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STRUCTURAL ANALYSIS OF COMPOSITE MATERIAL HELICAL GEAR UNDER DIFFERENT LOADING CONDITION

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ABSTRACT

Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. In recent years it is required to operate machines at varying load and speed. Gear teeth normally fail when load is increased above certain limit. Therefore it is required to explore alternate materials for gear manufacturing. Composite materials provide adequate strength with weight reduction and they have emerged as a better alternative for replacing metallic gears. In this work an attempt has been made to replace the metallic gears of steel alloy with the composites . The composites consider were the Aluminium Silicon carbide composite Carbon fiber epoxy composites and carbon fiber silicon carbide ceramic composite . Efforts have also been carried out for modelling of the transmittiing power gear assembly on creo 3.0 and fem based structural behaviour of different material were studied. Ansys 14.0 is used the analysis tool in the present work to detrmine the total deformation , von misses stress and the natural frequencies at various mode. Composite gears offer improved properties over steel alloys and these can be used as better alternative for replacing metallic gears.

KEYWORDS: Gearing ,Aluminium silicon carbide , Carbon Epoxy, Carbon fibre silicon carbide ,ANSYS.

INTRODUCTION

Composite material (also called a composition material or shortened to composite) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites,which are known as Robotic Materials.

In the present work an attempt has been made to replace the conventional steel alloy gearmaterial with composite material having an application in high power transmission system like an gearbox used in automobile industries.For this purpose 3-D model of the helical gear pair having the pininon as the driver and the gear as the driven for a paticular transmission ratio. was made in the pro-e cad software and the ansys 14.0 fem based analysis software was used as the analysis tool to carry out the static structural analysis in order to determine the behavior of the conventional steel alloy gear material and the proposed replacements of three different composite material under the different loading condition and also the model analysis were carried out in order to determine the natural frequency of gear system at different modes under the free vibration condition in order to avoid the situation of resonance. The simulation result determines the total deformation, Equivalent Von misses stress, Maximum shear stress, and natural frequencies at different modes under actual boundary conditions.

LITERATURE REVIEW

R. Yakut et al.[1] The purpose of the paper is to examine the load capacity of PC/ABS spur gears and investigation of gear damage. Further the usability of PC/ABS composite plastic material as spur gear was also investigated.The PC/ABS gears were tested by applying three different loading at two different numbers of revolutions on the FZG experiment set. The result shows that the usage of PC/ABS materials brings an advantage in many industrial area because such materials are durable against flame, air, ultraviolet lights and holding lower moister than PA66 GFR 30 materials.

Vivek Karaveer et al.[2] This paper presents the stress analysis of mating teeth of the spur gear to find maximum contact stress in the gear tooth. The results obtained from finite element Analysis are compared with theoretical Hertz equation values. The spur gear are modelled and assembled in ANSYS DESIGN MODELER and stress analysis of Spur gear tooth is done by the ANSYS 14.5 software. It was found that the results from both Hertz equation and Finite Element Analysis are comparable.

M. Patil et al.[3] This paper study the free vibration behaviour of composite spur gear using finite element method which is also known as first order shear deformation plate theory (FSDT). The finite element analysis has been carried out for composite gear as a 4 nodded and 8 nodded quadrilateral element with each nodes has five degree of freedom. Finite element formulation of composite gear is modelled and coded using MATLAB. Based on the numerical analysis which is carried out for of spur gear. The developed MATLAB code is validated with the available result and it can be concluded that the present FE code result are in good agreement with those of reference. Fundamental frequencies obtained for composite spur gear using MATLAB are presented. It is found that natural frequency increases with increase in fiber orientation.

A.D. Dighe et al.[4] In this paper the comparative performance spur gear of 30% Glass filled PA66 and 30% Glass filled PEEK was investigated at different torque and speed. Wear test of the spur gear pairs and the experiment spur gear tooth were performed on a FZG test machine. A weight loss is measured by 0.0001g sensitive weighing machine and the tooth temperature of gear is measured by Impact infrared thermometer. The experimental result of PA66 GF30 gears and PEEK GF30 gears are at different torque and speeds. The tooth temperature increases with increase in torque and increased temperature .Resulted into thermal softening of gear tooth which further increases specific wear rate. The comparative results of PA66 GF30 and PEEK GF30 gears show that the specific wear rate of PA66 GF30 is much higher than PEEK GF30 at all torque and speeds. Therefore the torque transmission capacity of PEEK GF30 is higher than PA66 GF30.

V. Siva Prasad et al.[5] This paper describes design and analysis of spur gear and it is proposed to substitute the metallic gears of sugarcane juice machine with polymer gears to reduce the weight and noise. A virtual model of spur gear was created in PRO-E, Model is imported in ANSYS 10.0 for analysis by applying normal load condition. The main purpose of this paper to analysis the different polymer gears namely nylon, polycarbonate and their viability Checked with counterpart metallic gear like as cast iron. Concluding the study using the FEA methodology, it can be proved that the composite gears, if well designed and analyzed, will give the useful properties like as a low cost, noise, Weight, vibration and perform its operation similar to the metallic gears. Based on the static analysis Nylon gear are suitable for the application of sugarcane juice machine under limited load condition in comparison with cast iron spur gears.

DESIGN OF HELICAL GEAR

Engineers usually prefers the spur gear because the Spur gears are easier to design and manufacture. When power is transmitted between parallel shafts. [29]There are, however, some design considerations like greater contact ratio, greater strength, and some operational requirements, such as, noiselessness, smoother engagement of meshing of teeth, for which the use of helical gears is preferred. When a pair of parallel helical gears mesh, the following conditions must be satisfied for proper running of the set:

- The gears must have helix angles of equal value
- The gear teeth of each member must have the same module, and
- The gear teeth of each member must have opposite helices, that is, one gear must have right-handed helical teeth while the other must have left-handed ones .

In this paper real involute gear pair with transmission ratio is analyzed. Based on the design equation about the various properties of gear tooth and making assumption for some variables , the dimensions for the transmission gear were calculated as:

ASSUMPTION:-

- Gear profile: - 20 degree full depth involute profile (standard)
- Normal pressure angle (α):- 20 degree
- Helix angle (β):- 16 degree
- Minimum no. of teeth on pinion (Zp) = 20
- Normal module (Mn) = 5

CALCULATED GEAR DIMENSION

Table 1 : gear dimension under the analysis

GEOMETRIC PROPERTIES	GEAR	PININON
Number of teeth	50	20
Pitch circle diameter (in mm)	260	104
Normal module	5	5
Helix angle (in degrees)	16	16
Face width (in mm)	65	65
Pressure angle (in degrees)	20	20
Addendum circle diameter (in mm)	270	114
Dedendum circle diameter (in mm)	247.5	91.5

PARAMETRIC SOLID MODELING OF HELICAL GEAR

Parametric solid modelling[36] allows the design engineer to let the characteristic parameters of a product drive the design of that product. 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. Pro-E has model the involute profile helical gear geometry perfectly. For helical gear in Pro-E, 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 helical gear and all essential information to create the model. By using the relational equation in Pro/ Engineer, the accurate three dimensional helical 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.

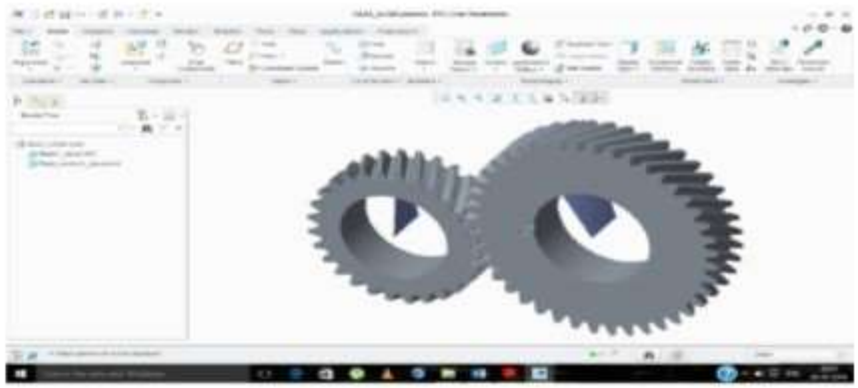


Figure 1: showing the solid model in creo 3.0 cad software

BENDING STRENGTH CALCULATIONS

Complete knowledge of the stresses which the gear teeth are subjected to is imperative for the determination of the different parameters of a gearing system. This should be as exact as possible and is a prerequisite for the proper design to avoid damage or failure of the gears within the stipulated life. Hence, the most important stresses which the gears normally encounter should be theoretically checked as regards load-carrying capacity.From theoretical considerations, appropriate gear dimensions can be reasonably arrived at by Using the design data available in books, manufacturer's manuals, journals, and the standard Specifications, such as IS, DIN, BS, GOST, and the various American standards. The most Important stresses which should be considered for gear designing are:
1. The stress due to the bending of the tooth, and
2. The stress created by contact pressure, generally known as Hertz stresses.

Wilfred Lewis introduced an equation for estimating the bending stress in gear teeth in which the tooth form entered into the formulation. The equation, announced in 1892, still remains the basis for most gear design today. In the lewis analysis the gear tooth is treated as a cantilever beam as shown in the figure. The tangential component of force (Ft) causes the bending moment about the base of the tooth.

ASSUMPTIONS:
1. The full load is applied to the tip of a single tooth in static condition.
2. The radial component is negligible.
3. The load is distributed uniformly across the full face width.
4. Forces due to tooth sliding friction are negligible.
5. Stress concentration in the tooth fillet is negligible

The bending stress generated in the gear were calculated for all the three torque condition . The bending stress were calculated by the lewis bending equation according to the AGMA standars . The value for all the factors were taken from the machine design data book according to the condition and all the units were in SI units The value for bending stress were gven in the table below:

$$\sigma_b = \frac{F_t}{b\ m\ J} K_v K_o (0.93 K_m)$$

Where, Face width (b) = 20 mm
Load distribution factor = 1.2
Geometry factor (J) = 0.594
Dynamic Factor (Kv) = 1.18
Overload factor (Ko) = 2

Table 2: showing bending stress for different torque condition

SR NO.	TORQUE RATING (N-m)	Bending stress (σ_b) MPa
1.	350	91.825
2.	400	104
3.	420	110

For the design to be in the safe condition the stress generated in the designed component at the designed condition should be less than than the permissible value of the stress for the material Hence in our the bending stress (σb) generated in designed gear is below the permissible value of the bending strength [σ] as calculated above with appropriate assunption of the factor of safety .

FEM ANALYSIS OF THE GEAR

Finite element analysis[37] 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. Fem is the easy technique as compared to the theoretical methods to find out the stress developed in a pair of gears. Therefore FEM is widely used for the stress analysis of mating gears.

In our project FEM based analysis is carried out by using the ANSYS 14.0 analysis tool with help of which we determines quantities like the total deformation, Equivalent Von misses stress, Maximum shear stress, natural frequencies and mode shapes under actual boundary conditions. Models for numerical analysis have been prepared in Creo 3.0 and these have been imported into ANSYS as IGES files for further analysis. Figure 3 shows FE analysis of gears for which model has been generated according to geometric dimensions obtained by calculation. 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. 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.

MATERIAL PROPERTIES

The main objective of this research work is to study the structural and vibrational characteristic of composite material gear for the heavy duty transmission system as compared to conventional steel alloy gear assemly assembly. The considered materials are the [34]carborized steel 10c4 with case hardening according to the IS 1570 , the Metal matrix composite composite (MMC) materials Al-SiC The [35]Al-SiC composite selected have AL 6061 matrix with 18% SiC reinforcedment materials , 50% cabon fibre reinforcement in epoxy resin and caron fibre reinforcement in silicon carbide matrix . The conventional steel alloy used for the gear material have disadvantages such as low specific stiffness and strength and high weight. Substituting the composite material for the gear have advantage of higher specific strength, less weight, high damping capacity, longer life, high critical speed and greater torque carrying capacity and can results in considerable amount of weight reduction as compared to steel The composite material have the orthotropic elastic behaviour rather than linear elastic properties.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 a composite 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 3 : mechanical properties of the material

PROPERTIES	UNITS	MATERIALS			
		STEEL 10C4	AL-SIC (20% SIC)	CARBON/EPOXY	CVI – C/SIC
Youngs modulus	GPa	210	150	450	95
Poision ratio	-	0.3	0.3	0.3	0.3
tensile strength	MPa	500	420	52	310
Density	Kg/m3	7850	2810	1800	2100

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 :

	Part 1	Part 2
nodes	92859	311726
elements	20526	71961

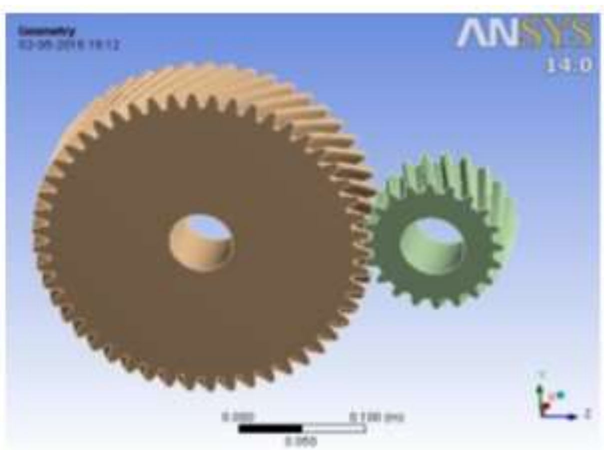


Figure 2 solid modlling in ansys

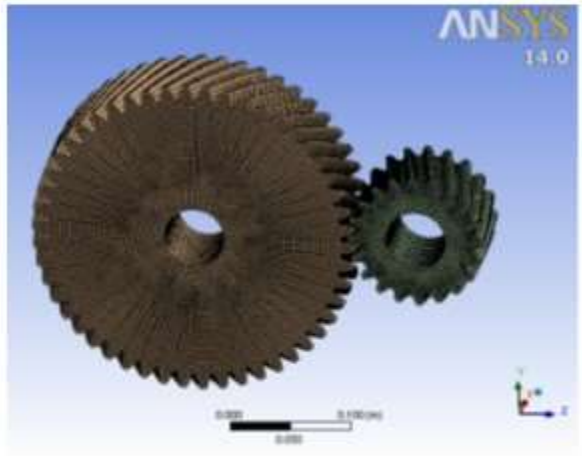


Figure 2 meshing in ansys analysis software

BOUNDARY CONDITION

For the purpose of analysing and to simulate the real condition the frictional less support is applied on inner rim of the pinion gear as well as the frictionless support is applied on the inner rim of gear to allow its tangential rotation but restrict from radial translation. Moment of moment of the appropriate magnitude equal to the torque consider in N-m is applied on the inner rim of pinion in clockwise direction as a driving.

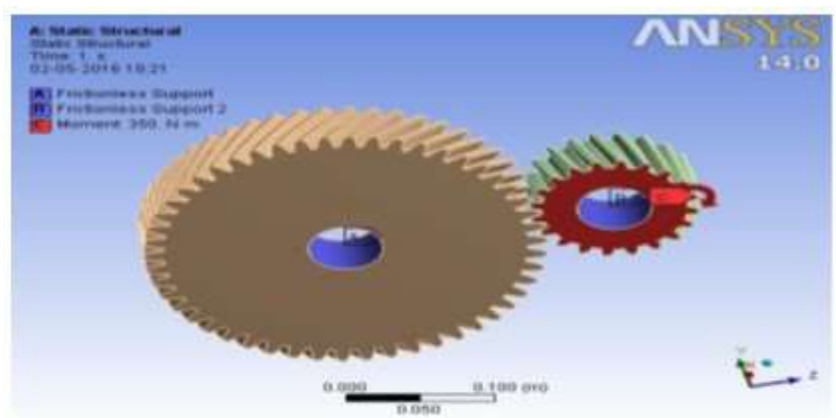


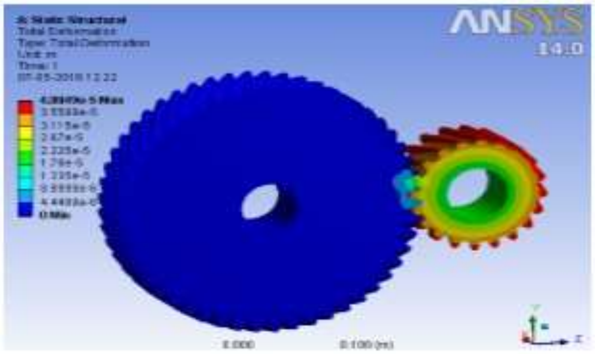
Figure 4: shows boundary condition in the gear assembly

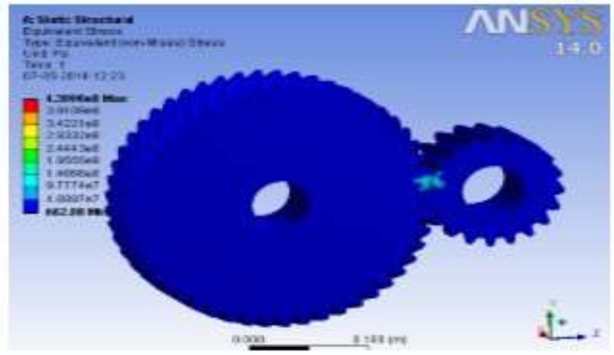
STATIC STRUCTURAL ANALYSIS

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 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.The FEM based structural analysis simulation results of steel alloy and the Al-SicC composite at different torque condition were shown below as:

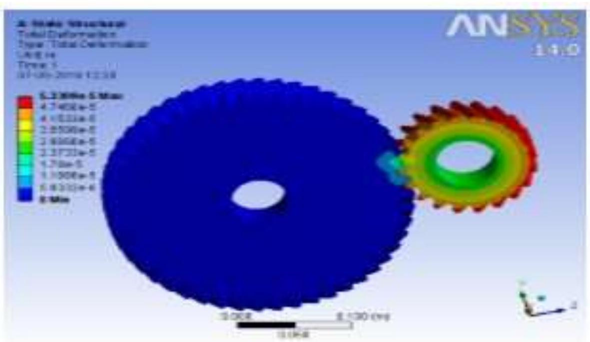
AT TORQUE = 350 N-M AT 4000 RPM

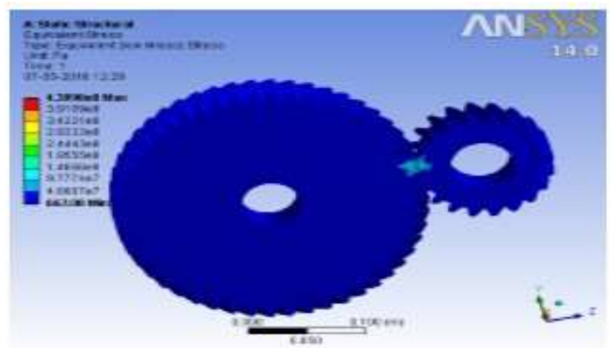
1. For conventional steel material



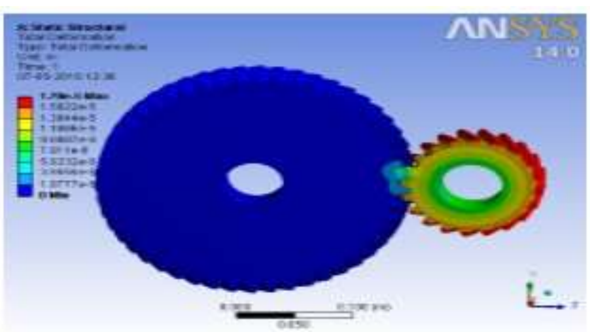


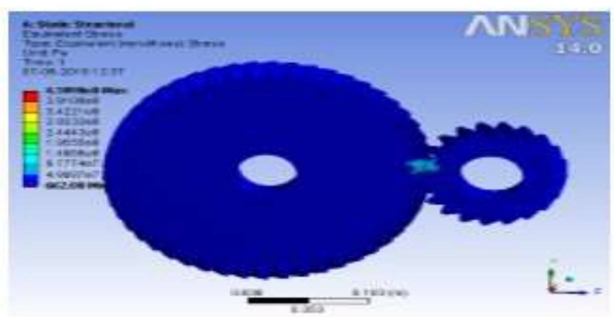
2. For the Aluminium silicon carbide composite (Al-SiC)





3. For the 50% carbon fibre reinforced in epoxy resin





4. For carbon reinforced silicon carbide ceramic composite

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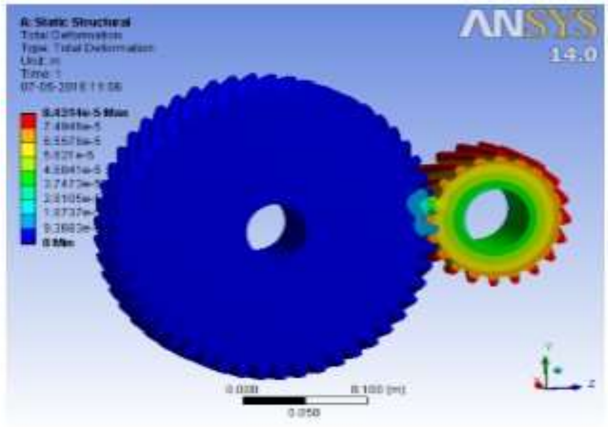
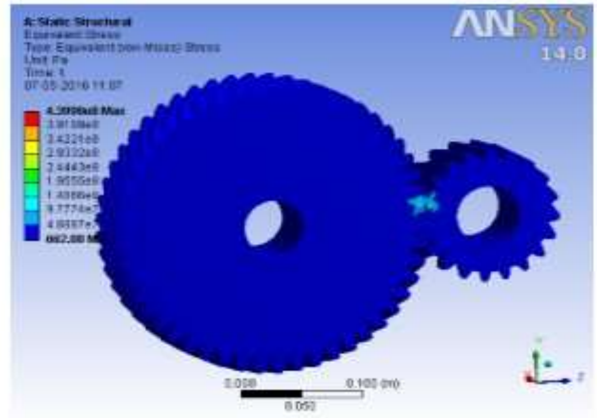
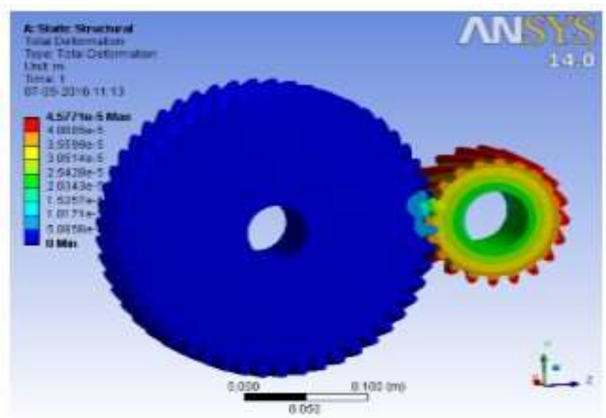
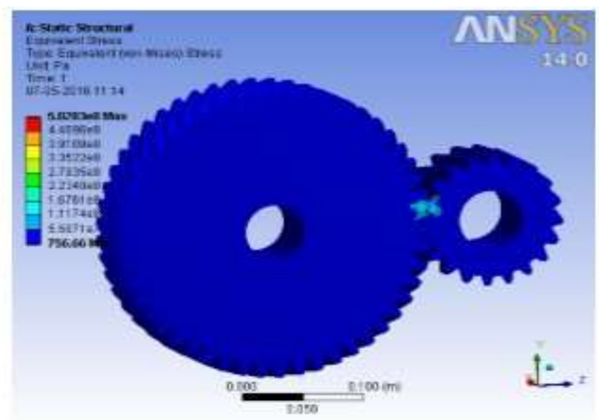




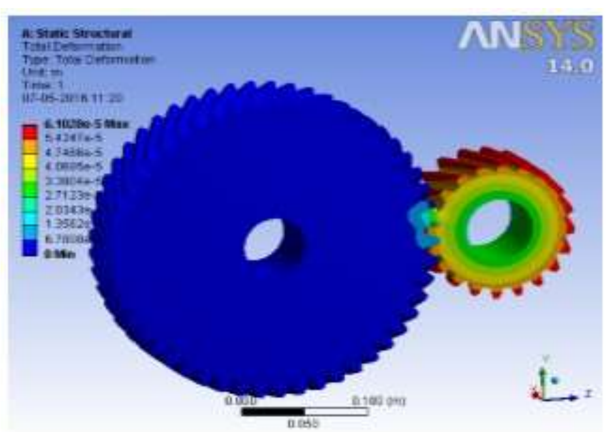
AT TORQUE = 400 N-m AT 3500 RPM

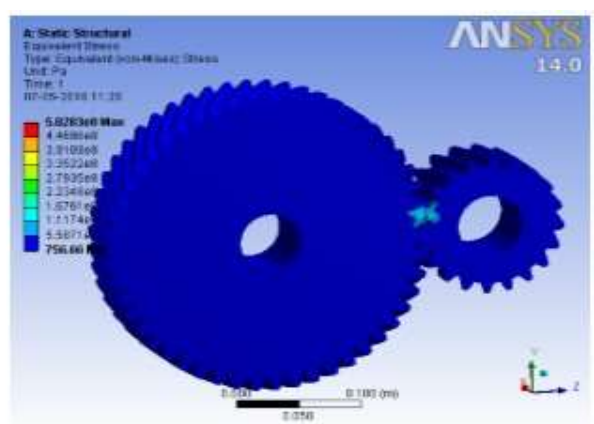
1. For conventional steel material





2. For Aluminium silicon carbide composite (Al-SiC)





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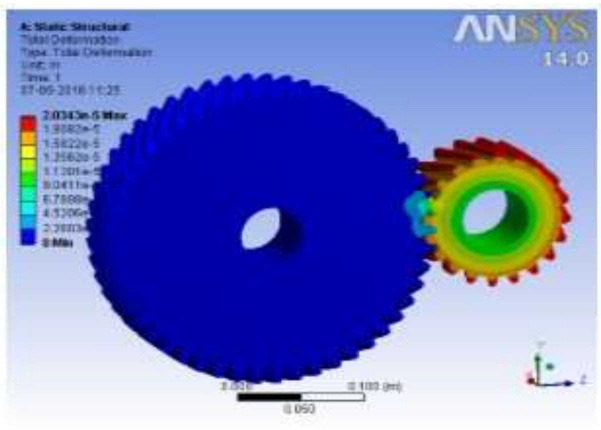
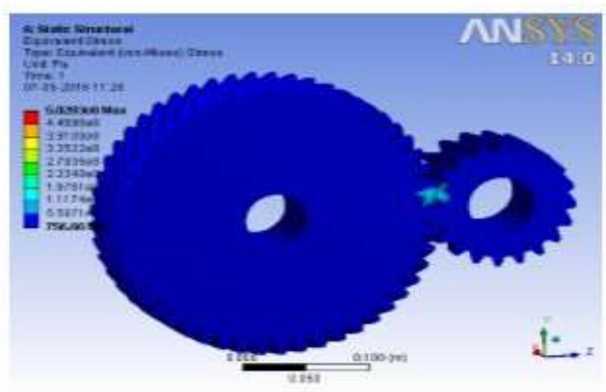
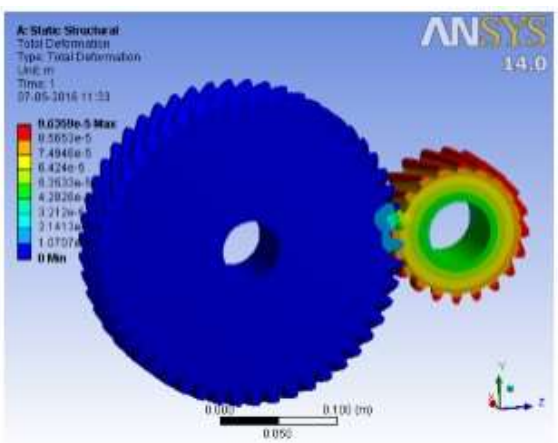
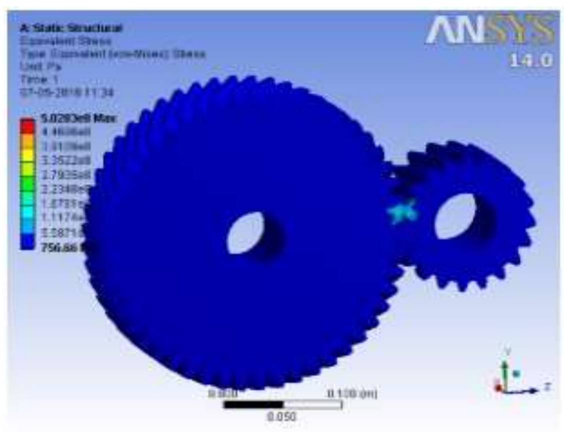
3. For the 50% carbon fibre reinforced in epoxy resinFor c- sic composite





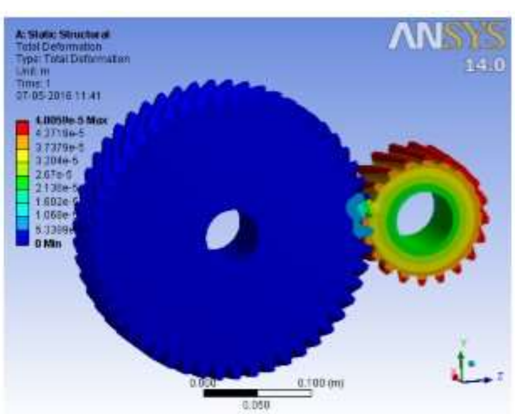
4. For Carbon fibered silicon carbide composite

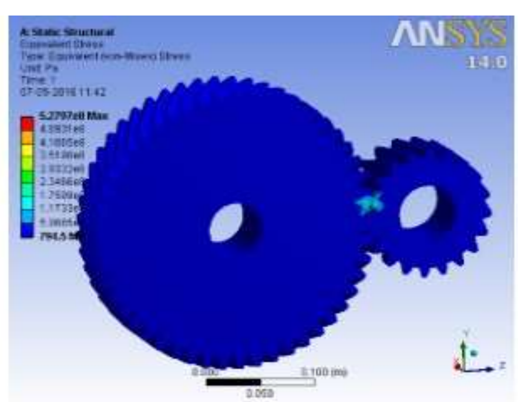




AT TORQUE = 420 N-m AT 3000 RPM

1. For the conventional steel material





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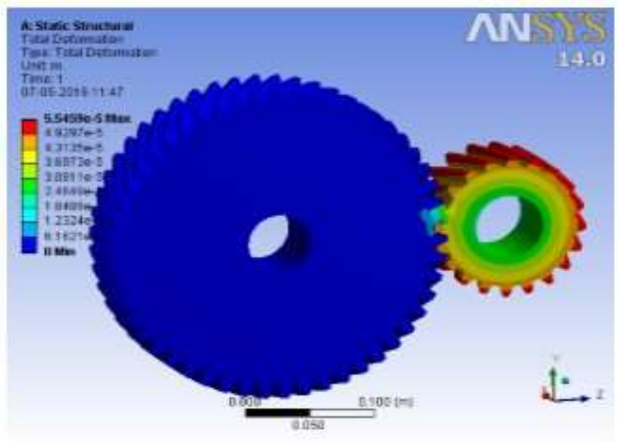
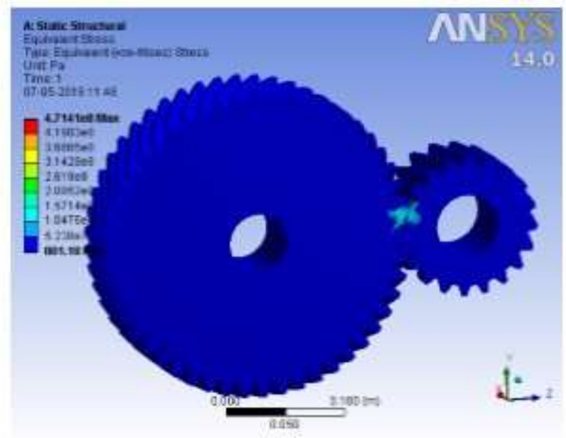
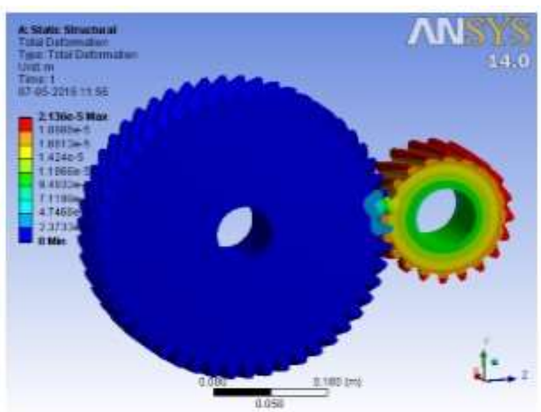
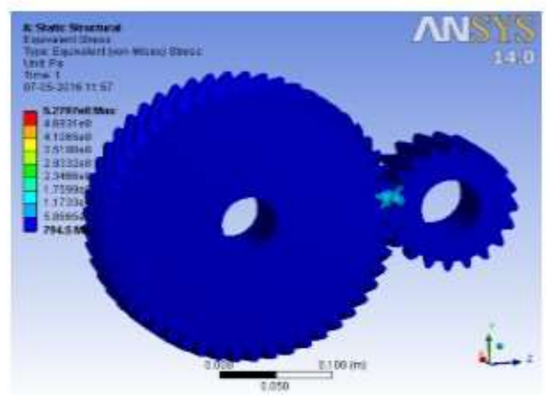
2. For the Aluminium silicon carbide composite



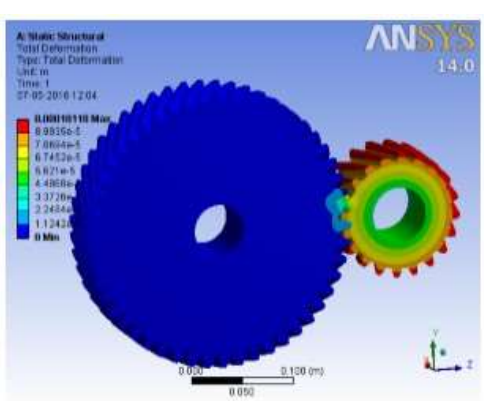


3. For the 50% carbon fibre reinforced in epoxy resin





4. For the carbon fibered silicon carbide ceramic



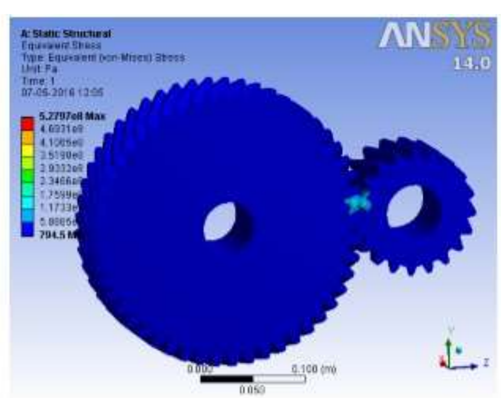


Table 4: showing results of fem stress analysis

TORQUE CONDITIONS	EQUIOVALENT STRESS (VON - MISSES) MPa				TOTAL DEFORMATION (m)			
	steel	Al-SiC	c-epoxy	C-SiC	steel	Al-SiC	c-epoxy	C-SiC
350 N-m	439.2	438.64	439.98	438.7	4e-5	5.3e-5	1.78e-5	8.43e-5
400 N-m	562.5	562.125	562.83	563.5	4.5e-5	6.1e-5	1.93e-5	9.69e-5
420N-m	590.6	589.9	590.25	587.2	4.8e-5	5.5e-5	2.13e-5	10.2e-5

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 . When an system is free from external forces is disturbed from its equilibrium position it starts vibrating due to the inherent forces. It will vibrate at its natural frequency and its amplitude will gradually reduce with time due to energy decapitation due to the resistance force by motion. This type of system is known as free vibration system.

Table 5: showing the variation of frequencies with modes

Mode	Frequency [Hz]			
	steel	Al-SiC	c-epoxy	C-SiC
1.	0.	0	0.	0.
2.	6.4079e-003			
3.	7.6126e-003	1.1053e-002		8.3534e-003
4.	0.59572	0.97874	1.8632	0.79395
5.	3.6502	5.9986	11.434	4.8639
6.	7.9002	12.983	24.747	10.527
7.	102.49	168.43	321.06	136.57
8.	131.31	215.79	411.33	174.97
9.	166.38	273.43	521.19	221.71
10.	1457.8	2391.4	4570.2	1942.3

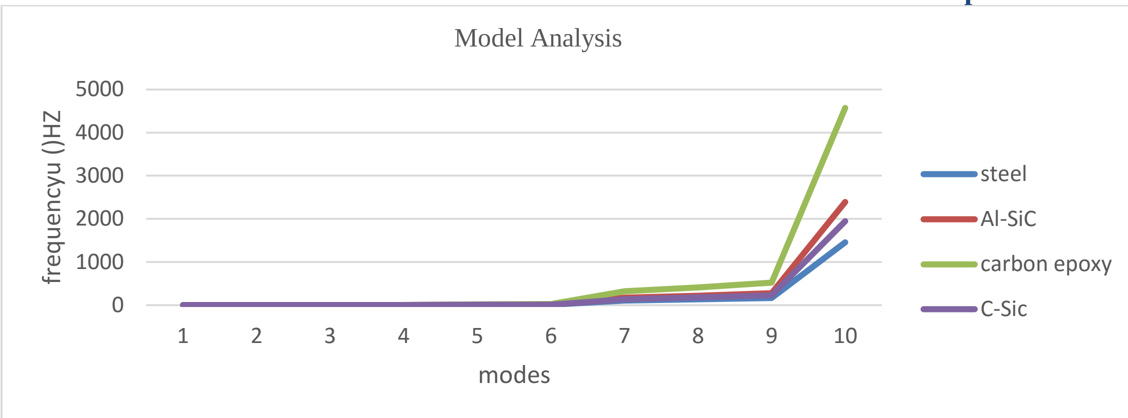


chart showing the variation of frequency upto 10 modes

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 6: showing camparison of mass for different material

COMPONENT	STEEL (KG)	AL-SIC (KG)	C-EPOXY (KG)	C-SIC (KG)
Gear	25.844	9.2512	0.7846	0.91756
Pinion	3.43	1.2278	5.9261	6.9137
Total mass	29.274	10.479	6.7107	7.83216

CONCLUSION

The objective of the project is to reduce the stress distribution, deformation and weight of spur gear by using composite materials in the application of gear box . For this purpose the solid model of the gears were designed in creo 3. 0 cad software using the relation and parameters for five different transmission ratios and theoretical and software based fem analysis analysis were carried out to find out the stress generated at different loading condition in comparison to each other . The tool which is used to analyses the composite and steel gear material is ANSYS The analysis were carried out under the static and model condition for the three torque condition to find out the total deformation,equivalent von misses stress and free vibrational natural frequencies upto 10 mode for both the material and the various conclusion were made.

1. The comparision between the conventional steel gear material and composite matrerials for different loading condition were carried out successfully for the gearbox appliaction.

2. The bending stress calculated for different loading condition through the lewis bending equation were below the permissible bending stress for given the material.

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

4. The FEM based model analysis for given material under free vibration condition for upto 10 modes shows that the natural frequencies for the carbon epoxy have the greater value as compared to other composites and hence the resonance chance were lower in carbon epoxy composite materials .

5. There is considerable reduction in mass for all the composite material materials as compared to the conventional steel material and there is about 64 % reduction in mass and the carbon epoxy composites have the greatest reduction in mass .

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

7. 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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