

COMPARISON OF STEEL AND COMPOSITE RAIL AXLE BY  
FINITE ELEMENT ANALYSIS

by

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Abstract

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Axles are one of the most important railway vehicle parts that supports the weight of both vehicle and passenger. Failure in Axle in its operating condition may cause heavy damage to the passenger and car as well, hence high strength design is required to mitigate the possibilities of axle failure. Generally steel axle is used in rail industry, nowadays there are more interest to replace steel axle to the composite axle. Use of advanced composite material such as Kevlar, graphite-fiber, carbon-fiber and glass-fiber with proper resin core resulted in remarkable achievements because of its specific strength and improve fatigue, specific modulus and reduction in energy requirements due to reduction in weight as compared to steel axle. This paper presents the modeling and analysis of metal composite rail axle using Epoxy carbon, resin Epoxy and 30NiCrMoV12.the overall objective of this paper is to analyze the metal composite axle to find out the best replacement for conventional steel axle in terms of reduced energy requirements reducing weight, comparing static behavior and the natural frequency of both conventional Rail Axle and Metal composite rail Axle when exposed to the same boundary and loading condition.it is also observed that compared to conventional material composite show lower stress and higher factor of safety.

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## Introduction

An Axle is one of the important component of rail vehicle which supports and transmits the weight of the vehicle and passenger to the wheels[1], due to which the horizontal and vertical loads formed during static and dynamic moving and carries braking and driving moment. Failures in Axle during operating condition may cause crash accidents causing heavy damage to the car and passenger; hence high strength design is required.[1]

The need to reduce axle weight is increased to improve the energy efficiency and mitigate the possible rail damage. Lightweight axles of railway vehicles reduce the un-sprung mass that leads to enhanced running performance on curves and reduced vehicle system noise and vibration. To achieve this change in material from conventional to composite is needed.[1]

By using composite material weight reduction can be achieved which leads to improve in energy efficiency. Composite also have high strength than conventional material which mitigate the possibilities of axle failure in running condition. This research paper mainly focused on use of hybrid structure to achieve weight reduction, high strength and higher factor of safety than conventional structure. Where two steel body and one composite body bonded by using appropriate bonding material and bolts to keep them together.

# Chapter 1

## 1.1 Composites

A Composite material can be defined as a combination of two or more material that results in better properties than those of the individual components used alone. In Contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. [20] The two constituents are a reinforcement and a matrix. Main advantage of composite material are their high strength and stiffness, combined with low density, when compared with bulk material, allowing for a weight reduction in finished part.

In composite material when there is single ply or lay-up in which all the layers or piles are stacked in the same orientation, the lay-up is called lamina. When the plies are stacked at various angles, the lay-up is called a laminate. [20]

In this research work carbon-fiber has taken as a composite material because of its high stiffness and low weight. Carbon fiber composite are about 10 times stronger and 5 times lighter than the steel. Together with the right resin systems, carbon fiber composites are also known for being extremely corrosion resistant and able to with stand wear.

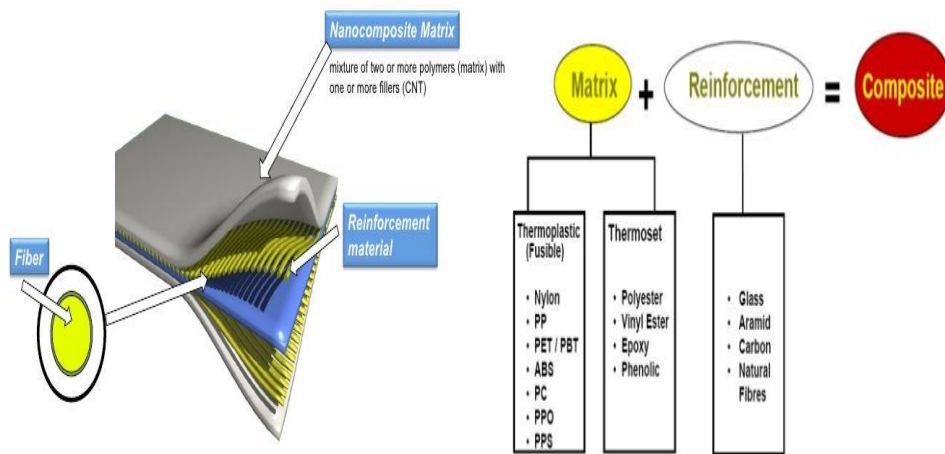


Fig 1.1-composite structure layout

Fig 1.2-composition of composite

## 1.2 Motivation and Objective

Rail axle is one of the important component of the rail vehicle which supports the weight of both passengers and vehicle. So, safety of passengers is important during cracking or braking of an axle. Rail axle are exposed to higher number of loading cycles because of that it is necessary to increase the factor of safety[2]. Composite has higher strength to low weight ratio because of that safety factor get increased and weight reduction can be achieved. A comparative study of both in terms of deflection, and the safety factor can improve understanding of concept.

The main aim behind this thesis work is to compare and correlate results obtained from analysis of conventional Alloy steel and composite material. Conventional design is used for the Alloy steel material and alternative design change is used for composite material and comparative study is being carried out to measure safety factor, deflection and stress. Normally Rail axle weighing around 350Kg, by using composite material with low density and high stiffness weight reduction can be achieved.

## Chapter 2

### Methodology

The existing geometries design for rail axle by American association of rail road were adopted for modeling of assembly in SOLIDWORKS. For conventional steel axle made from the same geometry and composite axle were divided into three Axle, outer steel Axle made, Inner steel Axle and composite Axle in between which made it hybrid Metal-Composite Rail Axle. Assumptions were made about the bolts dimensions which were used to kept whole Hybrid Metal-Composite Axle together. The material properties of the conventional steel were found from an existing data.

The geometry was brought to ANSYS V17 in IGES\* format and material properties were entered to ANSYS V17 Workbench. Load applied on the both side of Axle on bearing and on wheel seat in opposite direction and boundary condition applied on both end of Axle such way that six degrees of freedom were fixed for both end faces.

Normal stresses, Shear stresses and deflections were analyzed in post-processing. The Maximum stresses and the total deformations were taken into account.

The methodology followed for both the Conventional Steel Axle and for Metal-composite Axle were the same. Comparison was carried out for different output which were extracted.

## Chapter 3

### Geometry and boundary condition

#### 3.1 CAD model

Standard Axle design has been considered according to AAR (American association of Railroad). Two designs have been considered, one for the conventional steel Axle and one for the composite structure. conventional steel Axle was made of whole steel according to AAR standard[3]. Composite Axle made of three bodies, one was outer hollow steel Axle according to AAR with the length of 2159mm with varying thickness through length and inner diameter mm. Second body was inner solid steel Axle which had same length 2159mm and diameter of mm. And third body was composite body with thickness of 30mm and inner diameter of mm,2159mm length. Three bodies are assembled together using solid works 2016. Four bolts used for the bonding of metal and composite bodies. Which makes one whole assembly of composite Rail Axle.

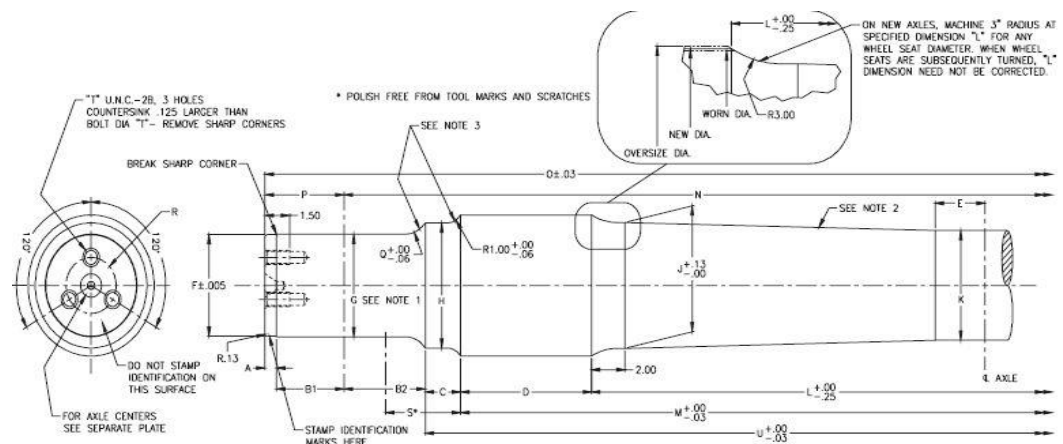


Fig 3.1- Axle standard by AAR[3]

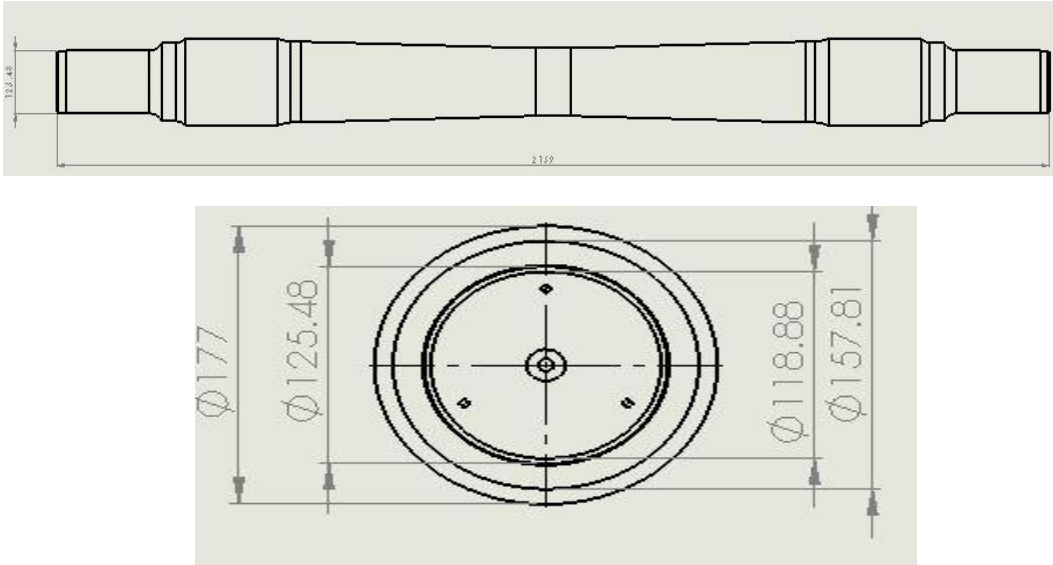


Fig-3.2 front and side view of Axle

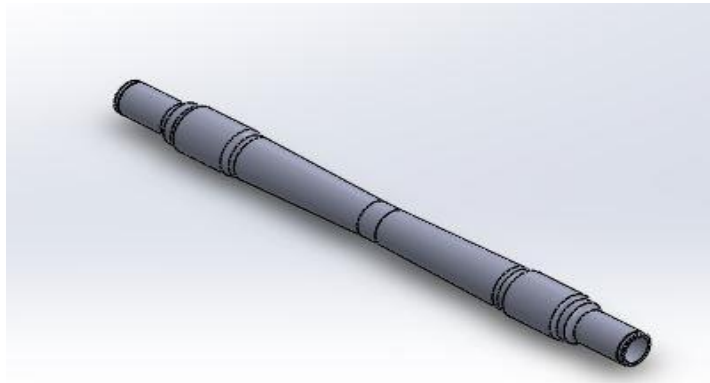


Fig-3.3 outer steel Axle body

As shown in above figure is the outer steel body of composite Axle Assembly which is made of same material as conventional alloy steel material that is used in Rail industry now a day to make Axle.



Fig-3.4 composite Axle Body

As shown in above figure Composite stake up of 30 mm on surface model can be seen. 30 mm thickness is used for the composite model with stake up of 11 plies.

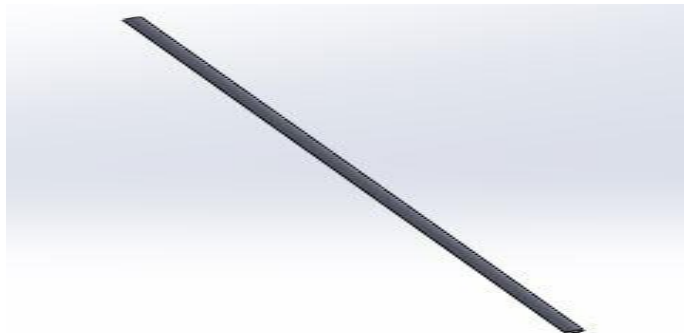


Fig-3.5 Inner Steel Body

And the inner steel body is used to give support to structure and the bolts that are used to keep the structure together.

All the three bodies as shown were assembled together to make one hybrid metal-Composite assembly. For the modeling of composite Axle body surface revolve was used.



All the three bodies assembled in SOLIDWORKS and imported to ANSYS ACP for composite modeling.

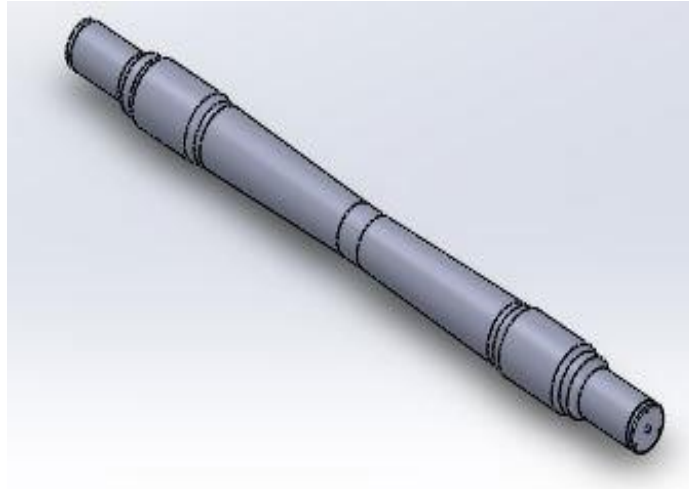


Fig-3.6 solid conventional Axle

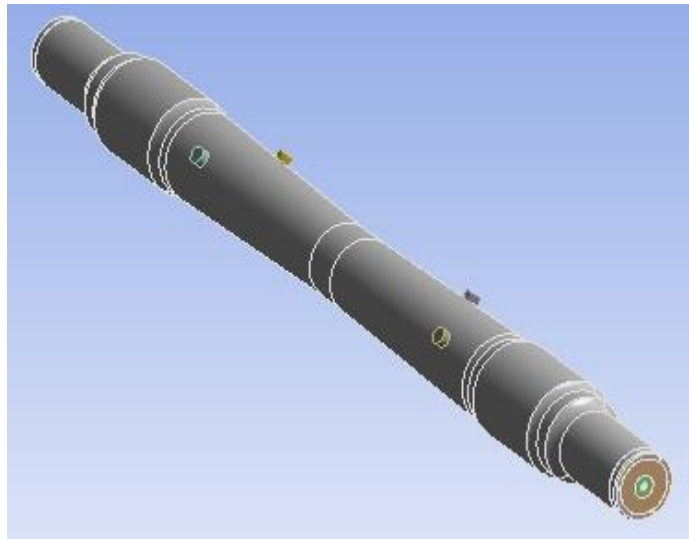


Fig-3.7 composite Axle Assembly

As shown in fig-6 conventional steel Axle is made According to AAR standard and as shown in figure-7 the three bodies are assembled together, and four bolts are used to bond

it together to make one Hybrid Composite Axle. Four bolts are inserted in horizontal and in vertical direction at same distance from wheel sheet.

As we know that Composite are not good at taking direct wear on its body, so this is the main reason for choosing this Design. Here composite body will come in between outer steel body and inner steel body. Outer steel body will take wear and composite body will take load and strengthen the structure. And inner steel body is used to give the support to the whole structure and to the 4 bolts that used to keep the structure together.

### 3.2 Meshing

The CAD model was meshed using Solid tetrahedral structure. Solid 72 is well suited with four nodes and having six degrees of freedom at each node: translation in the nodal x, y, z direction and rotations about x, y, and z directions. The element supports the stress stiffening, large deflection, and large strain capabilities.

This CAD model was meshed using body sizing and by use of tetrahedrons method. Here for the conventional Axle one body sizing used and 10mm mesh is generated. For the composite Axle Assembly Four body sizing use to generate 10mm mesh in all the Four parts which contains inner steel Axle, outer steel Axle, composite Axle in between and Four bolts.

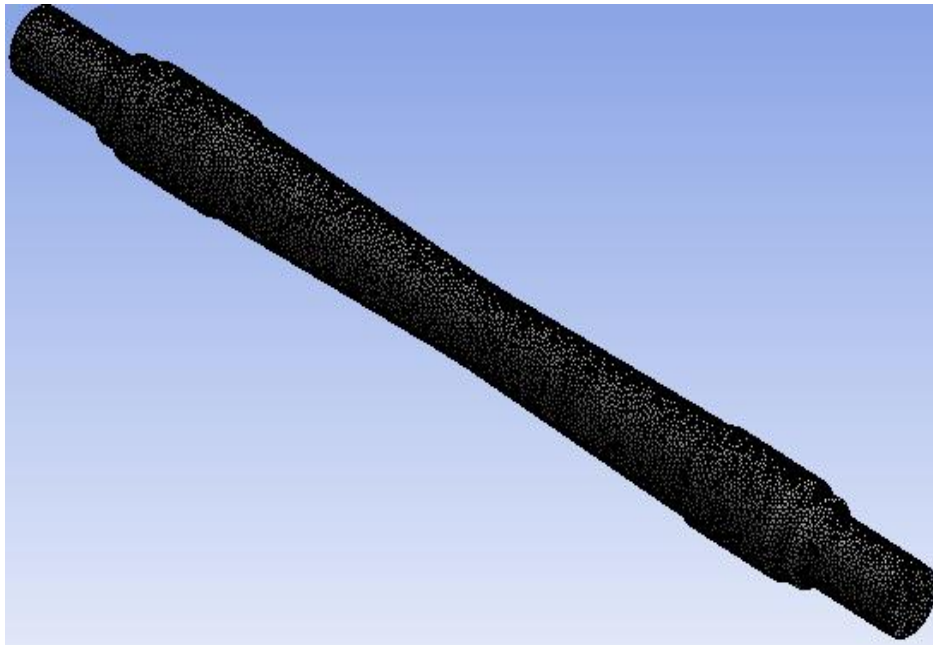


Fig-3.8 Conventional Axle CAD Mesh

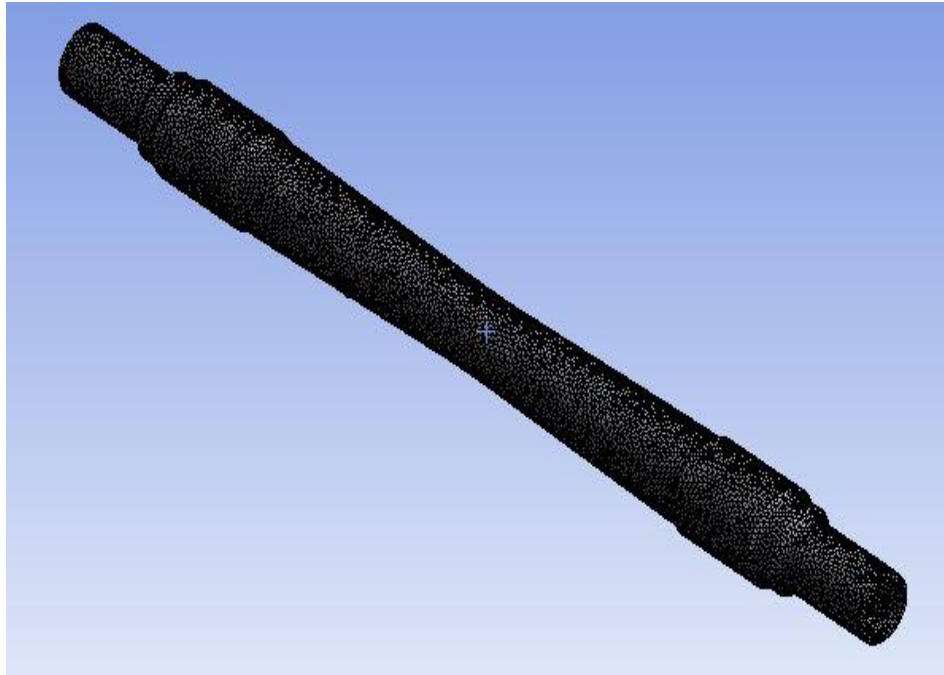


Fig-3.9 Composite Axle Assembly CAD Mesh

Statistics	
<input type="checkbox"/> Nodes	478906
<input type="checkbox"/> Elements	340929

Fig-3.10 Mesh data

This CAD model was saved as IGES file in \*.igs format so that they can transferred to ANSYS V17 Education Edition for Analysis.

### 3.3 Boundary condition

Here Loading condition has been considered according to AAR (American Association of Railroad) standards. For the boundary condition Fixed support are being considered at both the end of Axle for static, frequency and thermal analysis.

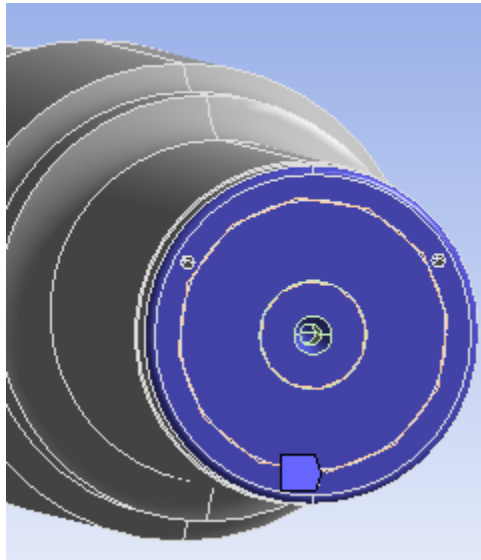


Fig-3.11 fixed support

Here the fixed support is applied on both side. For the conventional shaft there is only 2 faces to fixed support being given. And in Composite Assembly there total 6 faces considered as fixed support. Same boundary condition being used in all three static, frequency, and thermal analysis.

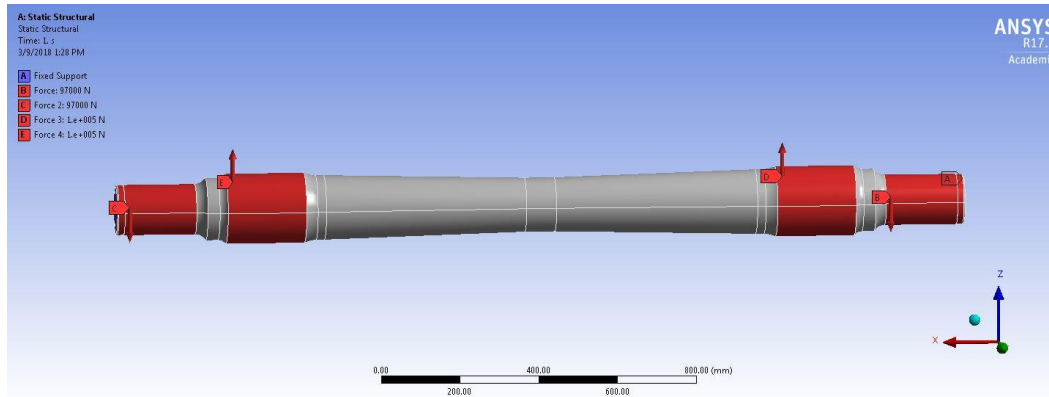


Fig-3.12 Force applied on Rail Axle

Here the force applied on the both the ends where bearing is being mounted in downward direction and another force applied in opposite direction on wheel sheets which is being coming from the track. Two forces of 97KN applies at both ends in downward direction and two forces of 100KN applied in upward direction on wheel sheets.[1] This force is measured by AAR which is for the static analysis of Rail axle.

Load at the end or called bearing is due to the weight of the Rail car body, passenger weight and bogie weight which contains many more parts mounted on it. Where the load on wheel sheet is due to opposite load acting on Axle through the track.

## Chapter 4

### Material properties

Material used for this Analysis was Epoxy Carbon UD for Composite and conventional material that used was 30NiCrMoV12. For better results in Composite Assembly Of Axle the Inner and outer Steel Axle were made from 30NiCrMoV12. The material properties required for the analysis are mainly:

- Poisson's ratio
- Ultimate tensile strength
- Tensile yield strength
- Young's modulus

#### 4.1 30NiCrMoV12 Steel

According to AAR standards material used for making conventional Rail Axle.

Chemical composition:

C	Si	Mn	Pa	S	Cr	Cu	Mo	Ni	V
0,26	0,40	0,020	0,015	1,00	0,20	0,60	0,40	2,70	0,08

Table-4.1: chemical composition (Maximum percentage contents)[4].

Physical properties:

Tensile Yield strength	490 MPa
Ultimate tensile strength	550 MPa
Poisson's ratio	0.3
Young's Modulus	1.8E+05 MPa
Density	8900 Kg/m <sup>3</sup>
Bulk Modulus	150000MPa
Shear Modulus	69231 MPa
Thermal Expansion Coefficient	1.2E-05 C <sup>-1</sup>

## 4.2 Carbon Fiber

Unidirectional prepreg Carbon fiber with 60% fiber volume concentration is used. It is a very strong material that is also very lightweight. Carbon fiber is five-times stronger than steel and twice as stiff. it is also chemical resistance. And have low thermal expansion coefficient. Because of this carbon fiber is very popular in many industries such as aerospace, automotive, military, and recreational application.



Fig 4.1- Carbon Fiber

## 4.3 Epoxy resin

Epoxy resin is a mixture of organic compounds which are highly viscous. There are mainly two types of it one is thermoplastic and thermoset. It's mainly used as resins and adhesive. They have better adhesive properties, high strength and modulus.

Properties	Carbon Fiber	Epoxy Matrix
E1 (GPa)	440	3
E2 (GPa)	14	3
V12	0.3	0.3
V23	0.15	0.3
G12 (GPa)	8	1.11
G23 (GPa)	6.087	1.11
CTE	-4.7E-07	1.5E-06

Table 4.2-Fiber and Matrix properties



## Chapter 5

### Simulation

#### 5.1 Static Analysis

Static analysis is being carried out in ANSYS V17. First solid conventional steel axle model brought to ANSYS V17. 30NiCrMoV12 material properties inserted into the engineering data. Then deformation and stress are being calculated. CAD Assembly with surface model brought to ANSYS V17 in ANSYS ACP(pre). Epoxy Carbon UD material assigned in the engineering data with 30NiCrMoV12 material. ACP Pre is being used for the composite layup.

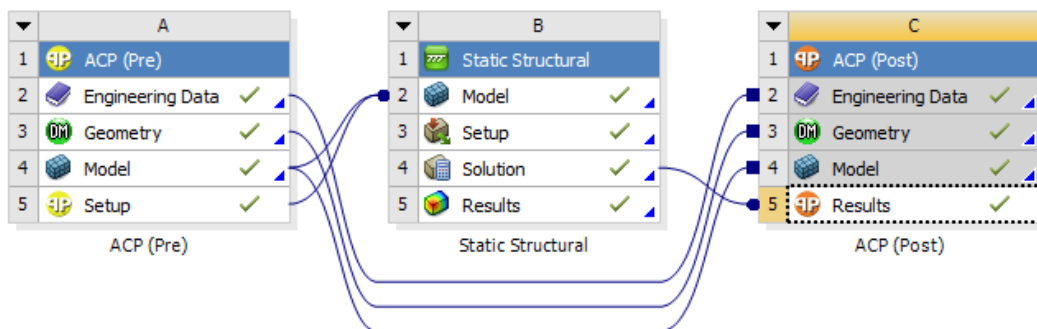


Fig-5.1 ANSYS module Prepost

As seen in above path of the process is being shown. For stacking 11 ply are being stacked up. Carbon fiber is being used for the stacking process. Ply angle are being analyzed using the performance analysis of angles. From total of 11 ply stack up 4 0-degree ply kept at surface and at the bottom for better resistance and for good torsion and bending affect. After that one 45/-45-degree ply being kept at the center for better shear forces generated due to one another. In between 45/-45,90-degree ply is being kept for the sequence

balanced. 0.27mm thickness being given to each ply. This stack up of 11ply is being repeated for 10 times so that gave total thickness of 30mm composite Body.

Name: Stackup.1  
ID: Stackup.1

General | Draping Coefficients | Analysis | Solid Model Opt.

Fabrics

Symmetry:  No Symmetry  
Layup Sequence:  Top-Down

Fabric	Angle
Fabric.1	0.0
Fabric.1	0.0
Fabric.1	0.0
Fabric.1	0.0
Fabric.1	45.0
Fabric.1	90.0
Fabric.1	-45.0
Fabric.1	0.0
Fabric.1	0.0
Fabric.1	0.0
Fabric.1	0.0
Fabric.1	0.0

Fig-5.2 stack up sequence

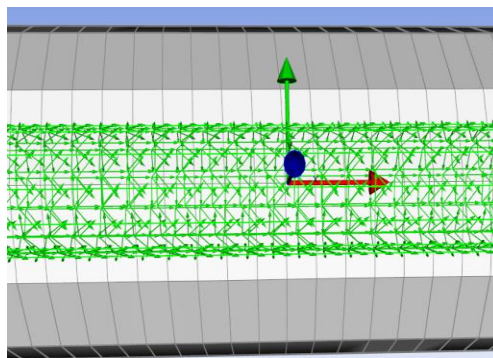


Fig-5.3 Fiber Direction

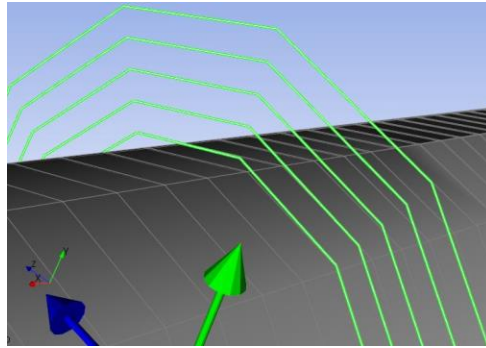


Fig-5.4 Ply direction

As shown the stack up is being used for ply layup with 11 plies at 0,45/-45, and 90 angles. Fiber direction is also shown for one stack up in Fig-16. Ply direction as shown in figure is normal from the surface.

30mm composite body being generated and brought it to the static structural. Boundary and loading condition being applied in the static structural. Post analysis being used for the solution analysis. Total deformation, Normal stress, strain for each outer, inner steel body and for composite body is being carried out in static structural. Interlaminar stresses, interlaminar shear stress and shear strain are being calculated from post solution.

## 5.2 Frequency Analysis

Modal analysis is being carried out with same boundary condition for both conventional steel axle and for the composite axle. Modal Analysis being used in ANSYS V17 for measuring natural frequency. 6 modes of frequency being measured for both the Axle. By choosing Modal Analysis dynamic properties of the system in the frequency domain can be analyzed.

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	104.05
2	2.	104.1
3	3.	306.15
4	4.	306.26
5	5.	550.39
6	6.	602.82

Fig-5.5 Natural frequency of Convectional Steel Axle

Tabular Data		
	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	114.62
2	2.	114.71
3	3.	320.26
4	4.	320.35
5	5.	613.83
6	6.	613.91

Fig-5.6 Natural frequency of Hybrid Composite Axle

Both frequency is being compared and total deformation for that mode is being carried out. By using Modal analysis different mode shape results can be found for different natural frequency. From Above figure it can be seen that the frequency for the composite Axle is higher than the Conventional Steel Axle.

### 5.3 Thermal Analysis

Due to increase in temperature of steel property of material changes and due to that the deformation value and stress value got increase by higher rate. Thermal analysis being carried out to measure the directional deformation of both the conventional and composite axle at 100 degrees Celsius .100 degree being achieved by giving thermal condition to the body. Directional deformation for Composite Axle being measured separately for all the three bodies. Same boundary and loading condition is being used for the Analysis. In Composite assembly thermal condition is given to all the three bodies and the 4 bolts.

## Chapter 6

### Results

#### 6.1 Static Analysis Results

For the static analysis boundary condition is being applied as shown before. deformation and stress are being carried out for conventional steel axle. For the composite Axle assembly deformation and stress are being carried out for outer steel, inner steel and composite body.

Deformation in conventional steel Axle 1.268mm.

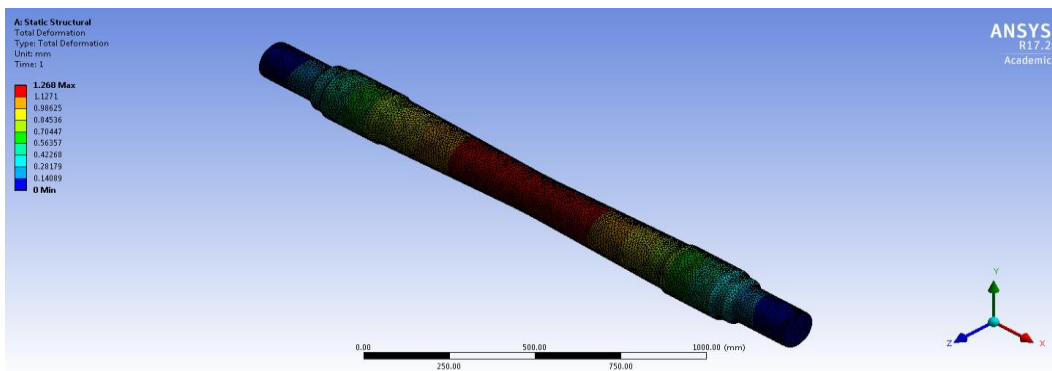


Fig-6.1 deformation in conventional steel

Stress in Conventional Steel Axle 191.38MPa.

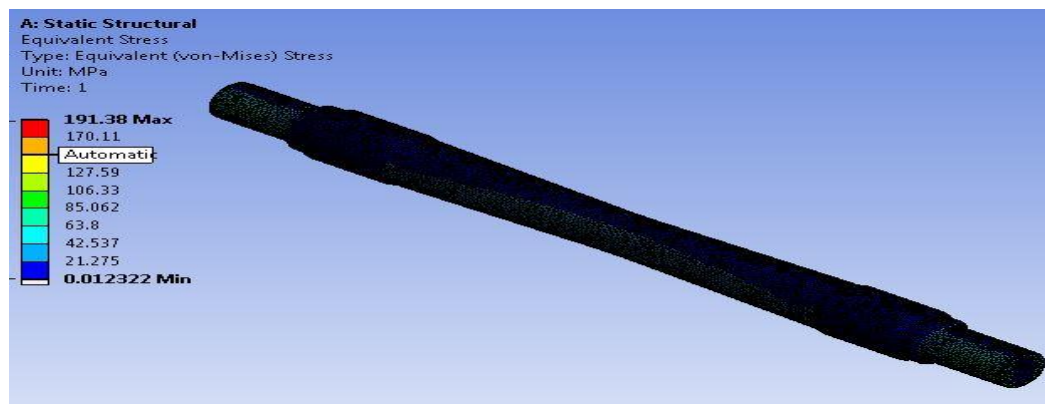


Fig-6.2 Stress in conventional steel

As shown in figure in conventional Axle shaft using conventional Alloy steel martial and by applying same boundary and loading condition the value of deformation and stress is 1.26mm and 191.38 MPa respectively.

Static analysis Result of Hybrid Metal-Composite Assembly.

Deformation in outer Steel Axle 1.1924mm.

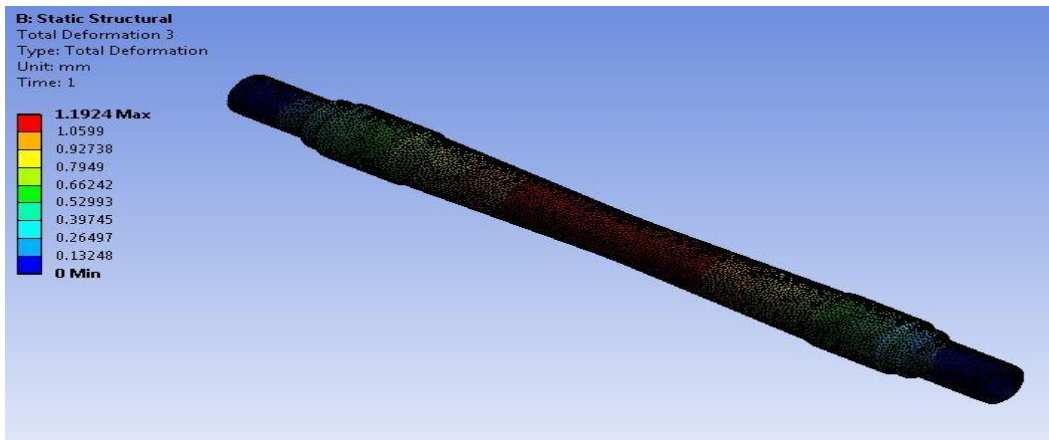


Fig-6.3 deformation in outer layer of steel

Deformation in composite Body 1.1913mm.

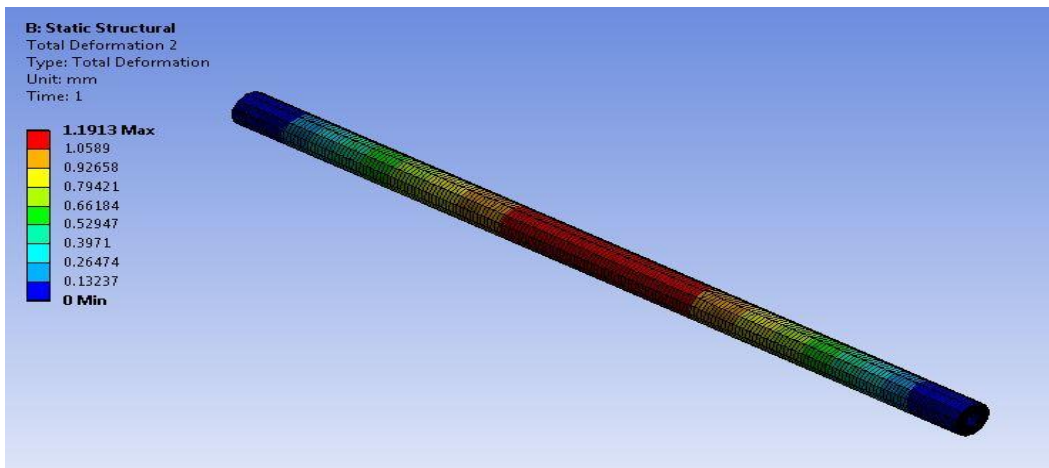


Fig-6.4 deformation in composite layer.

Deformation in inner steel Body 1.1899mm.

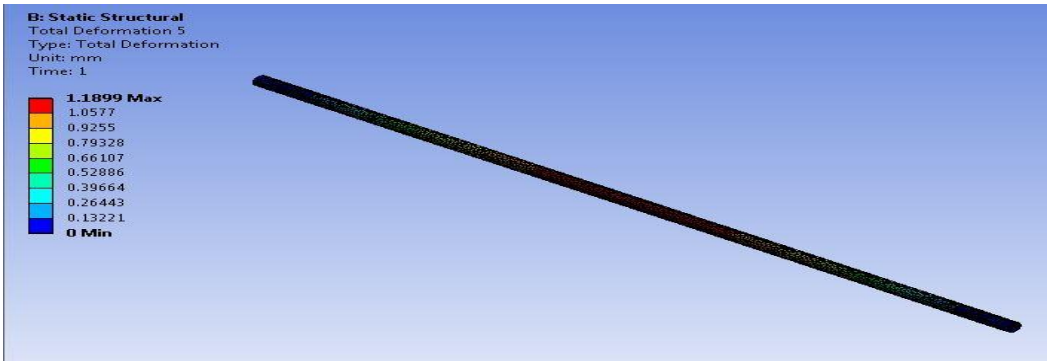


Fig-6.5 deformation in inner layer

Here by applying same boundary and loading condition deformation is carried out for each three layers of the Composite Axle assembly. For outer Steel Body the deformation value is 1.1924mm, for inner Steel Body the deformation is 1.18mm and for the Composite Body the deformation is 1.1913mm.

Stress in Outer Steel Body 162.08MPa.

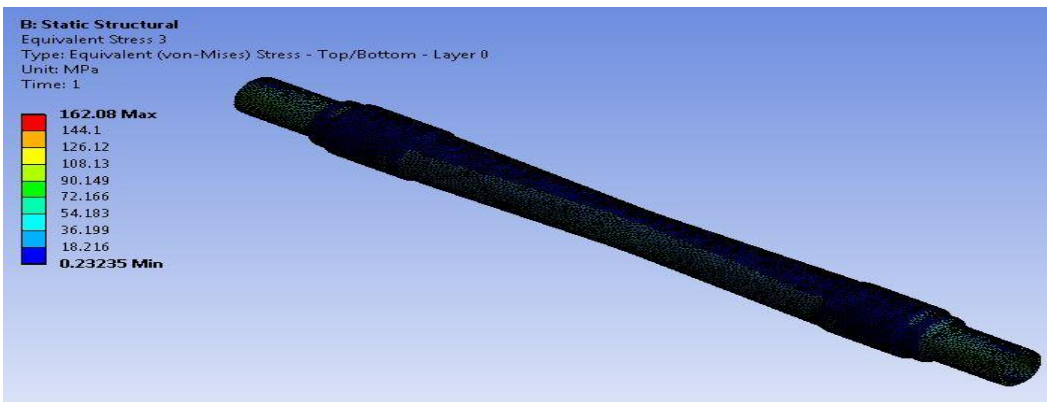


Fig-6.6 stress in outer steel Axle



Normal stress along the X-direction in Composite Body 61.149MPa.

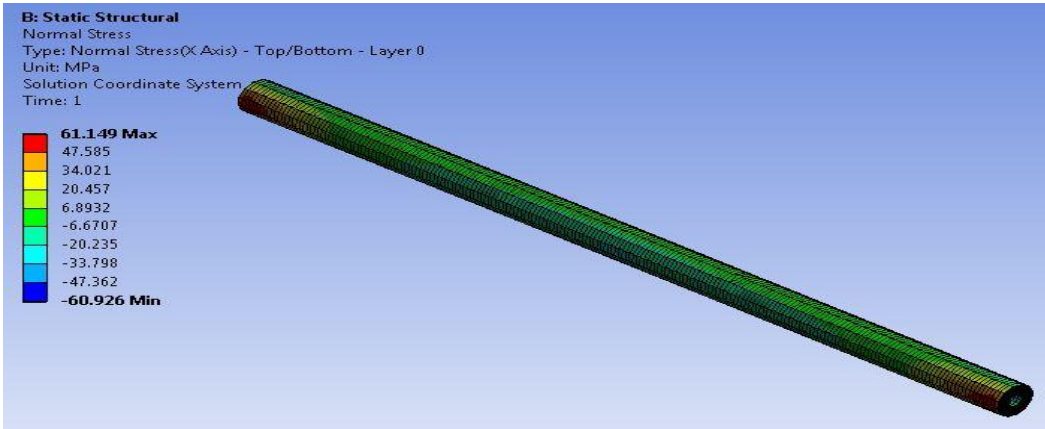


Fig-6.7 stress in composite Axle body

Stress in inner Steel Body 45.572MPa.

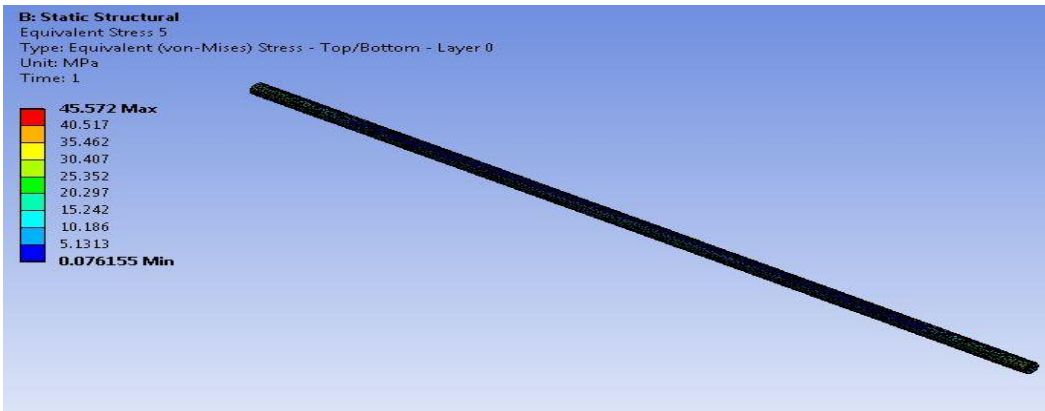


Fig-6.8 stress in inner Axle body

Here for the Hybrid Metal -Composite Axle Assembly the stress value for each Body is being measured. For the Outer Steel body, the stress value was 162.08MPa, For the inner steel Body the value of stress was 45.572MPa. And for the Composite Body the Normal Stress Along the X-axis is being measured which was around 61.149MPa.

Deformation in Steel Axle	Stress in Steel Axle
1.268mm	191.38mm

(a)

Safety Factor for Steel Axle
2.87

(b)

Table-6.1 Static Analysis Result of conventional Steel Axle (a), (b)

Deformation in Outer Steel Body	Deformation in Composite Body	Deformation in inner Steel Body
1.1924mm	1.1913mm	1.1899mm

(a)

Stress in outer steel Body	Stress in Composite Body	Stress in inner Steel Body
162.08MPa	61.149MPa	45.572MPa

(b)

Table-6.2 Static Analysis of Hybrid Metal-Composite Rail Axle (a), (b), (c)

Here from above table of comparison can conclude that deformation is being reduced in composite axle assembly compared to conventional steel axle. Value of the stress is being reduced drastically which makes the design safer. By using composite, load being distributed and taken by composite body which helped in making structure stronger and helped in reducing stress in outer body.

Safety Factor of Outer Body	Safety Factor of Composite Body	Safety Factor of inner Body
3.39	28.38	12

(c)

Here safety factor being calculated for conventional steel Axle and for all the three bodies of Metal-Composite Axle. The factor of safety for steel is being calculated by considering tensile strength by stress induced in the body.

$$FOS = \frac{\text{Tensile strength}}{\text{stress}}$$

In metal-composite Axle for all the three bodies factor of safety is being carried out. Calculation of factor of safety for outer and inner steel axle had same procedure as done in conventional steel axle but for the composite middle body the safety factor is being calculated by considering fiber strength and fiber concentration to normal stress along the x-direction.

$$FOS(\text{composite}) = \frac{(\text{tensile strength of fiber}) * (\text{fiber concentration})}{\text{Normal stress along the } x - \text{direction}}$$

minimum factor of safety taken into consideration and it got increased by 16% for the Composite Axle Assembly. Because of higher factor of safety design is safer than the conventional steel axle.

## 6.2 Frequency Analysis

For every natural frequency there is a corresponding vibration mode shape. Most of mode shapes can generally be described as being an axial mode, torsion mode, bending mode, or general mode. Modal analysis was carried out on Rail Axle. 6 modes have been taken into consideration for both metal and composite axle. For each six modes total deformation has been carried out. By comparison of frequency of steel and composite Axle can conclude that frequency of composite axle is higher than the metal axle.

	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	104.05
2	2.	104.1
3	3.	306.15
4	4.	306.26
5	5.	550.39
6	6.	602.82

(a)

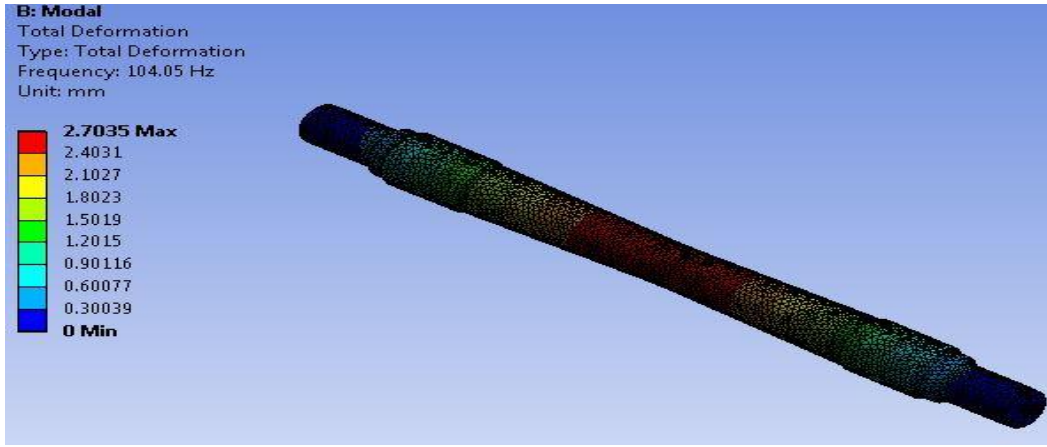
Tabular Data		
	Mode	<input checked="" type="checkbox"/> Frequency [Hz]
1	1.	114.62
2	2.	114.71
3	3.	320.26
4	4.	320.35
5	5.	613.83
6	6.	613.91

(b)

Table-6.3 frequency table for both (a)conventional steel Axle(b)Composite Axle

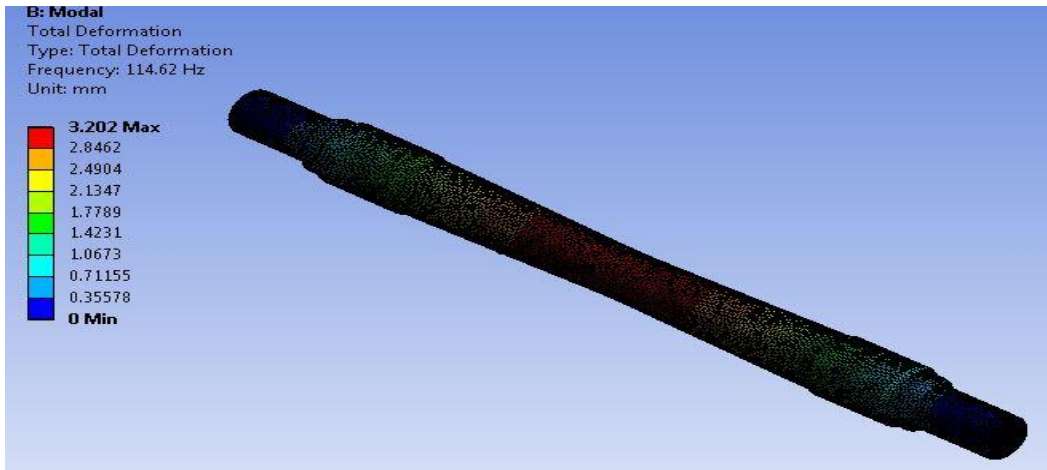
Three bodies of Metal-composite Axle were considered as one body for the Modal analysis and the frequency of the three bodies as one body being carried out for 6 Modes in Metal-Composite Axle.

Mode-1 Frequency Analysis Result for Conventional Steel Axle and Composite Axle



Mode-1 Frequency(Hz)	Total Deformation(mm)
104.05Hz	2.7035mm

(a)



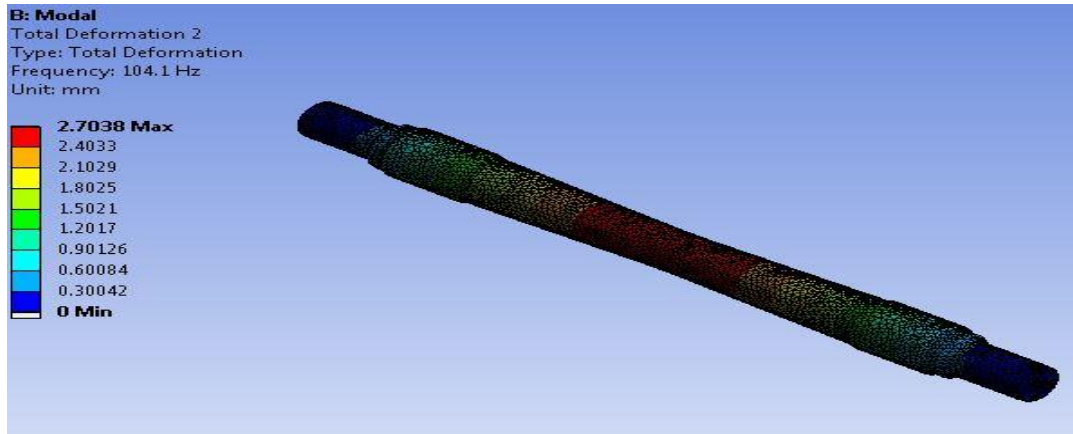
Mode-1 Frequency(Hz)	Total Deformation(mm)
114.62Hz	3.202mm

(b)

Fig-6.9 (a) Mode-1 frequency Analysis of Conventional Steel Axle

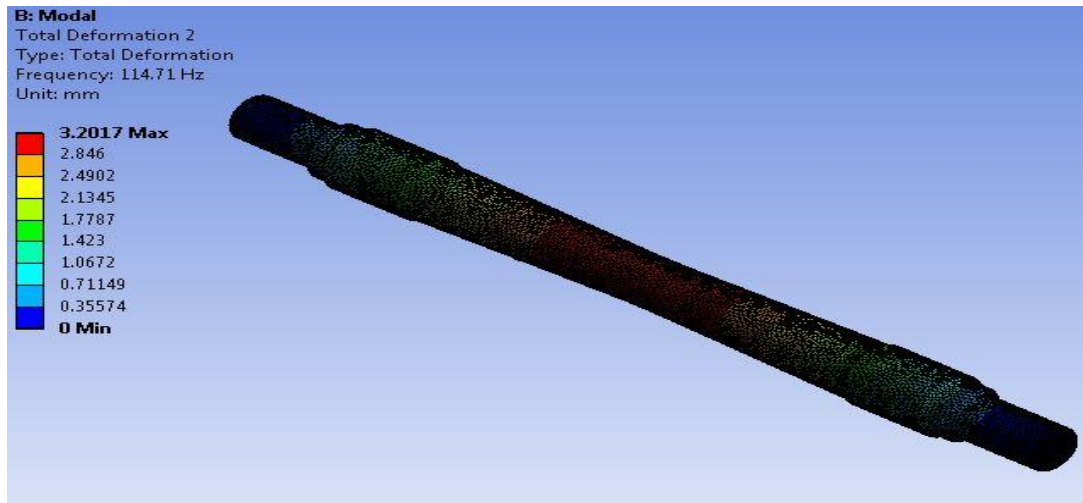
Fig-6.9 (b) Mode-1 frequency Analysis of composite Axle Assembly

Mode-2 Frequency Analysis Result for Conventional Steel Axle and Composite Axle



Mode-2 Frequency(Hz)	Total Deformation(mm)
104.1Hz	2.7038mm

(a)



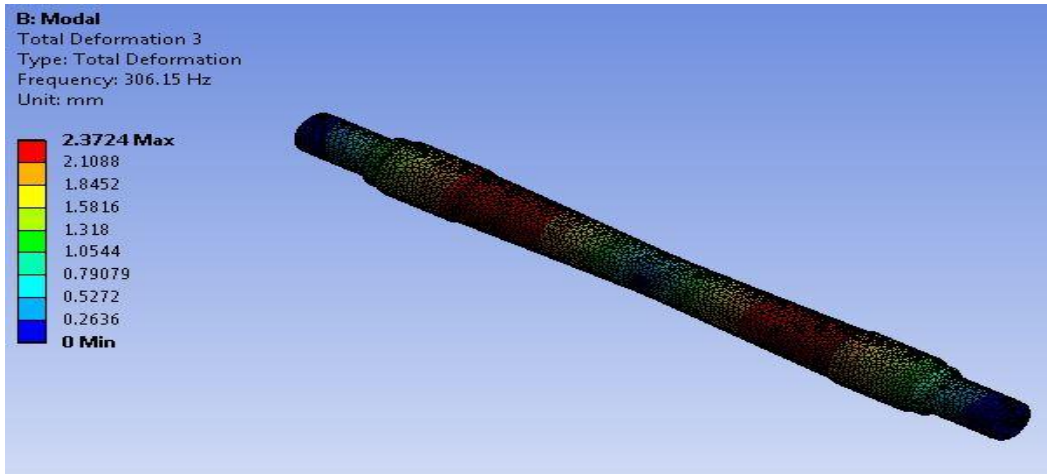
Mode-2 Frequency(Hz)	Total Deformation(mm)
114.71Hz	3.2017mm

(b)

Fig-6.10(a) Mode-2 frequency Analysis of Conventional Steel Axle

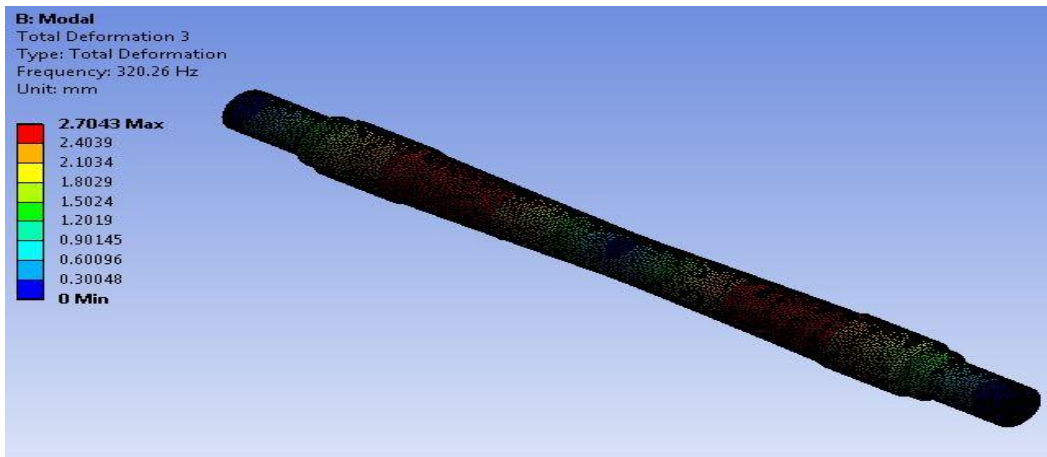
Fig-6.10(b) Mode-2 frequency Analysis of composite Axle Assembly

Mode-3 Frequency Analysis Result for Conventional Steel Axle and Composite Axle



Mode-3 Frequency(Hz)	Total Deformation(mm)
306.15Hz	2.3724mm

(a)

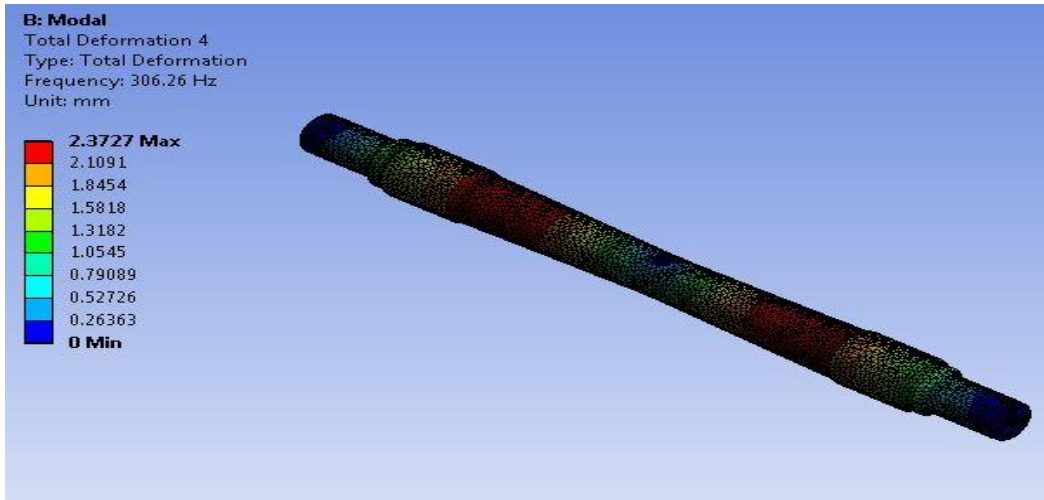


Mode-3 Frequency(Hz)	Total Deformation(mm)
320.26Hz	2.7043mm

Fig-6.11(a) Mode-3 frequency Analysis of Conventional Steel Axle

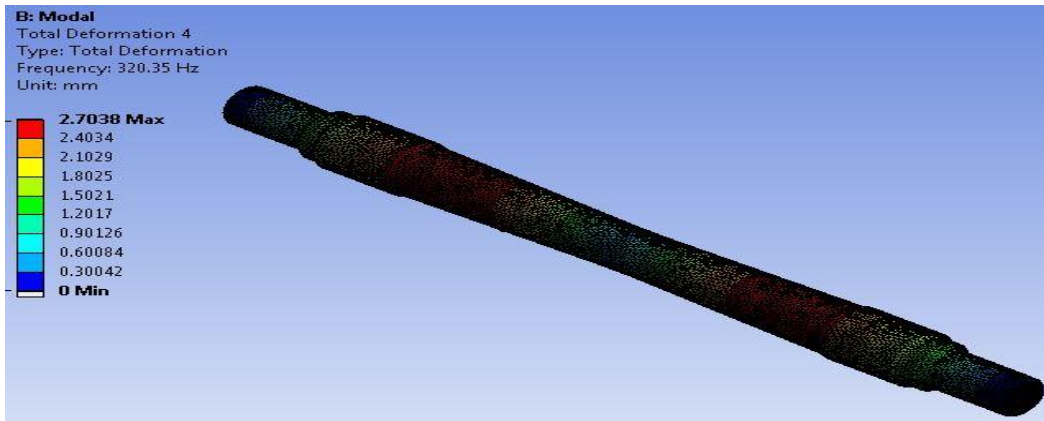
Fig-6.11(b) Mode-3 frequency Analysis of composite Axle Assembly

Mode-4 Frequency Analysis Result for Conventional Steel Axle and Composite Axle



Mode-4 Frequency(Hz)	Total Deformation(mm)
306.26Hz	2.3727mm

(a)



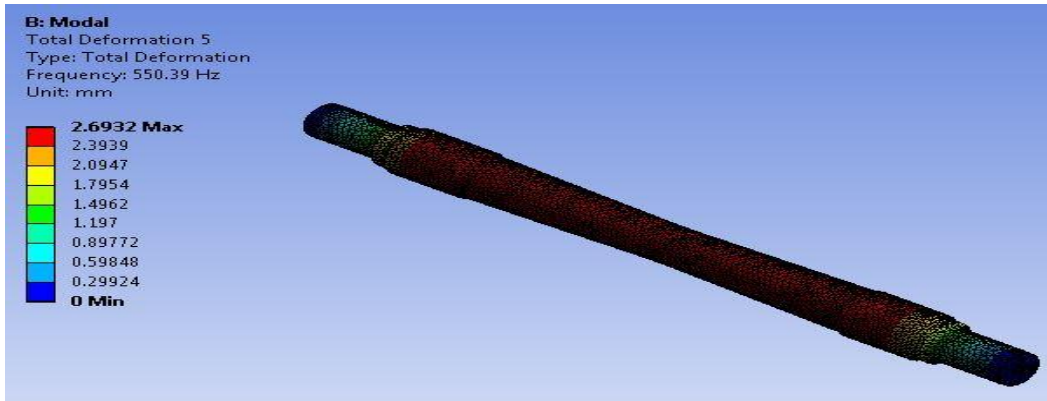
Mode-4 Frequency(Hz)	Total Deformation(mm)
320.35Hz	2.7038mm

Fig-6.12(a) Mode-4 frequency Analysis of Conventional Steel Axle

Fig-6.12(b) Mode-4 frequency Analysis of composite Axle Assembly

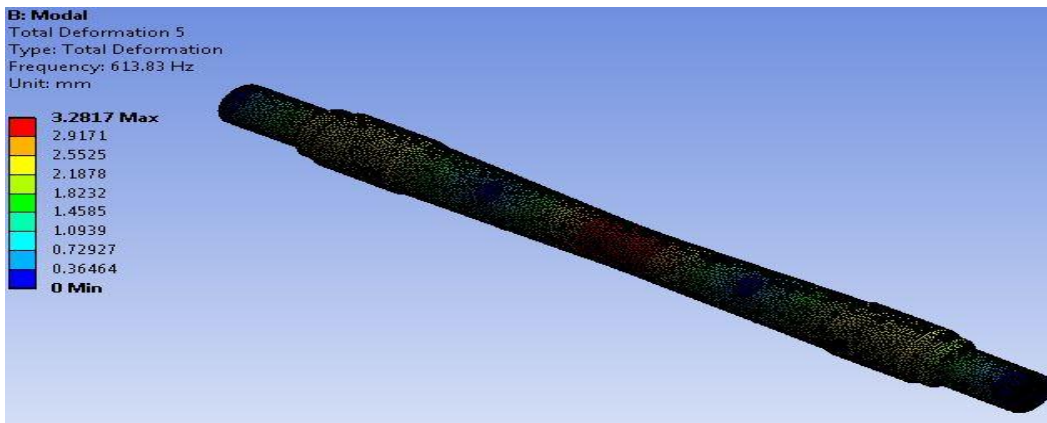


Mode-5 Frequency Analysis Result for Conventional Steel Axle and Composite Axle



Mode-5 Frequency(Hz)	Total Deformation(mm)
551.39Hz	2.6932mm

(a)



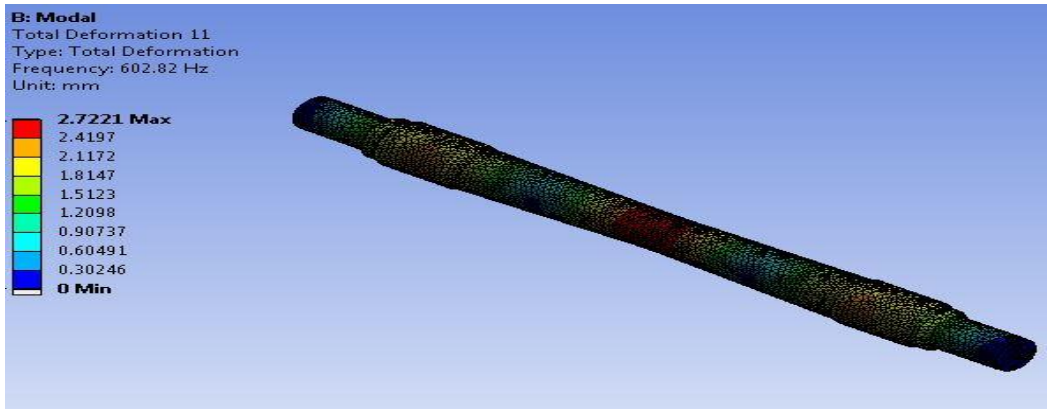
Mode-5 Frequency(Hz)	Total Deformation(mm)
613.83Hz	3.2817mm

(b)

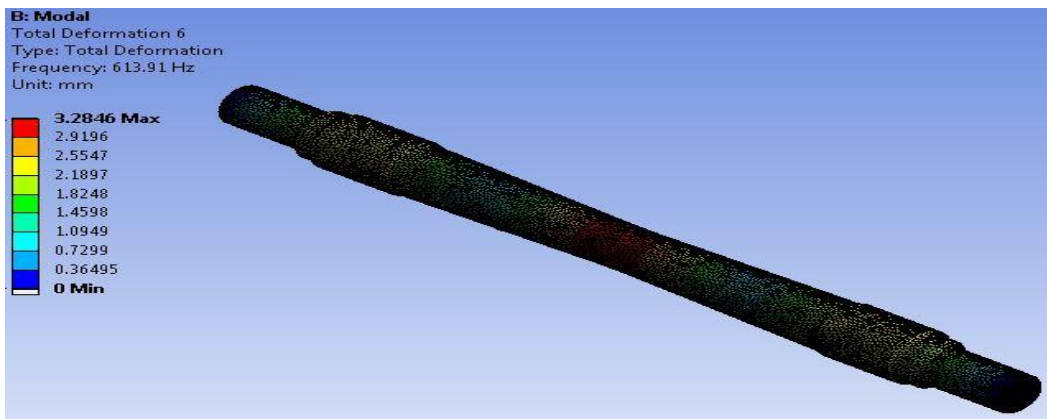
Fig-6.13(a) Mode-5 frequency Analysis of Conventional Steel Axle

Fig-6.13(b) Mode-5 frequency Analysis of composite Axle Assembly

Mode-6 Frequency Analysis Result for Convention Steel Axle and Composite Axle



Mode-6 Frequency(Hz)	Total Deformation(mm)
602.82Hz	2.7221mm



Mode-6 Frequency(Hz)	Total Deformation(mm)
613.91Hz	3.2846mm

Fig-6.14(a) Mode-6 frequency Analysis of Conventional Steel Axle

Fig-6.14(b) Mode-6 frequency Analysis of composite Axle Assembly

Comparison of Frequency and deformation

Frequency(Hz)	Deformation in Steel Axle(mm)
104.05Hz	2.7035mm
104.01Hz	2.7038mm
306.15Hz	2.3724mm
306.26Hz	2.3727mm
550.39Hz	2.6932mm
602.02Hz	2.7221mm

(a)

Frequency(Hz)	Deformation in Composite Axle(mm)
114.62Hz	3.202mm
114.70Hz	3.2017mm
320.26Hz	2.7043mm
320.35Hz	2.7038mm
613.83Hz	3.2817mm
613.91Hz	3.2846mm

(b)

Table-6.4 (a), (b) comparison of Frequency and deformation of conventional Axle and Composite Axle

Natural frequency can be measured by spring constant to mass ratio so by that definition less the mass of the body higher the frequency of that body. here from above comparison table can be seen that for all 6 modes different natural frequency and for all the natural frequency there is deformation is being carried out. From above definition and by comparison natural frequency is higher in composite Axle Assembly than the conventional steel axle. For all 6 modes the deformation in composite Axle Assembly is higher than the conventional steel axle because of higher frequency in composite Axle Assembly.

### 6.3 Thermal Analysis

Thermal analysis is being carried out for both metal and composite Axle. same boundary and loading condition applied on the both conventional and Composite Axle assembly. Thermal condition applied on both metal and composite Axle to 100 degrees. Because of the thermal condition body temperature got increased from 22 degrees to 100 degrees. Directional deformation in x-direction measures for the conventional steel axle and for each body of the composite Axle assembly.

Direction Deformation in Conventional Steel Axle is 0.23958mm.

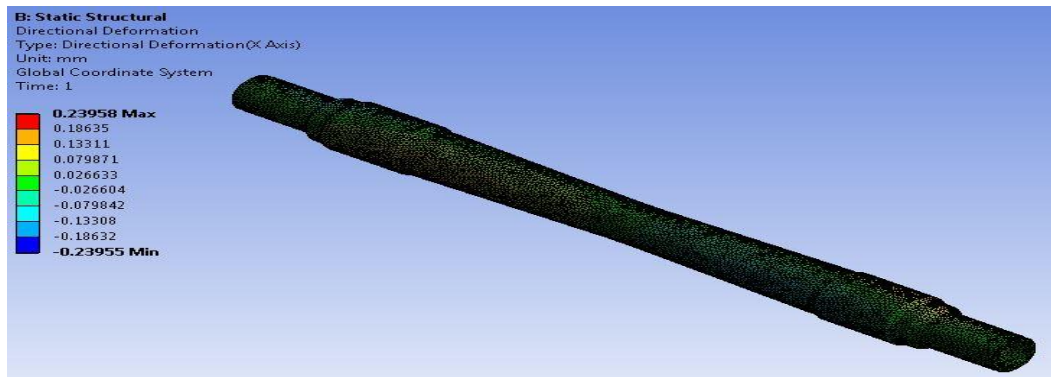


Fig-6.15 Directional deformation in metal Axle

Directional Deformation in Outer Steel Body is 0.23508mm

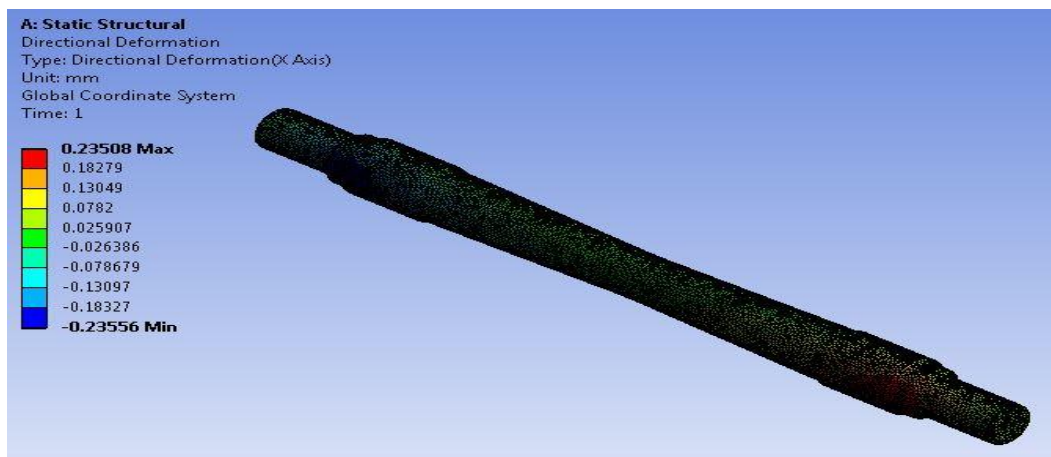


Fig-6.16 directional deformation for outer metal Axle

Directional Deformation in Composite Body is 0.1695mm

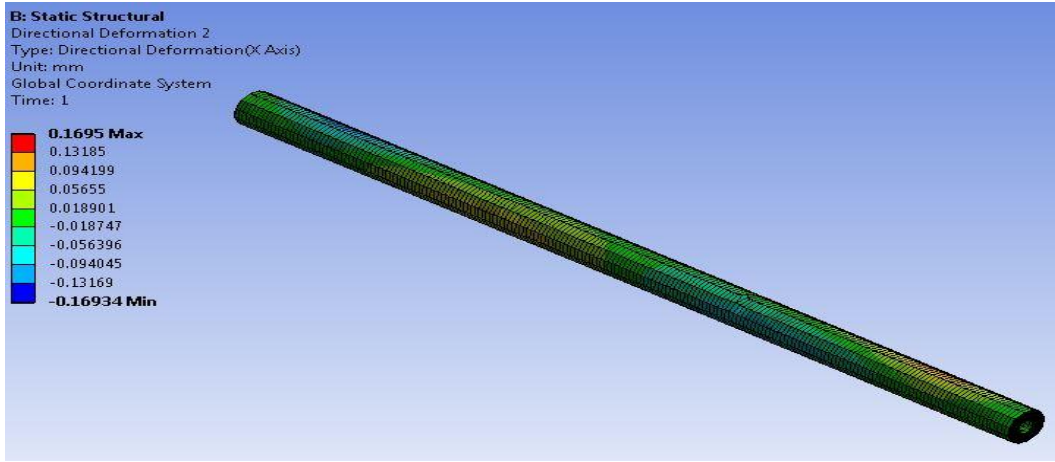


Fig-6.17 Directional Deformation in composite Axle body

Directional Deformation in inner steel Body is 0.086396mm

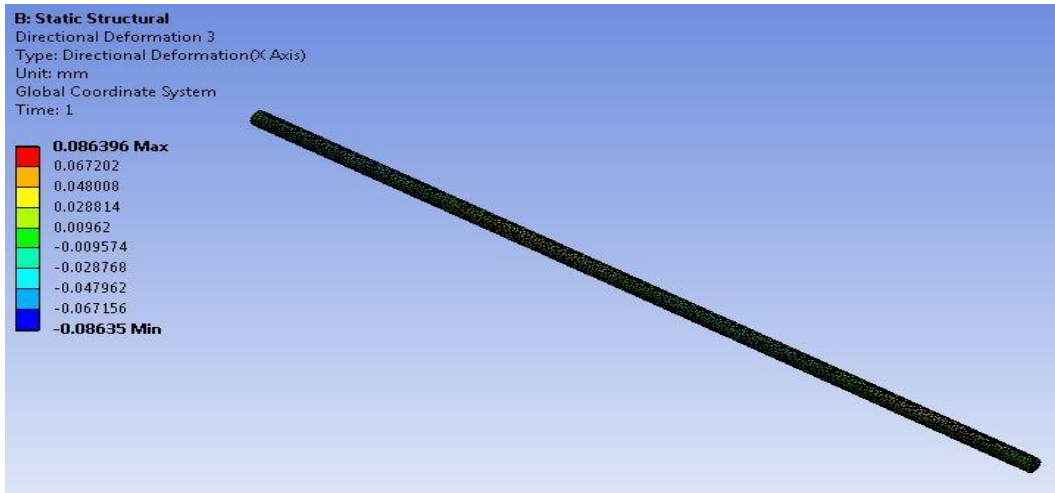


Fig-6.18 Directional Deformation in inner Steel Axle

### Result Comparison of Thermal Analysis

Deformation in Conventional Steel Axle	Deformation in Outer Steel Body	Deformation in Composite Body	Deformation in inner Steel Body
0.23958mm	0.23508mm	0.1695mm	0.086396mm

Table-6.5 Comparison of Directional Deformation in thermal Analysis

Here From above table we can see that by applying thermal condition of 100 degree to the rail axle body directional deformation changes. By comparison of deformation of conventional and Composite Axle Assembly the deformation in conventional steel axle is little higher than composite assembly axle as shown in table.

#### 6.4 Composite ACP Post Analysis result.

ACP Post Analysis also being carried out to measure the value of deformation and stress in Composite Axle Body. Value of deformation and stress by post analysis is being compared with the value of static analysis result.

Deformation value in post composite body measured 1.1913mm.

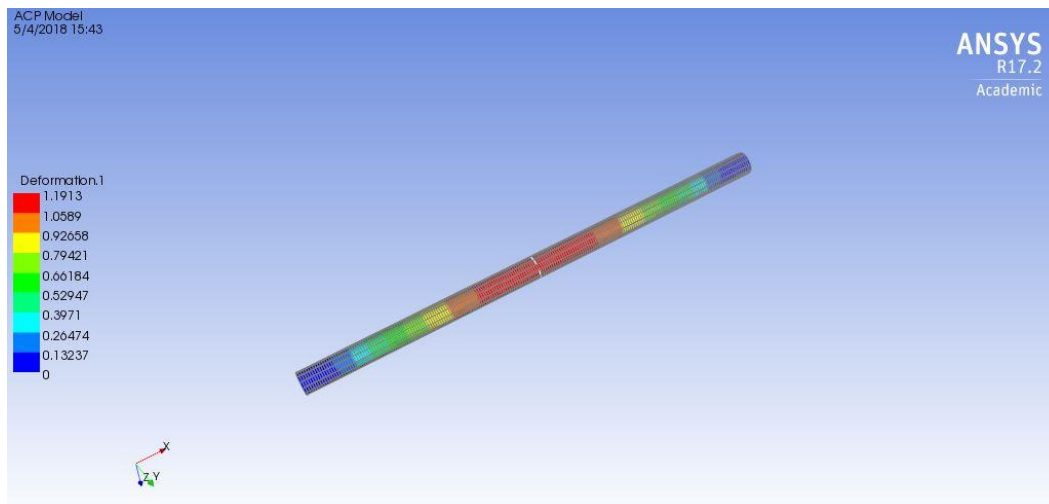


Fig-6.19 Deformation in composite body post Analysis

Stress value in composite body is being measured 58MPa.

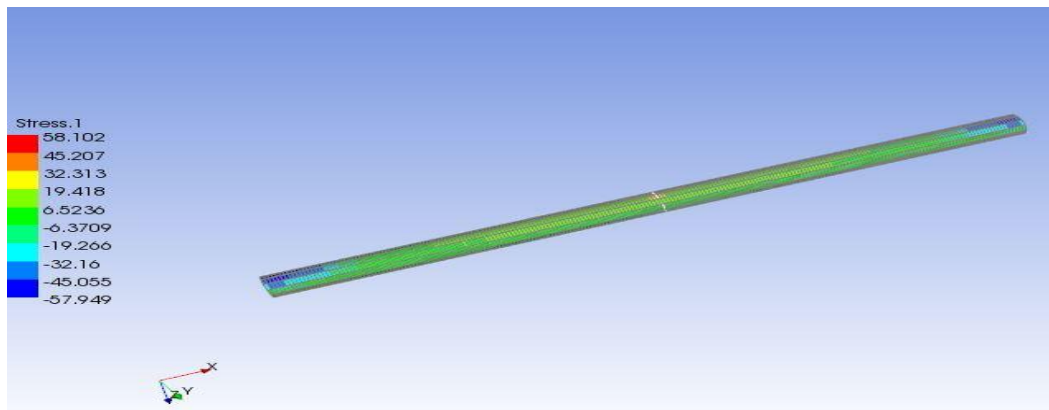


Fig-6.20 stress in composite body post Analysis



## Chapter 7

### Analytical Calculation

Conventional forces that used for the dimensioning of the axle are the ones represented in loading condition. Their analytical expressions are derived imposing the static balance of the wheelset, under nominal accelerations acting on the center of gravity suspended masses of the vehicle, the nominal acceleration is related to the typology of axle, to operational condition and the typology of train.

Considering as an example a trailer axle of non-tilting vehicle, the expressions for forces P acting on journals derive from an estimation of lateral acceleration equal to 0.15g, computed simultaneously with an increment on both journals of 25% of half the static load  $m1g$  acting on them.

Here,

- Weight(m)= 13,960kg
- Height(h)=1425mm
- Distance from center(b)=1000mm
- Center distance from wheel(S)=750mm
- Force on wheel1(Y1) =47,932N
- Force on wheel2(Y2) =23,966N
- Load(P)=(0.625+0.0875\*h/b) mg  
=96879N
- Load(Q)=[P(b+s)-P(Y1-Y2) R-Fi(2s-yi)]/2s  
=101967N

For tilting vehicles, the procedure to identify the conventional loads is the same one, but this load is increased, in order to consider the effect of higher cant deficiency causing larger unbalance between the loads acting on journals.

The necessary forces necessary for the calculation of the bending moment  $M_x$  can be derived from the static balance equations of the wheelset.  $F_i$  are the forces exerted by the masses of the unsprung elements located between the two wheels, typically brake disks, or the mass of the axle itself.[4]

## CONCLUSION

Composite material has low density compared to conventional steel material thus by composite axle is lighter than the conventional steel Axle. In this case the by using the composite material of 30mm thickness weight of axle is being reduced to 30% due to that reduction in energy can be achieved.

Deformation and stress analysis suggest that for conventional steel axle deformation and stress is higher compared to the Metal-composite Axle.

Rail Axle are important part of the rail system, so it is important to insure the safety of the passenger and vehicle. Composite has higher strength than alloy steel material and stress induced in the part is lower because of that safety factor got increased by 16% in metal-composite Rail Axle.

At 100 degree Celsius temperature the deformation in metal composite Axle is lower than the Conventional Steel Axle.

## FUTURE WORK

- By using same loading condition and changing in boundary condition dynamic analysis can be performed.
- As Rail Axle experiencing high number of loading cycles, fatigue analysis can be done, and life cycle can be found for the Axle.
- By changing material and fiber concentration better results can be achieved.
- Rail Car body and parts can be made from composites to reduce the overall weight of the vehicle.

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### Biographical Information

Samip Nikulbhai shah was born 12<sup>th</sup> of August 1995. He received his Bachelor of Engineering in Mechanical engineering from the Gujrat Technical University, India 2016. While there, he conducted research on Design of Rotational molding machine. He enrolled into Master of science in Mechanical and Aerospace Engineering program at the University of Texas At Arlington in Fall 2016. From August 2017, He started working under the guidance of Dr. Andrey Beyle, mostly working on the thesis related to Composite materials. He is proficient in ANSYS Workbench, ANSYS Composite Prepost, Solid works, and Auto-Cad. He has a certification By PTC in Creo and certification in Solidworks and Ansys. He graduated in May 2018.