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Modeling and Structural Analysis of Ladder Type Heavy Vehicle Frame

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Abstract: *The automobile is divided into two parts body and chassis. The chassis is basic structure of a vehicle. It contain all the engine parts and power systems but the frame is the main portion of chassis which do not contain any other assemblies like engine parts. Its principle function is to safely carry the maximum load for all designed operating conditions. This paper describes modeling and structural analysis of conventional type heavy vehicle frame. Weight reduction is now the main issue in automobile industries. In the present work, the dimensions of an existing heavy vehicle frame of a TATA 1109 EX2 vehicle is taken for modeling and analysis. The vehicle frame is initially modeled by considering 'C' cross section in SOLID WORKS 2011 and then it is imported to ANSYS 13.0. The analysis is done with three different composite materials namely Carbon/Epoxy, E-glass/Epoxy and S-glass/Epoxy subjected to the same pressure as that of a steel frame. The design constraints are stresses and deformations. The results are then compared to finalize the best among all the four frames.*
Keywords: *frame, Auto CAD 2012, SOLID WORKS 2011, ANSYS 13.0, TATA 1109 EX2.*

I. Introduction

Automotive chassis is a French word that was initially used to represent the basic structure. It is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering etc. are bolted. It gives strength and stability to the vehicle under different conditions.

At the time of manufacturing, the body of a vehicle is flexibly molded according to the structure of chassis. Automobile chassis is usually made of light sheet metal or composite plastics. It provides strength needed for supporting vehicular components and payload placed upon it. Automotive chassis or automobile chassis helps keep an automobile rigid, stiff and unbending. It ensures low levels of noise, vibrations and harshness throughout the automobile.

Automobile chassis without the wheels and other engine parts is called frame. Automobile frames provide strength and flexibility to the automobile. The backbone of any automobile, it is the supporting frame to which the body of an engine, axle assemblies are affixed. Tie bars that are essential parts of automotive frames are fasteners that bind different auto parts together. Automotive frames are basically manufactured from steel. Aluminum is another raw material that has increasingly become popular for manufacturing these auto frames. In an automobile, front frame is a set of metal parts that forms the framework which also supports the front wheels.

1.1 Types of frames

There are three types of frames

1. Conventional frame
2. Integral frame
3. Semi-integral frame

1.1.1 Conventional frame

It has two long side members and 5 to 6 cross members joined together with the help of rivets and bolts. The frame sections are used generally.

a. Channel Section – Good resistance to bending
b. Tabular Section – Good resistance to Torsion
c. Box Section – Good resistance to both bending and Torsion

1.1.2 Integral frame

This frame is used now in most of the cars. There is no frame and all the assembly units are attached to the body. All the functions of the frame carried out by the body itself. Due to elimination of long frame it is cheaper and due to less weight most economical also. Only disadvantage is repairing is difficult.

1.1.3 Semi – Integral frame

In some vehicles half frame is fixed in the front end on which engine gear box and front suspension is mounted. It has an advantage when the vehicle is met with an accident the front frame can be taken easily to replace the damaged chassis frame. This type of frame is used in American and European cars.

1.2 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, engine, gear box etc.,
3. To with stand the forces caused due to the sudden braking or acceleration.
4. To with stand the stresses caused due to the bad road condition.
5. To with stand centrifugal force while cornering.

1.3 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 vehicle.
4. Inertia Load – While applying brakes.
5. Static Loads – Loads due to chassis parts.
6. Over Loads – Beyond Design capacity.

II. Problem Specification

Weight reduction is now the main issue in automobile industries. Because if the weight of the vehicle increases the fuel consumption 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 frame of TATA 1109 EX 2 heavy vehicle frame. It is manufactured with Structural Steel. 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.

2.1 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 fiber 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 neighboring 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.

2.2 Specifications of Existing Heavy Vehicle TATA 1109 EX2 Frame

Sl. No.	Description	Dimension (mm)
1	Wheel base	3600
2	Front track	1800
3	Rear track	1690
4	Overall length of vehicle with load body	6600
5	Max. width	2270
6	Frame length	5620

Sl. No.	Description	Weight (kg)
1	Max. permissible FAW	7950
2	Max. permissible RAW	3950
3	Max. permissible GVW	11900
4	Passing payload for cab load body	8315

III. Design

Design may be done in two ways one way is the component design which is done by improving the existing ones. The other is conceptual design where there is no reference and creation of new machines. A new or better machine is one which is more economical in the overall cost of production and operation. The process of design is a long and time consuming one. From the study of existing ideas, a new idea has to be conceived. The idea is then studied keeping in mind its commercial success and given shape and form in the form of drawings. In the preparation of these drawings, care must be taken about the availability of resources like money, man power and materials required for the successful completion of the new idea into an actual reality. In designing a machine component, it is necessary to have a good knowledge of many subjects such as Mathematics, Engineering Mechanics, Strength of Materials, Theory of Machines, Workshop Processes and Engineering Drawing.

Generally the design of a component involves various steps in it. Initially, the drawings must be drawn in user friendly software and they must be converted into a 3D model. This 3D model must be imported into an analyzing medium where it is structurally or thermally analyzed to sustain the need.

Different steps involved in designing a component are

1. Part drawing
2. Modeling
3. Structural analysis

The present frame is divided in to individual components and each component is drawn, modeled and structurally analyzed by using software and its procedure is explained as below.

3.1 Part Drawing

It is a document that includes the specifications for a part's production. Generally the part drawings are drawn to have a clear idea of the model to be produced. The part drawing of the entire frame is drawn with all the views in AUTO CAD 2012.

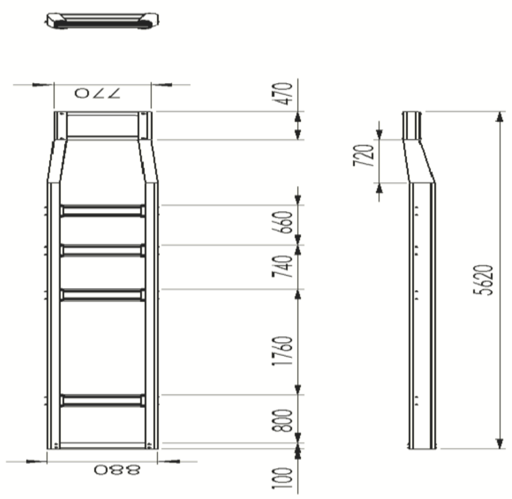

Fig. 3.1 Part drawing of assembly in AUTO CAD 2012

3.2 Modeling

It is the process of developing a mathematical representation of any three-dimensional surface of object via specialized software. The product is called a 3D model.

There are three basic types of three dimensional computer geometric modeling methods

1. Wire frame modeling
2. Surface modeling
3. Solid modeling

3.2.1 Wire Frame Modeling

A wire frame model is visual presentation of a 3 dimensional or physical object used in 3D computer graphics. It is created by specifying each edge of the physical object where two mathematically continuous smooth surfaces meet, or by connecting an object's constituent vertices using straight lines or curves. The object is projected on to a display screen by drawing lines at the location of each edge.
The wire frame format is well suited and widely used in programming tool paths for DNC (Direct Numerical Control) machine tools.

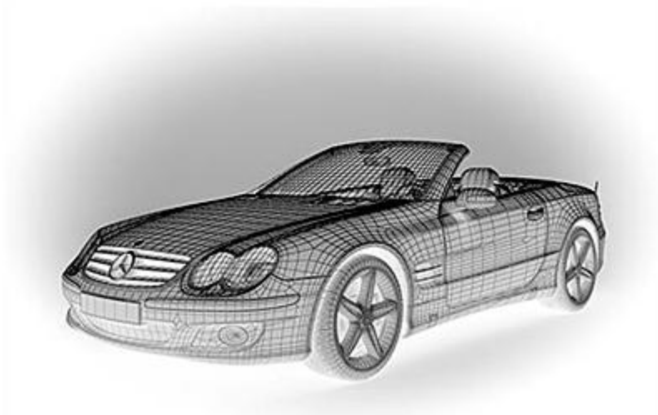

Fig. 3.2 Wire Frame Modeling

3.2.2 Surface Modeling

These models are with no thickness. These models are widely used in industries like automobiles, aerospace, plastic, medical and so on. Surface models should not be confused with thick models that are models having mass properties. The only difference between the soli model and the surface model is solid model will have mass properties.

Fig. 3.3 Surface Modeling

The present frame is modeled by solid modeling because of its ease in construction and realistic profile.

3.2.3 Solid Modeling

A solid model of an object is a more complete representation than its surface (wireframe) model. It provides more topological information in addition to the geometrical information which helps to represent the solid unambiguously. There are different software that are used for generating these solid models like Solid works and Pro.E. In this project the frame is modeled by using SOLID WORKS 2011. All the parts that are required for constructing the frame are modeled in part module by using different commands like extrude, rotate, loft, fillet, extrude cut etc..,

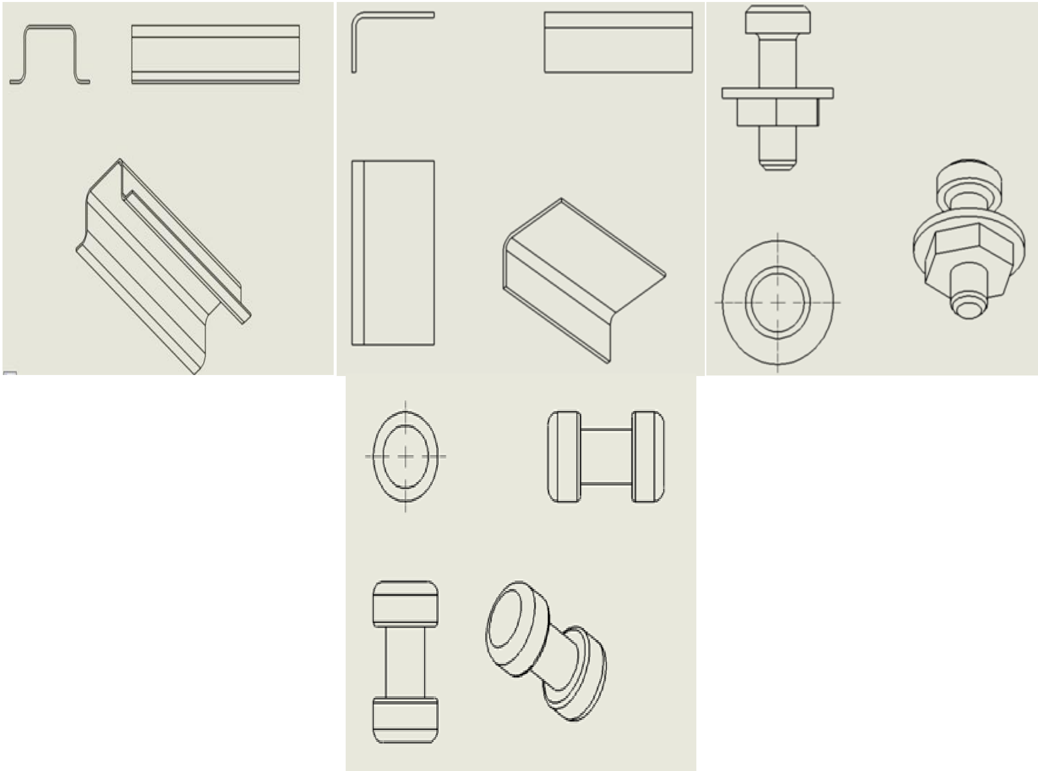

Fig. 3.4 Part drawings of components in SOLID WORKS 2011

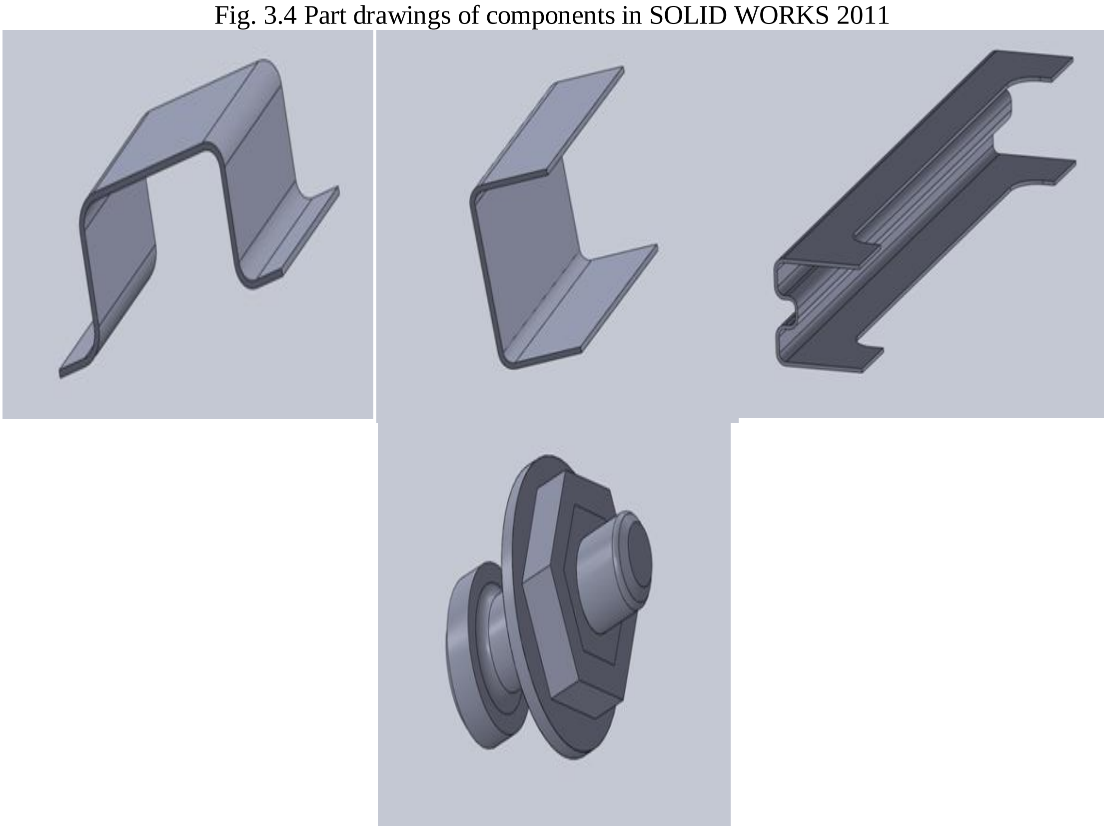

Fig. 3.5 Modeled components in SOLID WORKS 2011

3.3 Assembly

The components that are generated in part module are imported to assembly module and by using 'insert components' command and all these components are mated together to form the required assembly. The different views of assembly and the drawing generated in SOLID WORKS 2011 are as shown below.

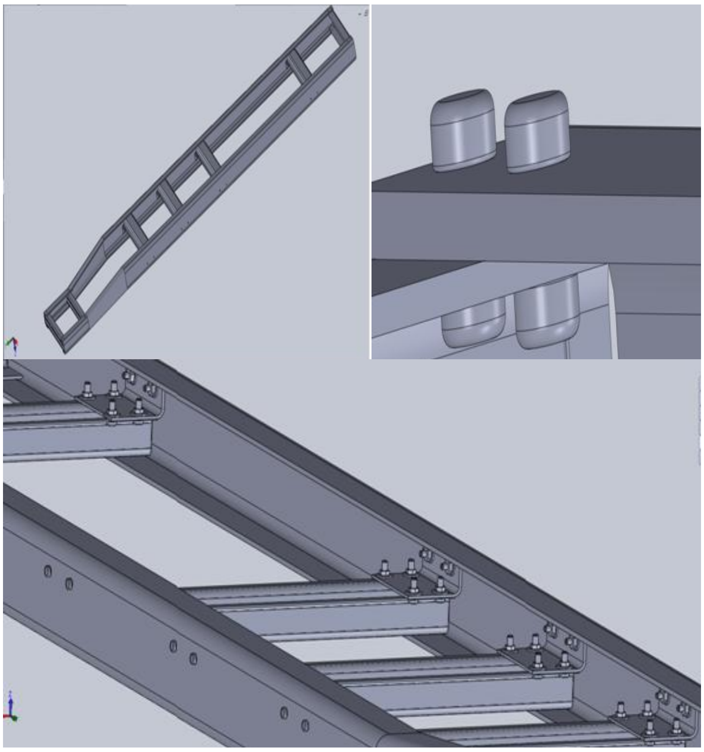

Fig. 3.6 Different views of the frame assembly in SOLID WORKS 2011

3.4 Structural Analysis

It is the methodology of determining the effects of loads on physical structures and their components. Structures subject to this type of analysis include buildings, bridges, vehicles, machinery, furniture, attire, soil strata, prostheses and biological tissue. Structural analysis incorporates the fields of applied mechanics, materials science and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often saving physical tests. Structural Analysis is thus a key part of the engineering design of structures.

The present frame model is converted into IGES format and it is then imported to ANSYS Workbench 13.0.There are various steps that are to be followed in analyzing a component structurally. They are

1. Mesh generation
2. Fixed supports
3. Application of loads
4. Evaluating result

3.4.1 Mesh Generation

The process for generating a mesh consists of three general steps

1. Set the element attributes
2. Set mesh controls (optional)
3. Meshing the model

It is not always necessary to set mesh controls because the default mesh controls are appropriate for many models. If no controls are specified, the program will use the default settings (DESIZE) to produce a free mesh. Alternatively, you can use the Smart Size feature to produce a better quality free mesh.

ANSYS Meshing technology provides multiple methods to generate a pure hex or hex- dominant mesh. Depending on the model complexity, desired mesh quality and type, and the time available to perform meshing, ANSYS Meshing provides a scalable solution. Quick automatic hex or hex-dominant mesh can be generated for optimal solution efficiency and accuracy.

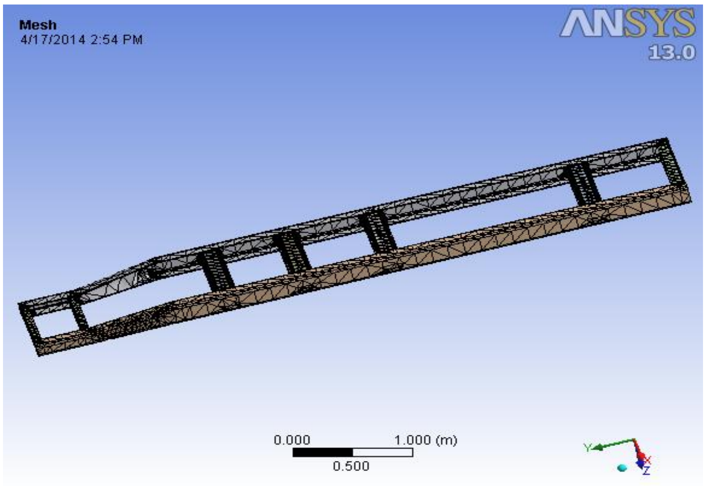

Fig. 3.7 Isometric View of Frame after Meshing

3.4.2 Fixed Supports

The fixed supports for the frame are placed at the wheel positions. The total number of supports is four. The first support is placed at 470 mm from the front end the second support is placed at 1680 mm from the rear side. The other two supports are placed at same positions on the other side.

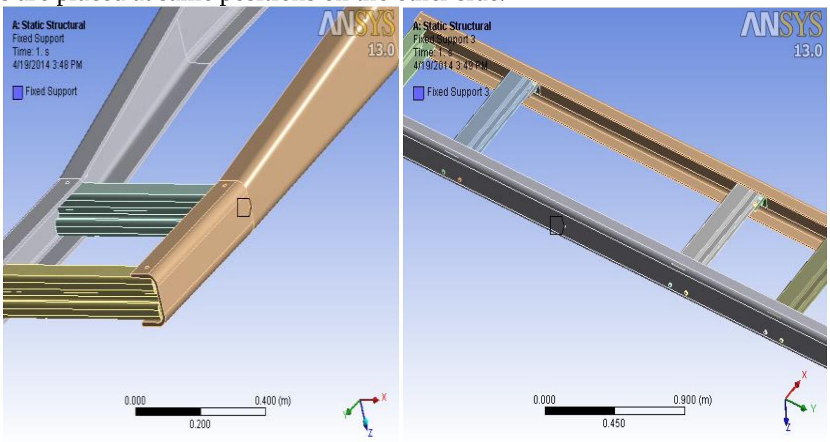

Fig. 3.8 Fixed supports at Front and Rear wheel positions

3.4.3 Application of Loads

The load application is the major part in the analysis of a component. There may be different types of loads like Uniformly Distributed Load, Uniformly Varying Load and Point Load.

The present frame carries the UDL through out its length.

From the vehicle specifications

FAW = 7950 Kg

RAW = 3950 Kg

Total GVW = 11900 Kg

As the frame supports the bodt by its two side frames, the load on each side member

= 11900/2 = 5950 kg

The total area on which the UDL is placed = 5620 × 100 = 562000 mm^2

Total pressure applied = Total load /Total area = 5950/562000

= 0.01058 kg/mm^2 = 0.1038 N/mm^2 = 0.1038 MPa

The pressure is applied on the two side members of the frame as shown in Fig. 3.9

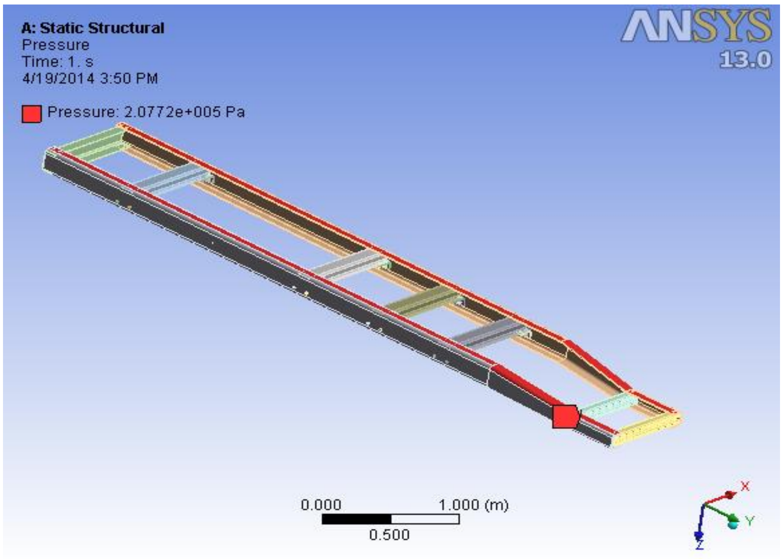

Fig. 3.9 Area on which Pressure is applied

3.5 Structural Steel

It is steel construction material, a profile, formed with a specific shape or cross section and certain standards of chemical composition and mechanical properties. Structural steel shape, size, composition, strength, storage, etc., is regulated in most industrialized countries. Composition 0.565%C, 1.8% Si, 0.7%Mn, 0.045%P and 0.045% S

3.5.1 Mass of Frame

The mass of an object is a fundamental property of the object, a numerical measure of its inertia, a fundamental measure of the amount of matter in the object.
Mathematical equation for mass is

Mass = Volume × Density

We know, Density of steel = 7850kg/m^3

Volume of frame = 4.9104×10^{-2} m³

Total mass of frame = 7850 × 0.049104

= 385.46 kg

3.5.2 Stresses developed in Frame

It is a physical quantity that expresses the internal forces that neighboring particles of a continuous material exert on each other. For example, when a solid vertical bar is supporting a weight, each particle in the bar pulls on the particles immediately above and below it. These macroscopic forces are actually the average of a very large number of intermolecular forces and collisions between the particles in those molecules. There are many types of stresses developed in a component. The frame is analyzed by considering Equivalent stress and normal stress.

Normal stress

The component of stress which is perpendicular to the plane on which the force is applied is called Normal stress. This stress is also called as principle stress. Its value should not exceed the yield strength of the material. In some of the situations design is considered to be safe if its value is less than the yield strength of the material. The normal stress distribution in the frame for structural steel is as shown in Fig. 3.10. From the Fig. 3.10 it can be inferred that

Maximum normal stress = 3359 Mpa

Minimum normal stress = - 6317 Mpa

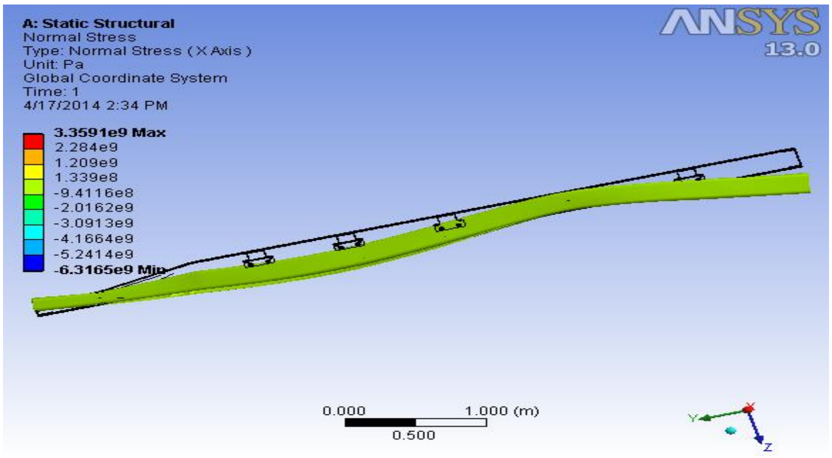

Fig. 3.10 Normal Stress Distribution in Frame (Structural Steel)

Equivalent stress

When an elastic body is subjected to loads in its three dimensions, the stresses will get developed along the principle axis of the bodystresses. These stresses should not exceed the yield stress of the material. VonMises postulated that, even though none of the principal stresses exceeds the yield stress of the material, it is possible for yielding of the same from the combination of stresses. So all these stresses in three dimensions are together called as Equivalent stress. Von Mises stress is considered to be a safe haven for design engineers. Using this information an engineer can say his design will fail, if the maximum value of Von Mises stress induced in the material is more than strength of the material. It works well for most of the cases, especially when the material is ductile in nature.

The Equivalent stress distribution in the frame for structural steel is as shown in Fig. 3.11. From Fig. 3.11 it can be inferred that

Maximum Equivalent stress = 17686 MPa (Approx.)
Minimum Equivalent stress = 0 MPa

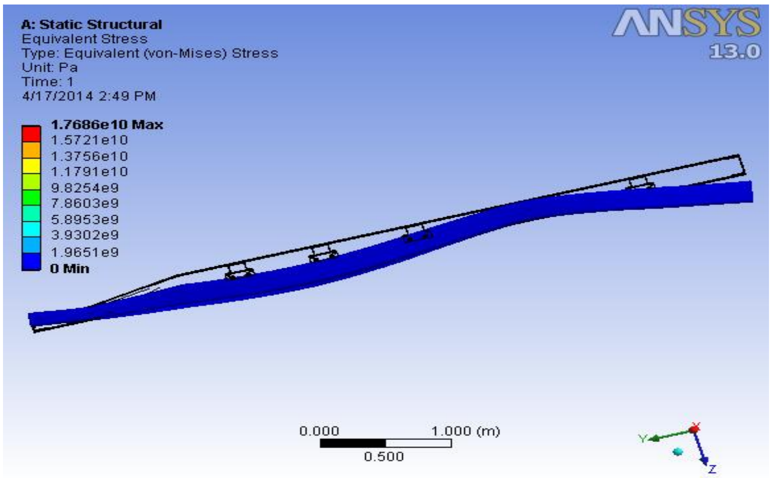

Fig. 3.11 Equivalent Stress Distribution in Frame (Structural Steel)

3.5.3 Deformation

When an object is subjected to loading its shape may be changed temporarily or permanently due to applied force. This change in shape is called deformation. If the object deforms permanently it is called plastic deformation or failure. If it deforms temporarily it is called elastic deformation. While analyzing a frame the frame should deform elastically within the maximum loading limit so that the design is safe. The values of deformation obtained in ANSYS 13.0 for structural steel are as shown in Fig. 3.12

Maximum deformation = 5.7 mm (Approx.)
Minimum deformation = 0 mm

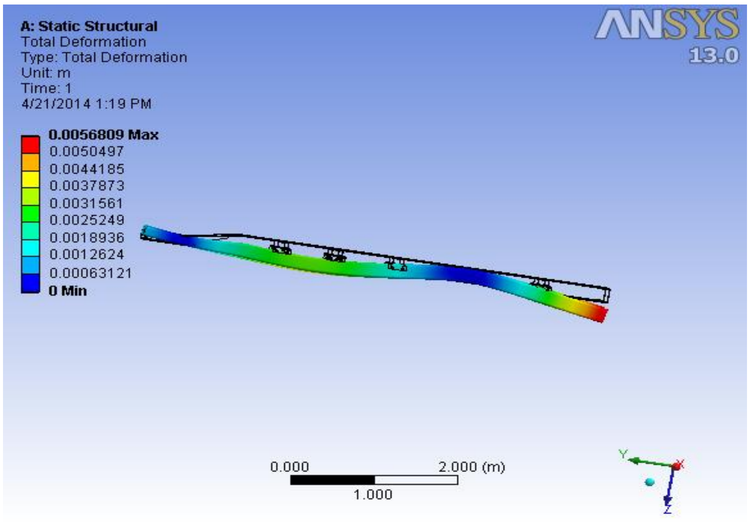

Fig. 3.12 Total deformation in frame (Structural steel)

3.6 Carbon/ Epoxy

Carbon-Fiber-Reinforced Polymer, Carbon-Fiber-Reinforced Plastic or Carbon-Fiber- Reinforced Thermo Plastic (CFRP, CRP, CFRTP or often simply carbon fiber, or even carbon) is an extremely strong and light Fiber-Reinforced Polymer which contains carbon fibers.

The binding polymer is often a thermo set resin such as epoxy, but other thermoset or thermoplastic polymers, such as polyester, vinyl ester or nylon, are sometimes used. The composite may contain other fibers, such as aramid e.g. Kevlar, Twaron, Aluminium or Glass fibers as well as Carbon fiber. The properties of the final CFRP product can also be affected by the type of additives introduced to the binding matrix (the resin). The most frequent additive is silica, but other additives such as rubber and carbon nanotubes can be used. CFRPs are commonly used in the transportation industry; normally in cars, boats and trains, and in sporting goods industry for manufacture of bicycles, bicycle components, golfing equipment and fishing rods.

Although carbon fiber can be relatively expensive, it has many applications in aerospace and automotive fields, such as Formula One racing and wherever high strength-to-weight ratio and rigidity are required such as sailing boats and rowing shell hulls, top-end bicycles and motorcycles, As manufacturing techniques improve and costs reduce it is becoming increasingly common in small consumer goods that require strength, lightness and stiffness such as laptop bodies, tripod legs, tent poles, fishing rods, hockey sticks, bows and arrows, racquet frames, stringed instrument bodies, drum shells, golf clubs, crash helmets and billiards cues.

Composition: Bisphenol-based epoxy 60-90%, Amine-based curing agent 1-30%, Imidazole-based curing catalyst 0.1-3% and Carbon Black 1-10%.

3.6.1 Mass of Frame

Mathematical equation for mass is

Mass = Volume × Density

We know Density of Carbon/Epoxy = 1600 kg/m^3

Volume of frame = 4.9104×10^{-2} m^3

Total mass of frame = 1600 × 0.049104 = 79 kg (Approx.)

3,6,2 Stresses Developed in Frame

The two types of stresses are considered for analyzing the frame and their respective stress distributions are as shown below

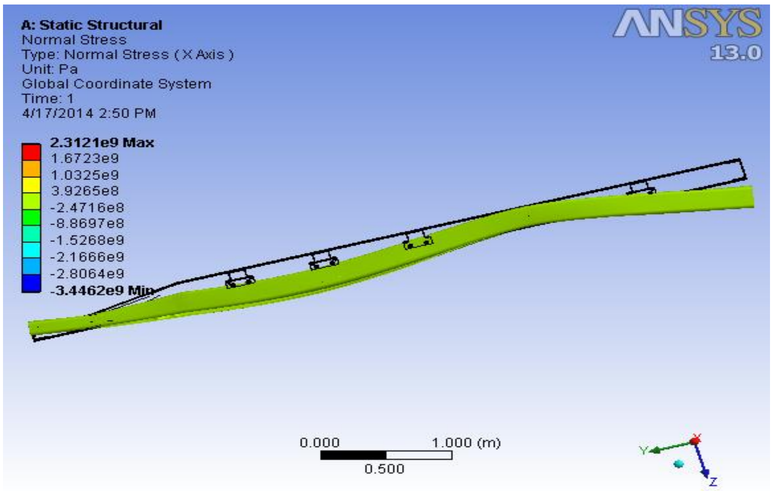

Fig. 3.13 Normal Stress Distribution in Frame (Carbon/ Epoxy)

Maximum normal stress = 2312 MPa
Minimum normal stress = -3446 MPa

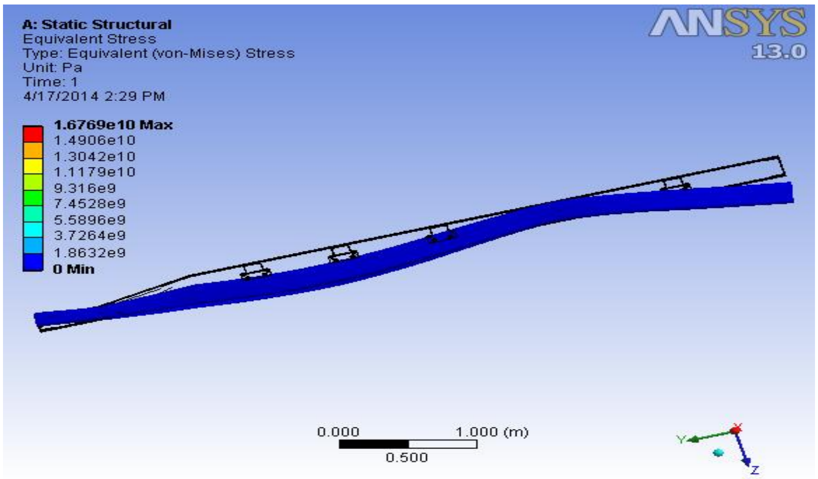

Fig. 3.14 Equivalent stress distribution in frame (Carbon/ Epoxy)

Maximum Equivalent stress = 16769 MPa
Minimum Equivalent stress = 0 MPa

3.6.3 Deformation

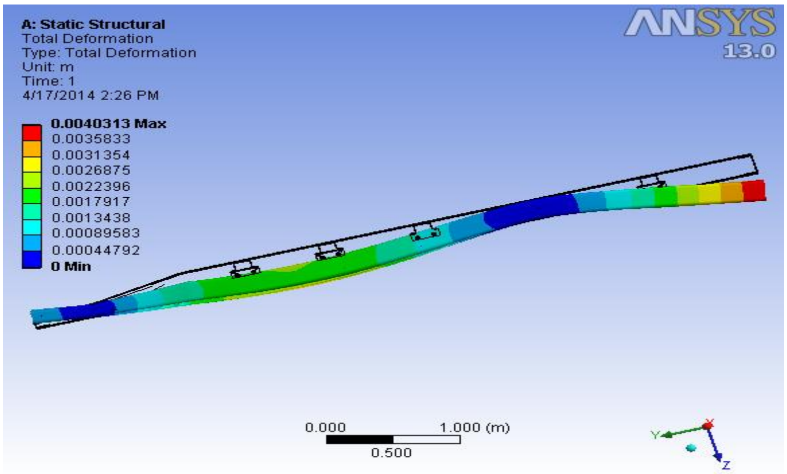

Fig. 3.15 Total Deformation in Frame (Carbon/ Epoxy)

Maximum deformation = 4.03 mm
Minimum deformation = 0 mm

3.7 E-glass/ Epoxy

An individual structural glass fiber is both stiff and strong in tension and compression that is, along its axis. Although it might be assumed that the fiber is weak in compression, it is actually only the long aspect ratio of the fiber which makes it seem so i.e., because a typical fiber is long and narrow, it buckles easily. On the other hand, the glass fiber is weak in shear that is, across its axis. Therefore if a collection of fibers can be arranged permanently in a preferred direction within a material, and if the fibers can be prevented from buckling in compression, then that material will become preferentially strong in that direction. Furthermore, by laying multiple layers of fiber on top of one another, with each layer oriented in various preferred directions, the stiffness and strength properties of the overall material can be controlled in an efficient manner. In the case of fiberglass, it is the plastic matrix which permanently constrains the structural glass fibers to directions chosen by the designer. With chopped strand mat, this directionality is essentially an entire two dimensional plane; with woven fabrics or unidirectional layers, directionality of stiffness and strength can be more precisely controlled within the plane.

E-Glass / Epoxy Resin Composites are extremely strong materials used in roofing, pipes and automobiles.
Composition: 54% SiO_2 - 15% Al_2O_3 - 12% CaO

3.7.1 Mass of frame

Mathematical equation for mass is

Mass = Volume × Density

We know Density of E-glass/Epoxy= 2600 kg/m^3

Volume of Frame= 4.9104×10^{-2} m^3

Total mass of Frame = 2600 × 0.049104 = 127.67 kg

3.7.2 Stresses Developed in Frame

The two types of stresses are considered for analyzing the frame and their respective stress distributions are as shown

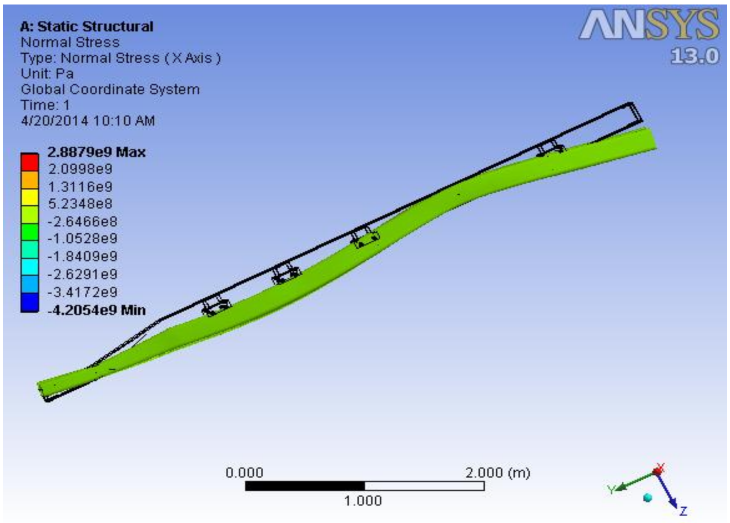

Fig. 3.16 Normal Stress Distribution in Frame (E-glass/ Epoxy)

Maximum normal stress = 2887.9 = 2888 Mpa (Approx.)
Minimum normal stress = -4205.4 = -4205 Mpa (Approx.)

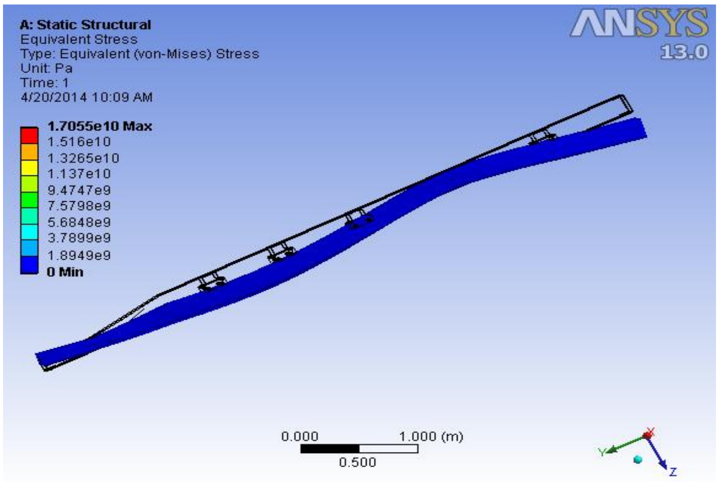

Fig. 3.17 Equivalent Stress Distribution in Frame (E-glass/ Epoxy)

Maximum Equivalent stress = 17055 Mpa

Minimum Equivalent stress = 0 MPa

3.7.3 Deformation

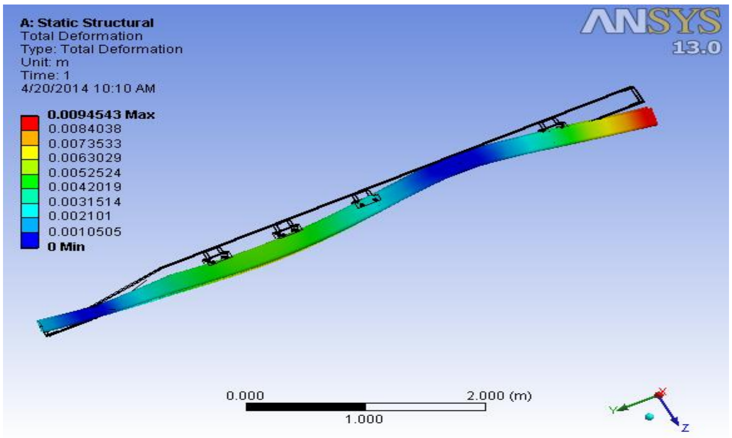

Fig. 3.18 Total Deformation in Frame (E-glass/ Epoxy)

Maximum deformation = 9.45 mm

Minimum deformation = 0 mm

3.8 S-glass/ Epoxy

The manufacturing process for glass fibers suitable for reinforcement uses large furnaces to gradually melt the silica sand, limestone, kaolin clay, fluorspar, colemanite, dolomite and other minerals to liquid form. Then it is extruded through bushings, which are bundles of very small orifices (typically 5–25 micrometers in diameter for E-Glass, 9 micrometers for S-Glass). These filaments are then sized (coated) with a chemical solution. The individual filaments are now bundled together in large numbers to provide a roving. The diameter of the filaments, as well as the number of filaments in the roving determines its weight.

Common uses of S-glass include high performance aircraft (gliders), boats, automobiles, baths, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, casts, surfboards and external door skins.

Composition: 64% SiO_2- 24% Al_2O_3- 10% MgO

3.8.1 Mass of Frame

Mathematical equation for mass is

Mass = Volume × Density

We know Density of S-glass/ epoxy = 2495 kg/m^3

Volume of frame = 4.9104×10^{-2} m^3

Total mass of frame = 2495 × 0.049104 = 123 kg (Approx.)

3.8.2 Stresses developed in Frame

The two types of stresses are considered for analyzing the frame and their respective stress distributions are as shown below

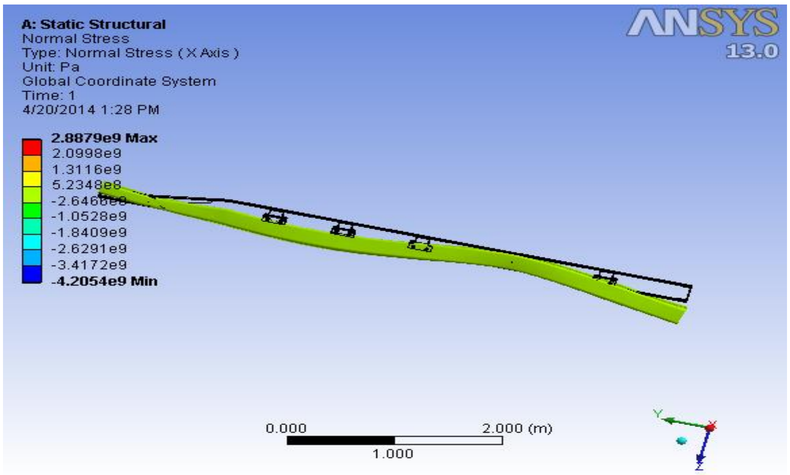

Fig. 3.19 Normal Stress Distribution in Frame (S-glass/ Epoxy)
Maximum normal stress = 2888 MPa (Approx.)
Minimum normal stress = -4205 MPa (Approx.)

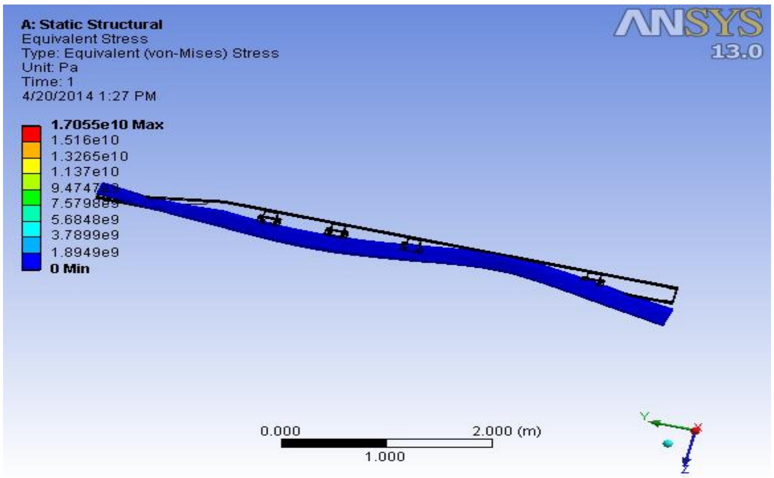

Fig. 3.20 Equivalent Stress Distribution in Frame (S-glass/ Epoxy)
Maximum Equivalent stress = 17055 MPa
Minimum Equivalent stress = 0 Mpa

3.8.3 Deformation

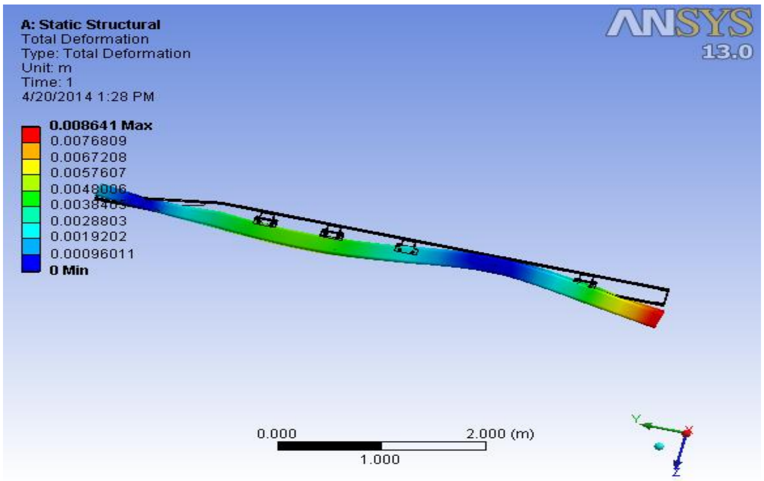

Fig. 3.21 Total Deformation in Frame (S-glass/ Epoxy)

Maximum deformation = 8.64 mm
Minimum deformation = 0 mm

IV. Results

From the above analysis using different materials, the results obtained for stresses and deformations are tabulated below.

Table 4.1 Comparison of Results

Material	Mass (kg)	Max.Normal stress (MPa)	Max.Equivalent stress (MPa)	Max.Deformation (mm)
Structural steel	385	3359	17686	5.68
Carbon/ Epoxy	79	2312	16769	4.03
E-glass/ Epoxy	128	2888	17055	9.45
S-glass/ Epoxy	123	2888	17055	8.64

From the above table it can be inferred that Carbon/ Epoxy is having the least values when compared to remaining three materials. For less mass the Carbon/ Epoxy gives more strength. It can be explained by following calculations

For Structural Steel,

Density = 7850 kg/m^3
Ultimate tensile strength = 900 MPa
Strength to weight ratio = 900/7850 = 0.1146 MNm/kg
= 115 Nm/g (Approx.)

For Carbon/Epoxy,

Density = 1600 kg/m^3
Ultimate tensile strength = 600 MPa
Strength to weight ratio = 600/1600 = 0.375 MNm/kg
= 375 Nm/g

The results obtained are represented graphically as shown below.

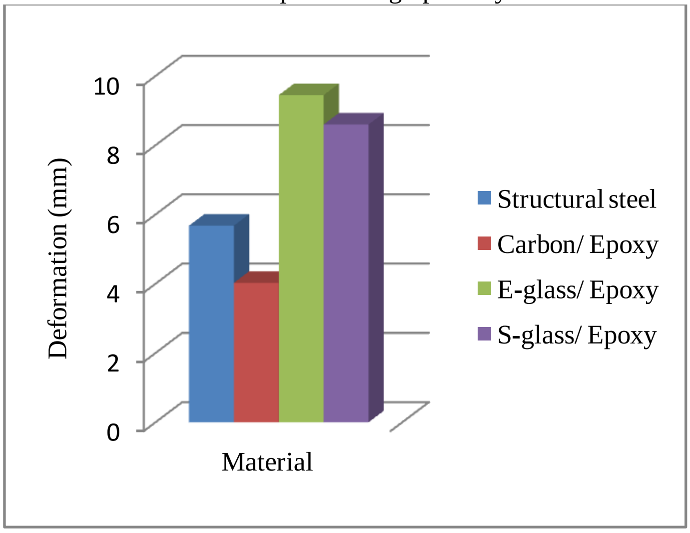

Fig. 4.1 Graphical Representation of Deformation

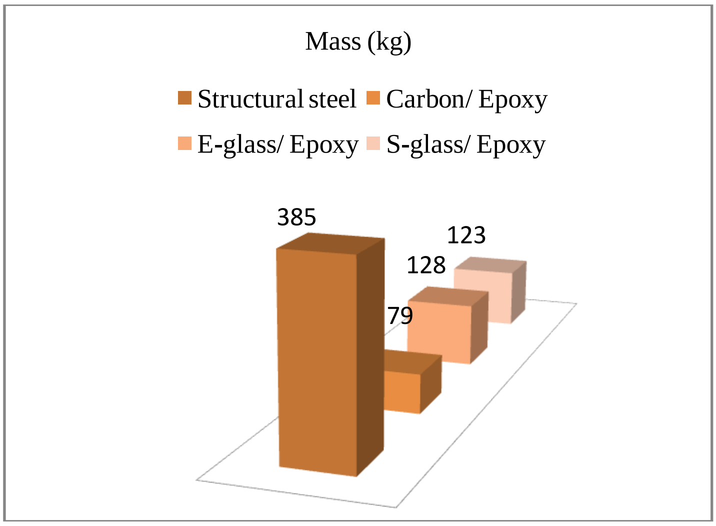

Fig. 4.2 Graphical Representation of Mass

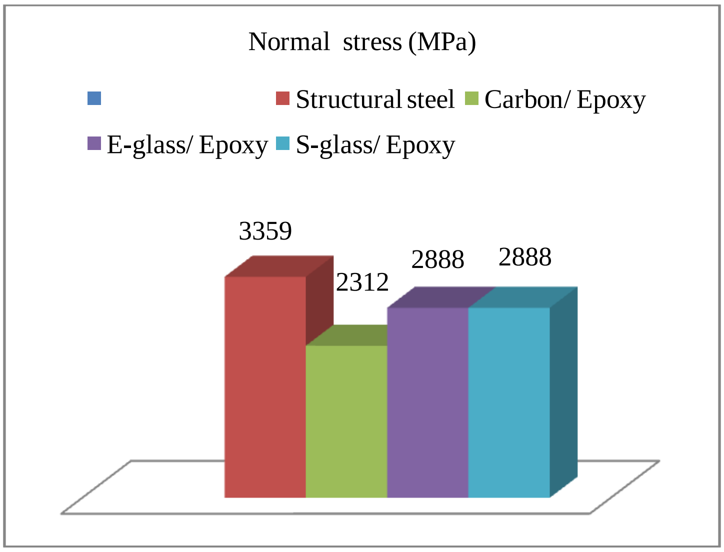

Fig. 4.3 Graphical representation of Normal stress

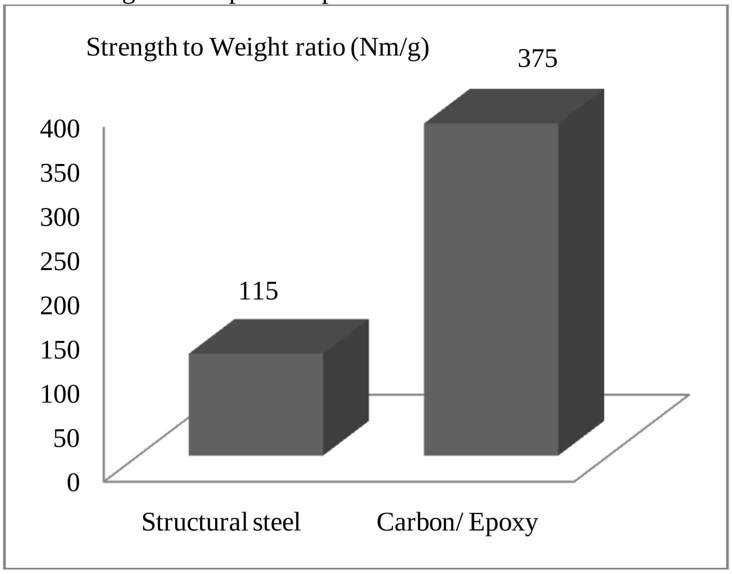

Fig. 4.4 Graphical Representation of Strength to Weight Ratio

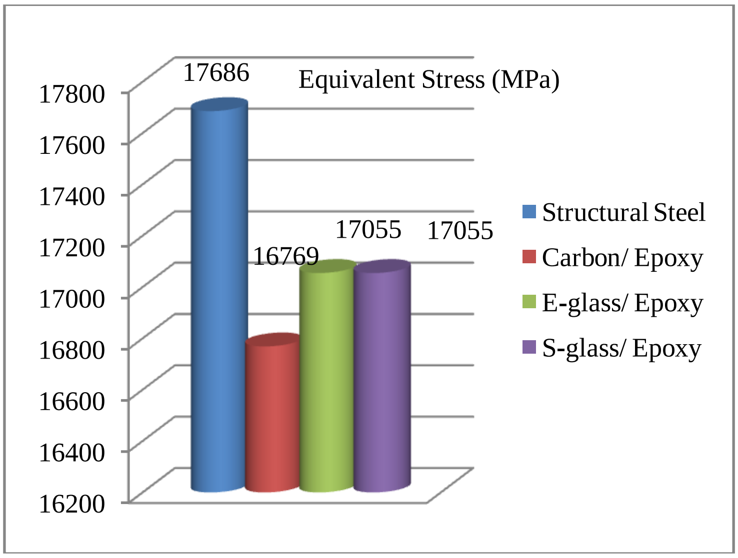

Fig. 4.5 Graphical representation of Equivalent stress

V. Conclusion

Present used material for chassis is steel. We have considered polymeric composites like Carbon/Epoxy, E-glass/Epoxy and S- glass /Epoxy for chassis material. By employing a polymeric composite heavy vehicle chassis for the same load carrying capacity, there is a reduction in weight of 70% to 80%**.** Based on the results it was inferred that Carbon/Epoxy polymeric composite heavy vehicle chassis has superior strength, less deformation, less normal stress and less weight compared to steel, E-glass/Epoxy and S- glass /Epoxy.

So we conclude that it is better to use Carbon/ Epoxy as a material for frames of heavy vehicle chassis. So that the fuel consumption decreases for the vehicles.

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