor comparison Graphs between four Different materials

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have low deformation compared to other two materials



Figure 43: safety factor circular section graph

4.8 Vonmises Stress Graph: The Vonmises Stress comparison Graphs between four Different materials
From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have good safety factor to other two materials

4.8.1: SQUARE CROSS-SECTION GRAPHS:

The Vonmises Stress comparison Graphs between four Different materials

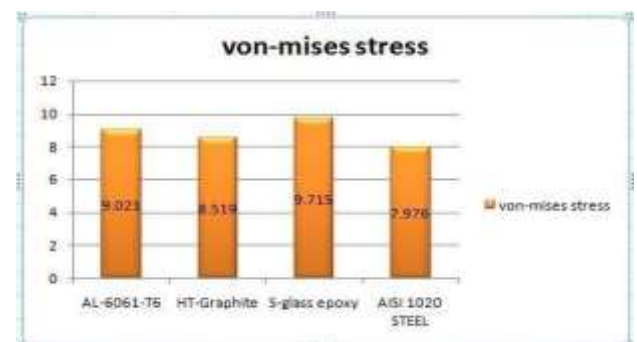


Figure 44: Von mises Stress Graph

4.8.2 Total deformation Graph The total deformation comparison Graphs between four Different materials

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have low stress compared to other two materials

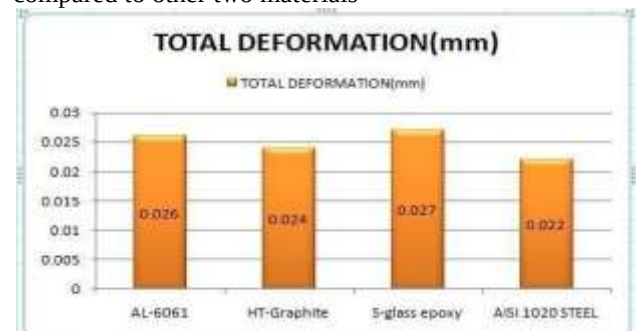


Figure 45: Total deformation Graph

4.8.3 Shear stress graph: The shear Stress comparison Graphs between four Different materials

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have low deformation compared to other two materials

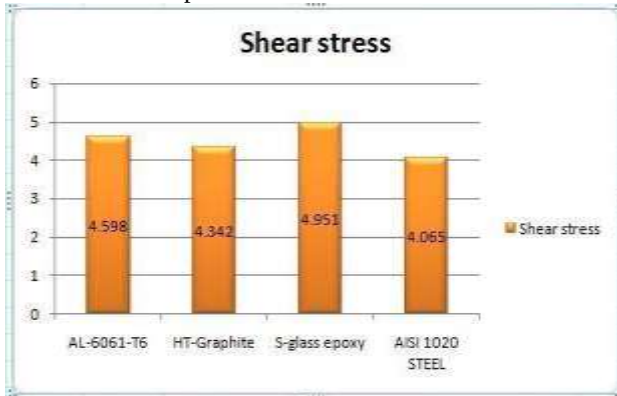


Figure 46: Shear stress graph

4.8.4 Safety factor: The safety factor comparison Graphs between four Different materials



Figure 47: safety factor square section

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have low deformation compared to other two materials.

From the above graph it can be concluded that AISI carbon steel and HT-Graphite epoxy have good safety factor compared to other two materials.

4.9 DISCUSSION

Comparison of Aluminium Alloy6061-T6 ,AISI 1020 Steel with HT Graphite epoxy and S-Glass Epoxy (Circular cross-section and Square cross-section):

Table 6.1:

Comparison of stress, shear stress, deformation, Fatigue for Circular cross- section frame member and square frame member

Table 6 Final results circular cross section

S.No	particular		Circular - cross section			
			Aluminium Alloy 6061-T6	HT- Graphite Epoxy	S-GLASS EPOXY	AISI 1020 STEEL
1	Von-mises stress(Mpa)	Max	15.049	14.075	15.761	12.331
2	Total deformation(mm)	Max	0.0255	0.0238	0.0267	0.0208
3	Shear stress(Mpa)	Max	8.437	7.891	8.840	6.914
4	Safety factor	Min	4.692	4.680	4.551	5.664

Table 7 Final results Square cross section

S.No	particular		Square - cross section			
			Aluminium Alloy 6061-T6	HT- Graphite Epoxy	S-GLASS EPOXY	AISI 1020 STEEL
1	Von-mises stress(Mpa)	Max	9.021	8.519	9.715	7.976
2	Total deformation(mm)	Max	0.026	0.024	0.027	0.022
3	Shear stress(Mpa)	Max	4.598	4.342	4.951	4.065
4	Safety factor	Min	10.348	11.135	5.747	12.037

IV. CONCLUSION

From the Results and Discussion which are tabulated in the above table composites (HT Graphite epoxy and AISI 1020) can be used as Bicycle frame material because of better results (Von-mises stress, shear stress, displacement & fatigue) when compared with Aluminium Alloy6061-T6.

Therefore, for the bicycle frame the Square cross section is more preferable because of high strength withstanding ability compared to circular cross section, Then in the two materials (HT Graphite epoxy and AISI1020) can be preferred when compared to S-Glass Epoxy, Alloy6061-T6 because of less cost and reasonably high strength than these materials

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