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# STRUCTURAL AND MODEL ANALYSIS OF A COMPOSITE MATERIAL DIFFERENTIAL GEARBOX ASSEMBLY

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## ABSTRACT

The main aim of the this project is to study the structural and dynamic behaviour of the gears in the differential gearbox assembly made up of the different composite material as compared to the conventional metallic materials as the Composite materials provide adequate strength with weight reduction and they have emerged as a better alternative for replacing metallic gears. The composites consider were the Aluminium Silicon carbide composite In this work an attempt has been made to replace the metallic gears of steel alloy with the composites For this purpose an parametric model of the differential gearbox was prepared according to the dimension calculated by the design equation on the creo 3.0 cad software and Ansys 14.0 is used the analysis tool to detrmine the total deformation , von misses stress and the natural frequencies at various mode for the different materials relative to each other when the gears in the gearbox transmit power at different speeds i.e-2400 rpm, 3000 rpm and 4000 rpm. The analysis results shows that the Composite gears offer improved properties over the conventional metallic gear and these can be used as better alternative for replacing metallic gears for the differential gearbox apllication.

**KEYWORDS**: Differential , Composites , Aluminium silicon carbide , CREO , ANSYS.

## INTRODUCTION

In automobiles and other wheeled vehicles, the differential allows each of the driving road wheels to rotate at different speeds, while for most vehicles supplying equal torque to each of them. A vehicle's wheels rotate at different speeds, mainly when turning corners. The differential is designed to drive a pair of wheels with equal torque while allowing them to rotate at different speeds. In vehicles without a differential, such as karts, both driving wheels are forced to rotate at the same speed, usually on a common axle driven by a simple chaindrive mechanism. When cornering, the inner wheel needs to travel a shorter distance than the outer wheel, so with no differential, the result is the inner wheel spinning and/or the outer wheel dragging, and this results in difficult and unpredictable handling, damage to tires and roads, and strain on (or possible failure of) the entire drive train. The Differential Box transmits mechanical energy from a prime mover to an output device. It also changes the speed, direction or torque of mechanical energy. Differential gearbox is used when high speed, large power transmission where noise abatement is important. Some limitations in existing Differential gear box are as follows:

- It has poor weight to strength ratio so high power loss.
- Metallic parts lead to corrosion so need to properly shielded.
- More wear in between the gears so required proper lubrication.
- Due to heaviness of Differential gear box, it needs to be strongly mounted thus increasing more weight and decreasing fuel efficiency.
- Its cost is more due to increasing cost of metals.

In this present work the analysis is conducted on the different composite material , to verify the best material for the gears in the gear box at higher speeds byanalyzing stress, displacement and also by considering weight reduction. For this purpose the modelling of thetransmittiing power gear assembly on creo 3.0 were made and fem based structural behaviour were carried out on the ansys 14.0 analysis tool.

## LITERATURE REVIEW

F. K. Choy et al. [1], provided a comparison and benchmarking of experimental results obtained from a damaged gear transmission system with those generated from a numerical model. conclusions for this study as follows: 1. A study of the dynamic changes in a gear transmission system due to (a) no gear tooth damage, (b) single gear tooth damage, (c) two consecutive gear teeth damage, and (d) three consecutive gear teeth damage is successfully conducted. 2. The vibration signature analysis using a joint time-frequency procedure, the Wigner-Ville distribution (WVD), seems to be quite effective in identifying single and multiple teeth damage in a gear transmission.

Erwin V. Zaretsky et al. [2], developed two computational models to determine the fatigue life and reliability of a commercial turboprop gearbox are compared with each other and with field data. These models are (1) the Monte Carlo simulation of randomly selected lives of individual bearings and gears comprising the system and (2) the two-parameter Weibull distribution function for bearings and gears comprising the system using strict-series system reliability to combine the calculated individual component lives in the gearbox. The Monte Carlo simulation consisted of the virtual testing of 744,450 gearboxes. These results were compared with each other and with two sets of field data obtained from 64 gearboxes that were first-run to Removal for cause, refurbished, placed back in service, and second run until removal for cause

Lei Wang et al. [3], researched the theory of hybrid-driving differential gear trains and carrying out experiment many times on the designed test-bench finally, this article obtains two conclusions: (1)This paper designed a test-bench of hybrid-driving two degree of freedom differential gear trains, and its mechanical properties are reliable and stable, low noise, smooth running. Generally speaking, it is able to achieve the anticipated purpose. (2)This test-bench uses PLC component to enable system control more precise, easy operation, debugging easy, gathering the data accurately and conveniently. It provides a good experimental platform for the basic theory research in the future.

C. Fetvaci [4], developed mathematical models of external and internal involutes spur gears according to the generation mechanism with a gear-type gear shaper. By applying the equations of the profile of the cutter, the principles of coordinate transformation, the theory of differential geometry, and the theory of gearing, the mathematical models of the tooth profile including the fillets, bottom lands, and working surfaces, have been given. To investigate the shape of the generated tooth root fillet surfaces, the mathematical model of trochoidal envelope of cutter tip has been derived. The cutter tip traces epitrochoidal curve in external tooth generation and hypotrochoidal curve in internal tooth generation.

B. Venkatesh et al. [5], obtained Von-Misses stress by theoretical and ANSYS software for Aluminum alloy, values obtained from ANSYS are less than that of the theoretical calculations. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions, which are safe and less than the other materials like steel. Aluminum alloy reduces the weight up to 5567% compared to the other materials. Aluminum is having unique property (i.e. corrosive resistance), good surface finishing, hence it permits excellent silent operation. Weight reduction is a very important criterion, in order to minimize the unbalanced forces setup in the marine gear system, there by improves the system performance.

By the above exhaustive literature review, we can say that the gear needs to be redesigned providing energy saving by weight reduction, providing internal damping, reducing Lubrication requirement without increasing cost. Such a scope is provided by application of composite material providing solution to other existing problems in current gears available. Therefore this work is concerned with the replacement of existing metallic gear with composite material gear in order to make it lighter and increasing the efficiency of mechanical machines with the aid of computer aided engineering.

## CALCULATIONS OF A CROWN GEAR AND PINION

The main aim of the project is to verify the best material for the gears in the gear box at higher speeds by analyzing stress, displacement and also by considering weight reduction focus on the mechanical design and contact analysis on assembly of gears in gear box when they transmit power at different speeds at 2400 rpm, 5000 rpm and 6400 rpm. Analysis is also conducted by varying the different composites materials for gears. Differential gear is modeled in CREO 3.0 . The ANSYS 14.0 fem software were used as the analysis tool for determing the structural behaviour of various composites under the given loading conditions.

**Specifications Of Used Heavy Vehicle**

1. Truck model used: - Ashok Leyland 2516 M
2. Engine :- 6 Cylinder Turbocharged Intercooled
3. Maxiumum Power :- 165 HP @ 2400 rpm
4. Maximum Torque :- 550 kgm @ 1600 rpm
5. Maximum Speed :- 74.5 Kmph

ASSUMPTIONS:

- Gear profile: - 20 degree full depth involute profile (standard)
- pressure angle (α):- 20 degree
- bevel gear arrangement = 90 degree
- Pitch cone Angle (φ) = 45°
- Back cone Angle (β) = 45°
- Module (M) = 10
- Number of teeth on gear = Zg =50
- Number of teeth on pinion = Zp = 8

Velocity Ratio (V.R)

V.R=TG/TP= DG/DP=NP/NG
V.R=TG/TP=50/8=6.25
V.R=NP/NG
6.25=2400/NG
NG=384rpm

Minimum no. of teeth on pinion (Zp)

For satisfactory operation of bevel gears the number of teeth in the pinion must not be less than

where v.r=velocity ratio $$\frac{48}{\sqrt{1+(vr)^2}},$$

$$=\frac{48}{\sqrt{1+(6.25)^2}}=7.5$$

hence the assumed value of the pinion is in safe condition

Pitch circle diameter (D)
Pitch circle diameter for the gear (Dg) = M*Zg = 10* 50 = 500 mm
Pitch circle diameter for the pinion (Dp) = M*Zp = 10 * 8 = 80 mm

Pitch angle (θ)
Since the shafts are at the right angles , the pitch angle were given as:
For the pinion = θp1=tan-1(1/v.r) =tan-1(1/6.25) =9.0

Pitch angle of gear θp2=90°- 9=81

formative number of teeth (Te)

for the pinion Zep= Zpsecθp1=8sec9 =8
for the gear = Zeg=Zgsecθp2=50sec81 =319.622

1. Pitch Cone Distance (AO):

$$AO = \sqrt{\left(\frac{D1}{2}\right)^2 + \left(\frac{D2}{2}\right)^2}$$

AO = 250 mm

2. Face Width (b):

$$\left.\begin{array}{l} b = \frac{AO}{3} \\ \text{or} \\ b = 10m \end{array}\right\} \text{whichever is lesser}$$

b = 126.5/3 = 83.33 mm and b = 10 *10 = 100 mm ∴ b = 85mm (approx)

## CALCULATION OF SUN GEAR AND PLANET PINION

1. Pitch circle diameter (D)

Diameter of sungear =Dg=150mm
Diameter of pinion =Dp=70mm

2. Number of tooth on gear

Number of teeth on gear = Zg =18
Number of teeth on pinion = Zp = 15

D=Dg+Dp=220
T= Zg+ Zp = 33

3. Module = M=D/T=220/33=6.66=7(according to stds)

4. Velocity Ratio

V.R = Zg/Zp = DG/DP=NP/NG
V.R = Dg/Dp =150/70=2.142
V.R=NP/NG
2.142=2400/NG
NG=1120.448rpm

5. Pitch angle

Since the shafts are at right angles therefore pitch angle
for the pinion = θp1=tan-1(1/v.r)
=tan-1(1/2.142)
=25.025

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Pitch angle of gear θp2=90°-25.025=64.974

6. Formative Number Of Teeeth

For the pinion = Zep = Zp secθp1=15sec25.025 =16.554
For the gear = Zeg = Zg secθp2= 8sec64.974 =42.55

7. Pitch Cone Distance (AO):

$$AO = \sqrt{\left(\frac{D1}{2}\right)^2 + \left(\frac{D2}{2}\right)^2}$$

AO = 82.7mm

8. Face Width (b): 82.7/3 = 27.5 mm

## SOLID MODELING OF BEVEL GEAR

During the gear design, the main parameters that would describe the designed gear such as module, pressure angle, and number of teeth could be used as the parameters to define the gear. CREO has model the involute profile helical gear geometry perfectly. For Bevel gear in CREO relation and equation modelling is used. Relation is used to express dependencies among the dimension needed for defining the basic parameters on which the model is depends. The gears with different geometric properties can be modelled from the existing model by just varying the few parameters on which it depends.

In this work, module, pressure angle, numbers of teeth and the helix angle of both the gears are taken as input parameters. Pro/Engineer uses these parameters, in combination with its features to generate the geometry of the Bevel gear and all essential information to create the model. By using the relational equation in Pro/ Engineer, the accurate three dimensional Bevel gear models are developed. The assembly of gear is done by consider the left and right helical gear. Then the file is saved as IGES format. The proportions of gear obtained from theoretical analysis have been used for preparing geometric model of gear.

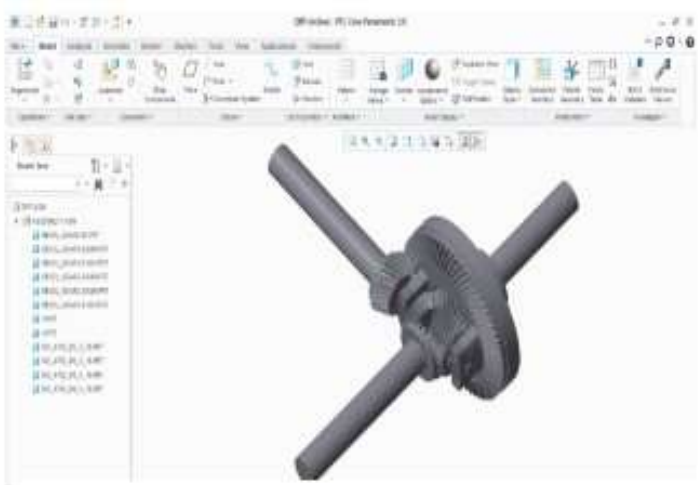

**figure 1 : solid model of differential in creo 3.0**

***figure 1 : solid model of differential in creo 3.0***

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## FEM ANALYSIS OF THE GEAR

Finite element analysis is a computer based analysis technique for calculating the strength and behaviour of structures during the given boundary condition. In the FEM the structure is represented as finite elements and are joined at particular points which are called as nodesFinite element analysis is the numerical solution of the behavior mechanical components that are acquired by discretizing the mechanical components into a small finite number of building blocks (known as elements) and by analyzing those mechanical components for their acceptability and reliability. Finite Element Method is the easy technique as compared to the theoretical methods to find out the stress developed in a pair of gears. Models for numerical analysis have been prepared in CREO 3.0 and these have been imported into ANSYS as IGES files for further analysis. The proportions of gear obtained from theoretical analysis have been used for preparing geometric model of gear. The condition for analysis has been assumed as static.

## MESHING OF GEAR ASSEMLY

For the analysis of the gear assembly to study its structural behaviour at different loadinf condition an 3 – D model of the gear assembly were made in creo 3.0 and were imported in ansys analysis software as an iges file format . After importing the model in ansys the appropriate material were assingned to the model and then meshing were done in ansys which divide the whole body into small tethydral element connected by nodes . the tottal node and element for the two were given in the table below :

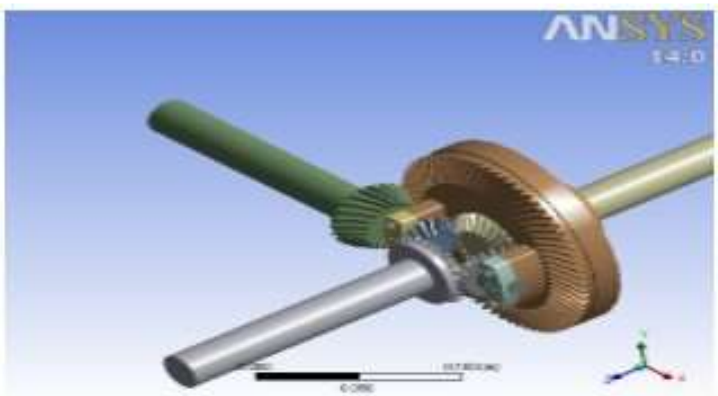


***Figure 2:Solid modelled of differential gearbox in ansys***

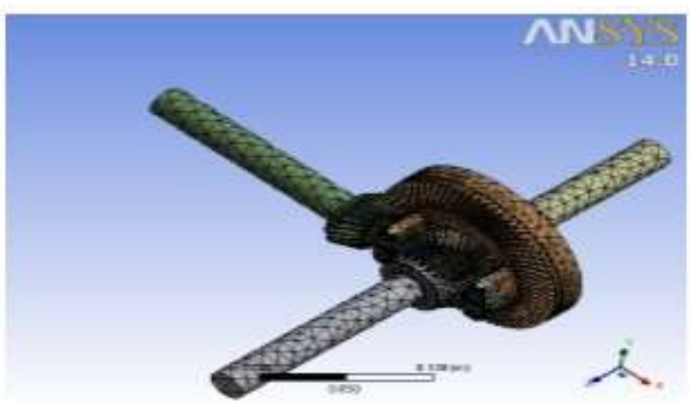


***Figure 3:Meshing of differential gearbox in ansys***

## MATERIAL PROPERTIES

The main aim of the project is to focus on the mechanical design and contact analysis on assembly of gears in gear box when they transmit power at different speeds at 2400 rpm, 5000 rpm and 6400 rpm. Analysis is also conducted by varying the different materials for gears, The analysis is conducted to verify the best material for the gears in the gear box at higher speeds by analyzing stress, displacement and also by considering weight reduction. Design calculations are done on the differential of Ashokleyland 2516M by varying materials and speeds. Differential gear is modeled in CREO 3.0 . The ANSYS 14.0 fem software were used as the analysis tool for determing the structural behaviour of various composites under the given loading conditions. The three different materias were considered for the at three different loading condition the different material considered are for the purpose of the Analysis Cast Iron, Nickel Chromium Alloy Steels and Metal matrix composite Aluminium Silicon Carbide Al-Sic. The cast iron in the melleable cast iron og grade MCI A , the steel alloy is the nickel chromium steel and the composite is the Metal matrix composite Al-sic.The condition for analysis has been assumed as static. For FEA analysis of gear manufactured from composite Young's modulus is calculated theoretically and Young's Modulus and Poisson's ratio for alloy steel have been taken from design data book. Young's modulus of acomposite material is anisotropic (varies with direction) and can be estimated using the rule-of-mixtures. The various mechanical properties of the selected material were given in the table below.

***Table 1 : mechanical properties of the selected material***

| PROPERTIES | UNIT S | MATERIALS | | |
|---|---|---|---|---|
| | | Cast Iron | Chromium nickel steel alloy | Al-Sic |
| Youngs modulus | GPa | 190 | 200 | 150 |
| Poision ratio | - | 0.27 | 0.28 | 0.3 |
| tensile strength | MPa | 400 | 680 | 420 |
| density | Kg/m3 | 7300 | 7800 | 2800 |

## TORQUE CONSIDERATION

For the analysis purpose three different torque condition rotating at different rpm were consider for the pupose of considering the real situation to see the stress produced in both the material and their ability to carry power relative to each other. All the condition and factor taken were accordind to the AGMA standards and all the units are in SI units. The different torque consider were given in the table below as:

***Table 2 : diferent torque considered***

| SR NO. | TORQUE (N-M) | R.P.M |
|---|---|---|
| 1. | 490 | 2400 |
| 2. | 390 | 3000 |
| 3. | 294 | 4000 |

## STATIC STRUCTURAL ANALYSIS

A static structural analysis were done to analyse the behaviour of the structure under the steady loading conditions, while ignoring inertia and damping effects, such as those carried by time varying loads. All types of non-linearity are allowed such as large deformations, plasticity, creep, stress stiffening, contact elements etc. this result will determined whether the structure will withstand for the applied external loads. If the stress values obtained in this analysis crosses

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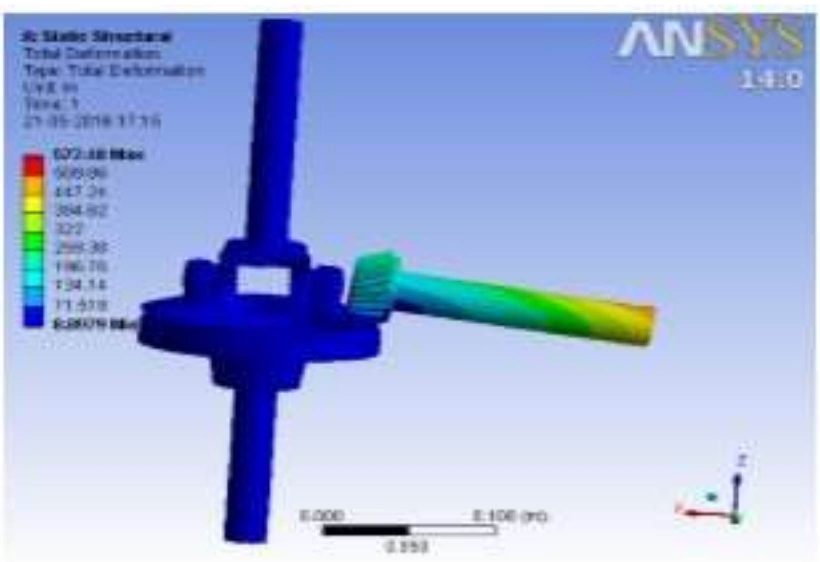
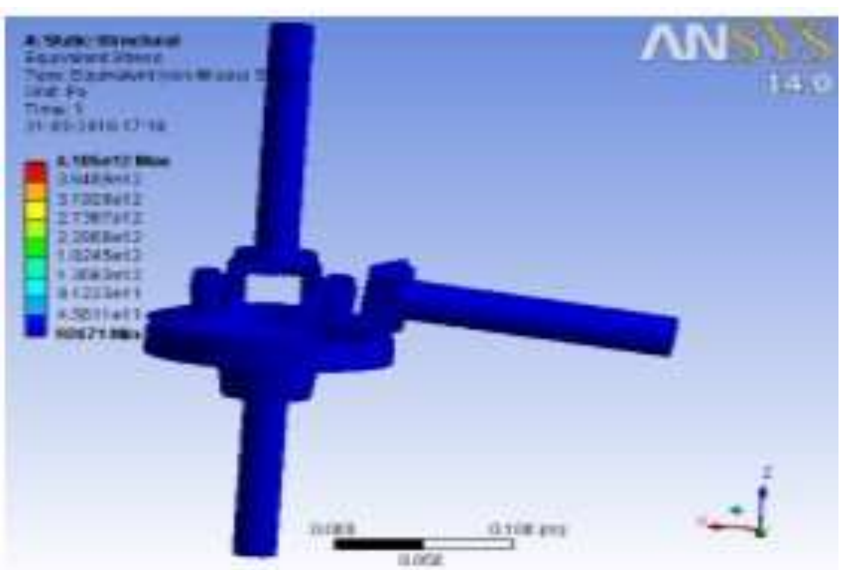
the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary.In this project the FEA based analysis tool were used to study the structural behaviour of the different composite material under the given boundary conditions by determining the total deformation, Equivalent Von misses stress, for each composite material and then the comparison were done In the Ansys the region with high stress were shown in red color while the region having less stress were shown in blue color.In this present work FEM based structural analysis simulation results shows the behaviour of cast iron , steel alloy and the Al-SicC composite materials at different torque condition the results of the static structural were shown below as:

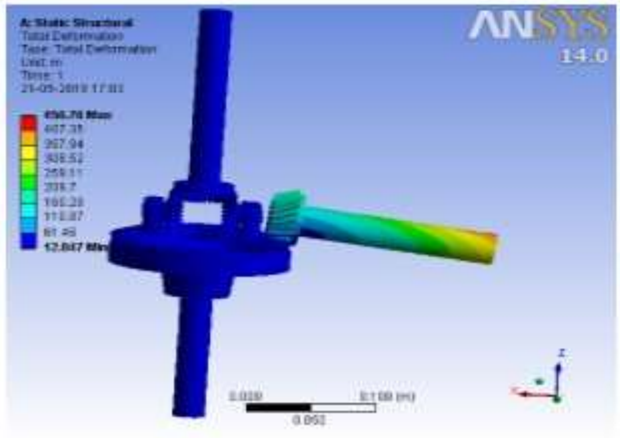
FOR THE CAST IRON




***At torque = 390 N-m***

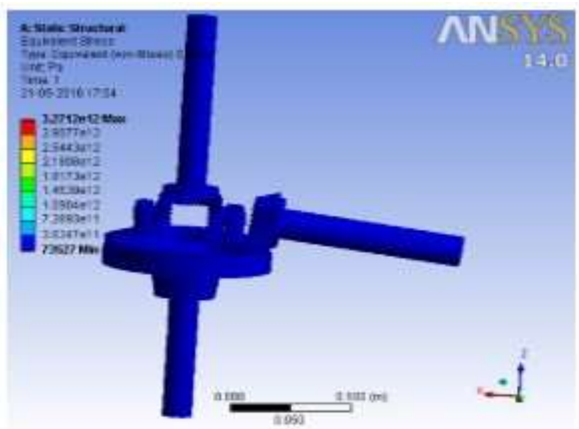


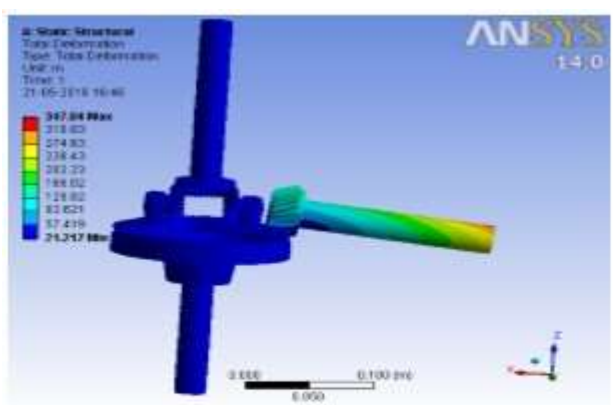

***At torque = 490 N-m***

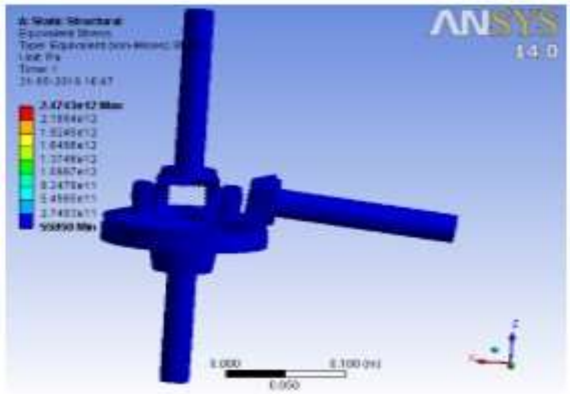


2.

***At torque = 294 N-m***

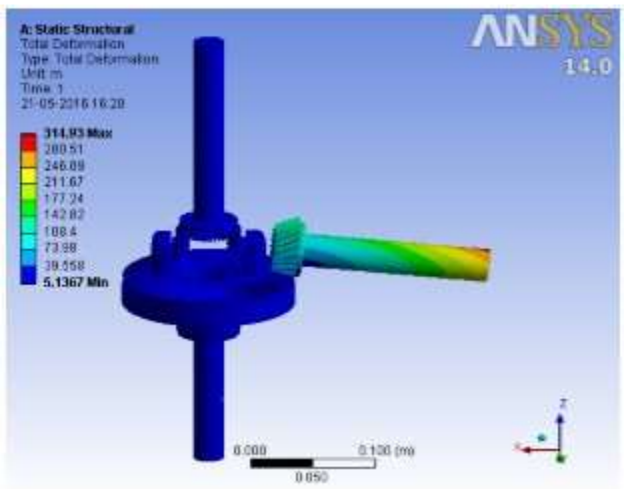


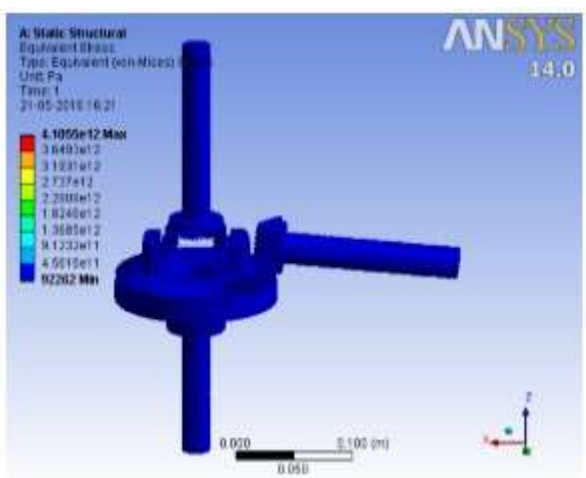




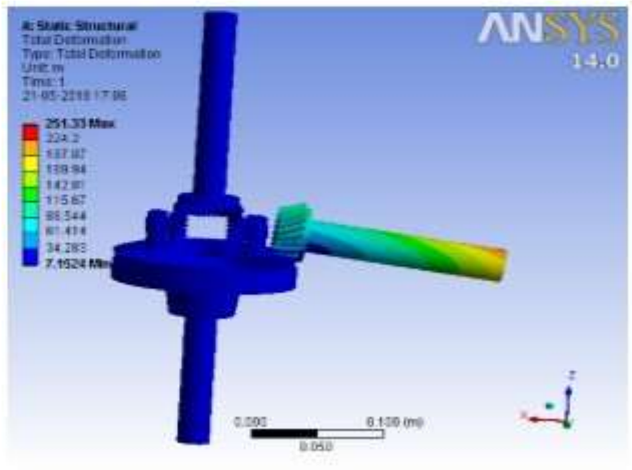

FOR THE STEEL ALLOY

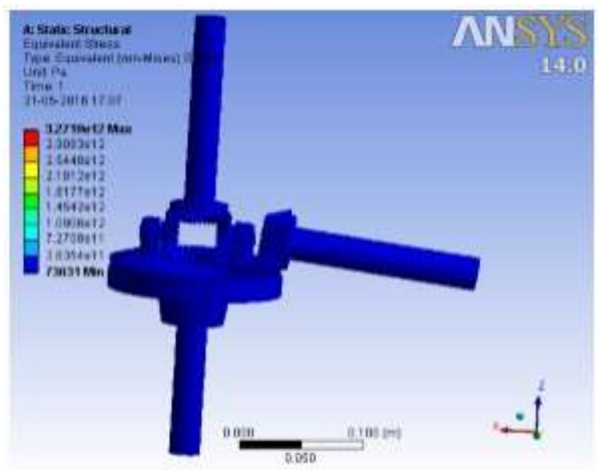
At torque = 490 N-m



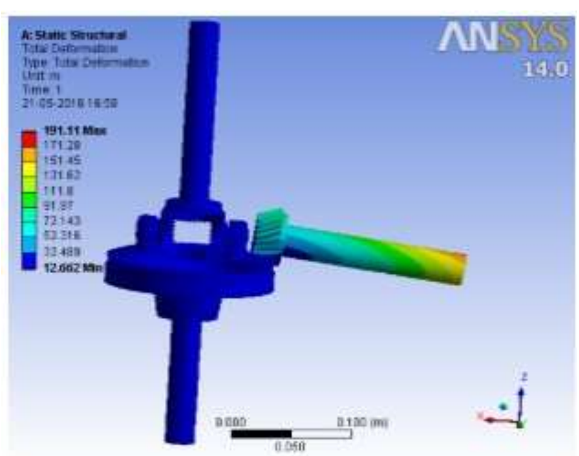



At torque = 390 N-m




At torque = 294 N-m



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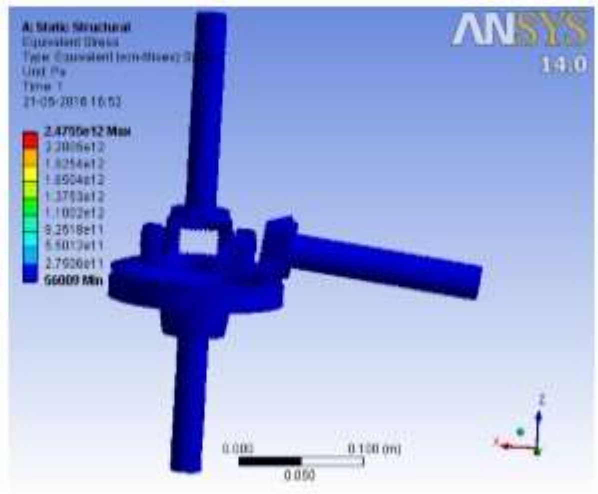
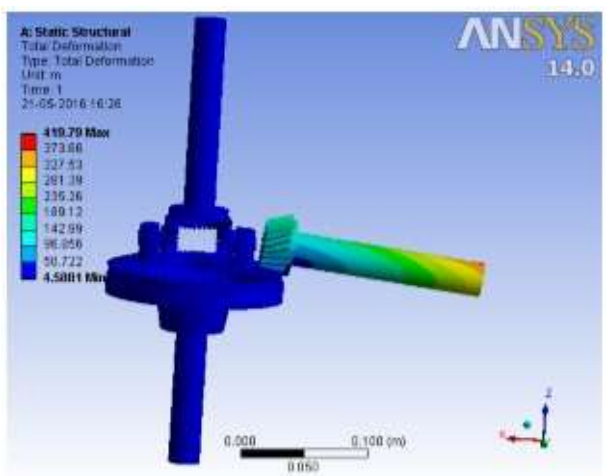
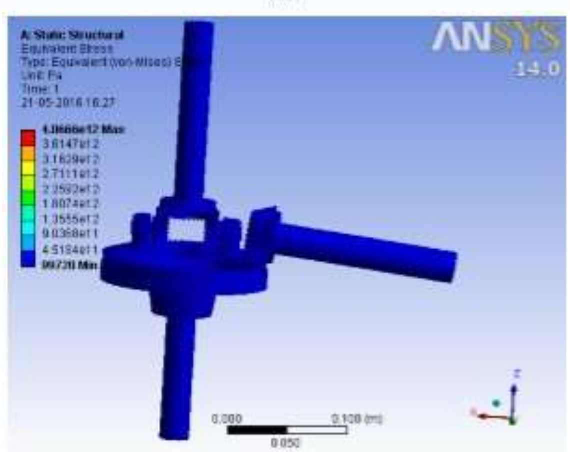



FOR THE AL-SIC
At torque = 490 N-m



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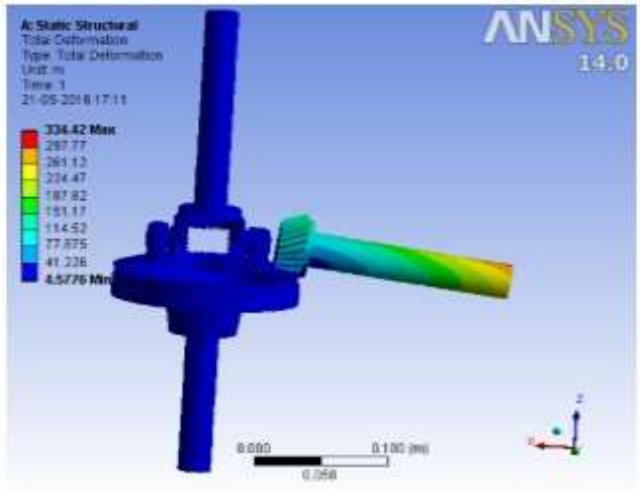
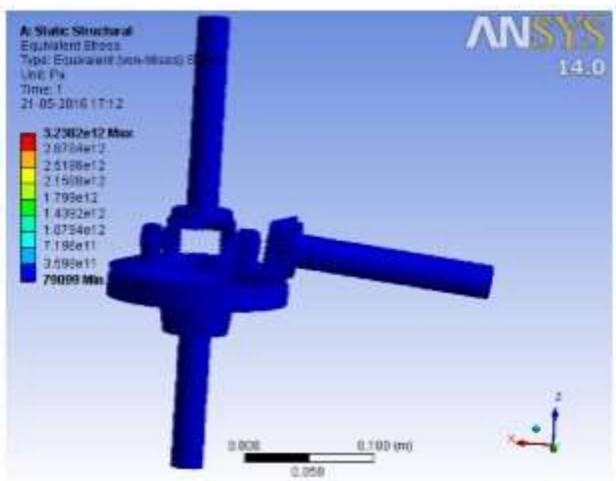
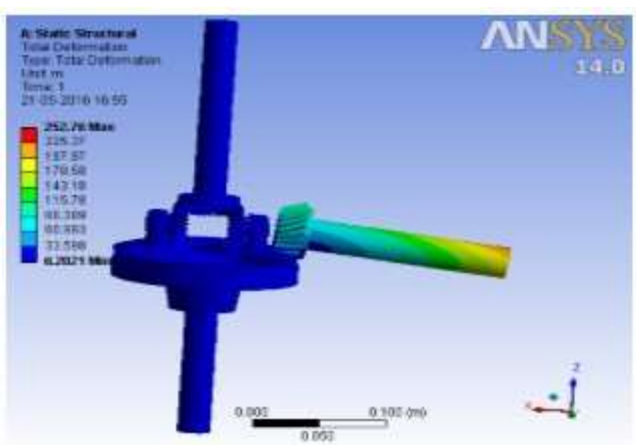



***At torque = 294 N-m***




***At torque = 390 N-m***



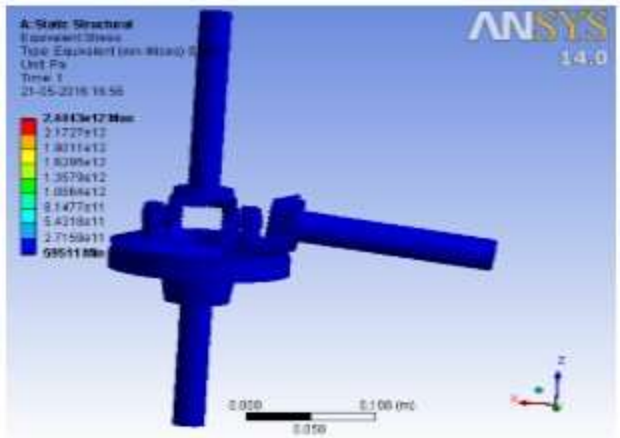



***Table 3: showing results of fem stress analysis***

| Torque (N-m) | TOTAL DEFORMATION (M) | | | EQUVALENT VON MISSES STRESS (MPA) | | |
|---|---|---|---|---|---|---|
| | CAST IRON | STEEL ALLOY | AL-SIC | CAST IRON | STEEL ALLOY | AL-SIC |
| 490 | 572.48 | 314.93 | 419.93 | 4.105e12 | 4.107e12 | 4.066e12 |
| 390 | 456.76 | 251.33 | 334.42 | 3.271e12 | 3.28e12 | 3.23e12 |
| 294 | 347.04 | 191.11 | 252.76 | 2.47e12 | 2.49e12 | 2.44e12 |

## MODEL ANALYSIS OF GEAR MATERIAL

Modal analysis is used to analysis the behaviour of the structure during the dynamic loading condition. It determine the vibration characteristics such as natural frequencies and mode shapes of a structure as these parameters are most important for the design of structure during the dynamic loading conditions in order to avoid the resonance situation. In this work with the help of ansys analysis tool the natural bending frequency of drive shaft were determined up to 10 mode of both the material were determined.The gear assembly designed on creo containing gear as well as the pinion should rotates at the speed lower than the first natural bending frequency of in order to avoid whirling vibration. In this work with the help of ansys analysis tool the natural bending frequency were determined up to 10 mode for all the material considered in order to determine the suitable material for heavy duty vehicle.

***Table 4: showing the variation of frequencies with modes***

| MODE | MATERIALS | | |
|---|---|---|---|
| | CAST IRON | NIKELCHROMIUM STEEL | AL-SIC |
| 1. | 0. | 0. | 0. |
| 2. | | | |
| 3. | 2.5727e-003 | 3.2043e-003 | 4.8942e-003 |
| 4. | 1.0325 | 1.3375 | 1.9318 |
| 5. | 41.361 | 53.583 | 77.377 |
| 6. | 72.647 | 94.115 | 136.14 |
| 7. | 74.614 | 96.663 | 139.63 |
| 8. | 140.4 | 181.89 | 262.88 |
| 9. | 185.77 | 240.66 | 348.71 |
| 10. | 331.48 | 429.44 | 620.59 |

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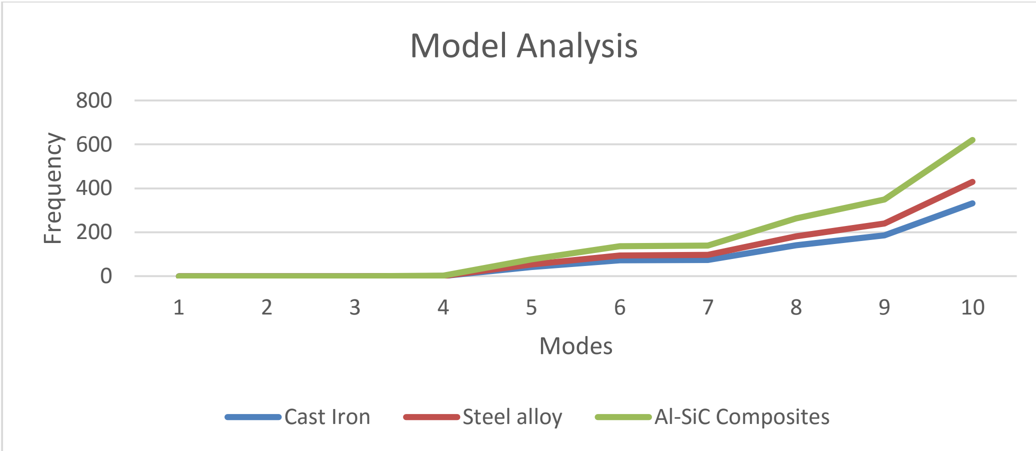


***Chart representing the distribution of frequency***

## WEIGHT ANALYSIS OF GEAR MATERIAL

As the reason for considering the different – different composite were ther quality of light weight and good strength as compared to conventional steel materials. Thus for the analysis purpose an gear assembly of gear and pinion were made in creo 3.0 and analysis were done using the ansys 14. 0 analysing tool which shows that's there has been the considerable reduction in weight of the gear assembly which is shown in the table below:

***Table 5: showing camparison of mass for different material***

| SR NO. | CAST IRON (kg) | NICKEL CHROMIUM STEEL (kg) | AL-SIC (kg) |
|---|---|---|---|
| Bevel gear 1 -1 | 0.6749 | 0.73602 | 0.26421 |
| Bevel gear 2-1 | 0.0792 | 0.08635 | 0.0031 |
| Bevel -1 | 0.74192 | 0.80375 | 0.2885 |
| Bevel -2 | 1.7827 | 1.9313 | 0.69328 |

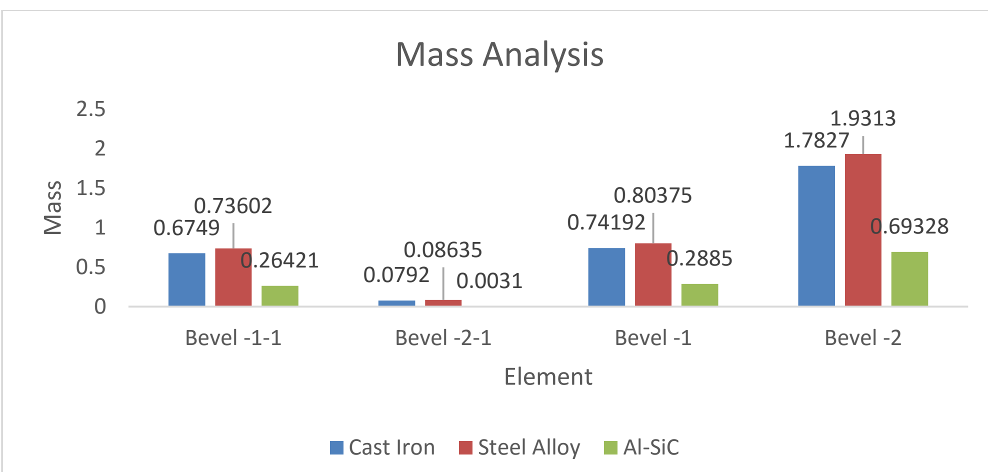


***Chart representing the distribution of masses***

## CONCLUSION

The main aim of the project is to focus on the mechanical design and contact analysis on assembly of gears in gear box when they transmit power at different speeds at 2400 rpm, 5000 rpm and 6400 rpm. Analysis is also conducted by varying the different materials for gears, The analysis is conducted to verify the best material for the gears in the gear box at higher speeds by analyzing stress, displacement and also by considering weight reduction. Design calculations are done on the differential of Ashokleyland 2516M by varying materials and speeds. Differential gear is modeled in CREO 3.0 . The ANSYS 14.0 fem software were used as the analysis tool for determing the structural behaviour of under the given loading conditions. The three different materias were considered for the at three different loading condition the different material considered are for the purpose of the Analysis Cast Iron, Nickel Chromium Alloy Steels and Metal matrix composite Aluminium Silicon Carbide Al-Sic. The bending stress calculated for different loading condition through the lewis bending equation were below the permissible bending stress for both the material

1. The Fem based static analysis at different loading condition shows that the total deformation and stress induced in the material were less for the composite as compared to others metallic considered.

2. The FEM based model analysis for both material under free vibration condition for upto 10 modes shows that the natural frequencies for the metal metrix composites have larger value as compared to other metallic material and hence the resonance chance were lower in MMC composite materials .

3. There is considerable reduction in mass for the composite material materials as compared to the conventional steel material of about 64 % reduction in mass.

4. The gears are materials are capable of transferring the power upto 175 KW.

5. From the above analysis it can be concluded the composites material can successsfully replaced the steel gear for the gearbox applcation.

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