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Static and Dynamic Analysis of Helical Gear Using Alternative Material

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Abstract

Gears are one of the most critical components in mechanical power transmission systems. The bending and surface strength of the gear tooth are consider to be one of the main contributors for the failure of the gear in gear set. The three dimensional solid model can be generated in pro E. This model is imported in ansys and then contact stress and bending stress can be calculated in ansys for different face width and helix angle. Contact stress and bending stress can also be calculated by hertz, Lewis and AGMA equation. Bending stress can be occur in the root of gear and contact stress can be occur between meshing of two gear. Finally these two methods bending and contact stress results both are compared with each other for different face width and helix angle Different material can also be tried for weight and cost optimization. And also to increase corrosion resistance which might be cause of failure.
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Keywords: *Helical gear; Stress Analysis; Composites; Static load; ANSYS; Solidworks.*

1. Introduction

Gears are most common means of transmitting power in the modern mechanical engineering world. With the moving wheel of science and technology the use of gears has become more common in all the upcoming industries. Gearing is one of the most effective methods for transmitting power and rotary motion. Helical gears are currently being used increasingly as a power transmitting gear owing to their relatively smooth and silent operation, large load carrying capacity and higher operating speed. Helical gears have smoother and silent operation than the spur gears because of a large helix angle that increase the length of the contact lines. Helical gears will have more capabilities to transmit load between two parallel shafts as compared to similar module and equivalent width of spur gears. Designing highly loaded helical gears for power transmission systems that are good in strength and low level in noise necessitate suitable analysis methods that can easily be put into practice and also give useful. Helical gears are used in fertilizer industries, printing industries and earth moving industries. Helical gears are also used in steel rolling mills, section rolling mills, power and port industries.

The demand made on materials for better overall performance are so great and diverse that no one material can satisfy them. This led to a resurgence of the ancient concept of combining different materials in an integral composite material system that result in a performance unattainable by the individual constituent and offers great advantages. Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. Composites are widely used in aerospace, defense and it in automotive industries because of its unique properties like high specific strength, wear resistance, high hardness, strength-to-weight, strength-to-cost, etc.
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2. Literature Review

Utkarsh M. Desai et.al[1] evaluated the overall performance of machine by replacing alloy gear with composite gear of 30% glass filled poly-ether-ether-ketone(peek). Such Composite materials provide better and improved mechanical properties such as better service life, better strength to weight ratio and hence resulting in less chance of failure. In this work, analysis is performed on composite material PEEK by replacing metallic gear which improves the working life of gear. For analysis the modeling is carried out in SOLIDWORKS and bending stress analysis of spur gear is performed in ANSYS V14.

Von mises stress for alloy steel is found as 6.50 MPa while for composite material it was found to be 5.96MPa as shown in figure.

To determine bending stress of gear tooth, analytical and finite element method is incorporated. After modeling it can be concluded that strength of composite material GF 30 PEEK spur gear is more than alloy steel spur gear. Also the density of composite material GF 30 PEEK is very less compared to alloy steel spur gear.

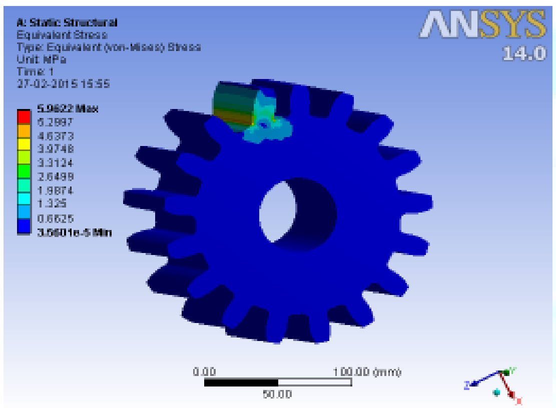

Fig. 1. Von mises stress for GF 30 PEEK material spur gear

P.B.Pawar et al.[2] established that the metallic gears can be replaced by composite material to enhance the performance of machine and have longer service life of spur gear. To prove their point, they carried out modeling and finite element analysis of gears of nylon, steel and Al-SiC using ANSYS V14.0. To perform experiments Al-SiC had been prepared by stir casting. The design of gear is done by Lewis formula and Hertz theory.

Models for numerical analysis have been prepared in CATIA v5 and they were imported into ANSYS. Analysis for spur gear was carried out for static conditions. So we can conclude that the gears prepared form Al-SiC provides improved hardness, tensile strength, lighter weight, longer service life over base metal gears.

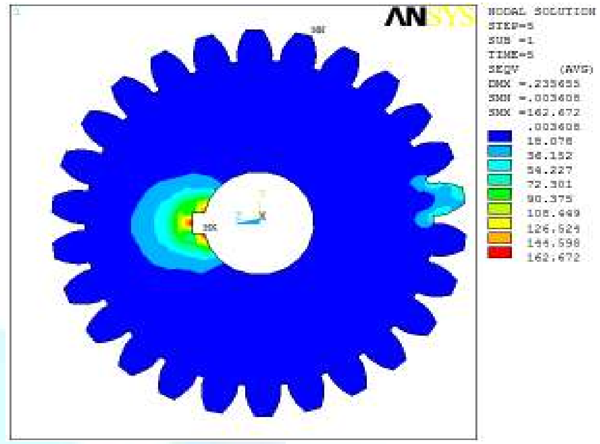

Fig. 2 Von Mises Stress plot for 750N tangential force

S.Mahendran et al.[3] numerically suggested that composite materials gear are capable to replace existing cast steel gear in Tata Super Ace. Analysis of spur gear with cast steel and composite materials like fiber and epoxy was carried out by using FEA. The values of weight and stress has been compared and found that composite material are more better than cast steel.

Fibers produce high strength composite materials because of their small diameter; they contain far fewer defects compared to the material produced in bulk. As a general rule, the smaller the diameter of fiber, the higher its strength, but often the cost increases as the diameter becomes smaller. In addition, smaller diameter high strength fibers have greater flexibility and are more compliant to fabrication processes such as weaving or forming over radii.

Epoxy resins are easily and quickly cured at any temperature from 5°C to 150°C, depending on the choice of curing agent. One of the most advantageous properties of epoxies is their low shrinkage during cure which minimizes fabric print-through and internal stresses. High adhesive strength and high mechanical properties are also enhanced by high electrical insulation and good chemical resistance. Epoxies find uses as adhesives, caulking compounds, casting compounds, sealants, varnishes and paints, as well as laminating resins for a variety of industrial applications.

From these analysis we got the stress values for composite materials is less as compared to the cast steel spur gear. Composite material is capable of using automobile vehicle gear boxes up to 1.5KN in the application of Tata Super Ace model in place of existing cast steel with better results.

M.Keerthi et al.[4] numerically found that stress values for composite material is approximately same as compared to the structural steel, gray cast iron and aluminum alloy. They first calculated mathematical model of spur gear for Tata Super Ace. Followed by selection of materials and there by modeling was done in Solidworks and imported those files to Ansys Workbench. Materials like Structural steel, Gray cast iron, Aluminum alloy, Epoxy E Glass UD were considered for analysis under various values of torque to obtain total deformation and Von mises stress for the meshed models. Natural frequency were calculated for all the materials and compared with natural frequency of existing gear to check the safety of the design of newer materials. From the paper, we can conclude that the composite materials are very amenable to replace the traditional cast iron gears.

Mohit Singh et al.[5] numerically suggested that composite material have potential to replace metallic gears. To prove their point they considered composites like Aluminum Silicon carbide composite, Carbon fiber epoxy composite and carbon fiber silicon carbide ceramic composite. For the analysis of the gear assembly to study structural behavior at different loading conditions an 3-D model of gear assembly was made in creo 3.0 and were imported to ansys software. Ansys was used as analysis tool in the present work to determine he total deformation, Von mises stress and the natural frequencies at various conditions.

The main objective of this paper was to study structural and vibrational characteristic of composite material gear for heavy duty transmission system in comparison to conventional steel alloy gear assembly. From this work, we can conclude that composite material taken under consideration were capable to transfer the power upto 175 KW. The weight of the gear pinion assembly of Al SiC, C-Epoxy, C-SiC is much lesser than the conventional steel. The Carbon Epoxy had the greater value of natural frequency under free vibration condition upto 10 modes and hence it can be concluded that there are less chances of resonance in carbon epoxy composite material.

J. Venkatesh et al.[6] suggested that in the gear design the bending stress and surface strength of the gear tooth are considered to be one of the main contributors for the failure of the gear in a gear set. Thus, the analysis of stresses has become important as an area of research on gears to minimize or to reduce the failures and for optimal design of gears In this work, bending and contact stresses are calculated by using analytical method as well as Finite element analysis. Modified Lewis beam strength method is used to estimate bending stress . The 3-D solid model of helical gear is generated by using Pro-e-solid modeling software . Ansys software package is used to analyze the bending stress. Modified AGMA contact stress method is used to calculate contact stresses. In this also Pro-e solid modeling software is used to generate contact gear tooth model. Ansys software package is used to analyze the contact stress of helical gear assembly. Finally both the methods bending and contact stress results are compared with each other. In this work analytical and Finite Element Analysis methods were used to predict the bending and contact stresses of involute helical gear. Bending stresses of the helical gear are calculated by using modified Lewis beam strength equation and Ansys software package. Contact stresses are calculated by using AGMA contact stress equation and Ansys software package. Analysis is carried out for different number of teeth which are 18,20 and 25 and different helix angle and different bending stress is found out as shown in the figure. Induced bending stress is a major function of number of teeth and helix angle influence is less on contact stresses. As a result, based on this finding if the material strength value is criterion then a gear with minimum number of teeth with any maximum helix angle of more face width is preferred.

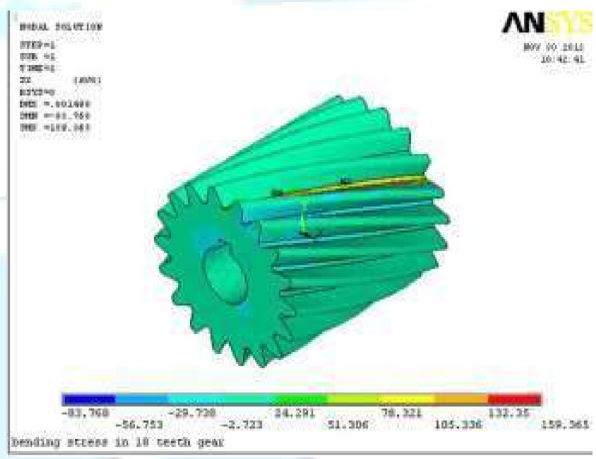

Fig 3. Bending Stress in helical gear

3. Project Objective

The objective of the project is to reduce the stress distribution, deformation and weight of helical gear using composite material in the application of gear box. The designed composite helical gear is compared with the existing gear material, such as aluminium alloy, structural steel, EN-24 and epoxy e glass fiber. The tool which is used to analyze the different materials is ANSYS. The final outputs of these analyses for all the materials are to be compared. From this comparison, the stress induced, deformation and weight for composite helical gear material are to be less than that of the general helical gear material.

4. Project Description

Model= TATA SUPER ACE
Engine= TATA475 TCIC BSIII
Material of gear = 20MnCr5
Module m_n = 3.5mm
Pressure angle ϕ = 20°
Helix angle φ= 15°
Face width b = 20mm
Pitch circle diameter of gear d_g =80mm
Number of teeth on gear Z_g = 22
Power = 40KW@4500rpm
Torque = 140Nm@2500rpm
Gear speed

$$n_g = 2500rpm$$

h_a = 1 m =3.5mm

h_f = 1.25 m = 4.37 mm

Power $P = \dfrac{2*\pi*n_g*T}{60}$

$$P = \frac{2*\pi*2500*140}{60} = 36.65KW$$

Number of teeth on pinion

$$Z_p \geq \frac{2*h_a*\cos^3\varphi}{m_n*\sin^2\phi}$$

$$Z_p \geq \frac{2*3.5*\cos^3(15^\circ)}{3.5*\sin^2(20^\circ)}$$

$$Z_p \geq 15.40$$

$$Z_p = 18$$

$$\frac{Z_g}{Z_p} = \frac{d_g}{d_p} = \frac{n_p}{n_g}$$

$$\frac{22}{18} = \frac{80}{d_p} = \frac{n_p}{2728}$$

Pitch circle diameter of pinion and speed of pinion (d_p and n_p)

$$d_p = 66mm$$

$$n_p = 3334rpm$$

Theoretical Tangential Force(F_t)

$$F_t = \frac{P}{V}$$

$$V = \frac{\pi*d_p*n_p}{60*1000}$$

$$V = 11.52m/s$$

$$F_t = \frac{40*10^3}{11.52} = 3472N$$

Velocity Factor (K_v)

$$K_v = \sqrt{\frac{78+(200V)^{1/2}}{78}} = 1.27$$

Assuming Service Factor K_a = **1** and Load Distribution Factor $K_m = 1.5$

Effective Load $F_{eff} = \dfrac{K_a*K_m*F_t}{K_v} = 4100N$

Wear Strength (F_w)

Ratio factor for helical gear $Q = \dfrac{2Z_p}{Z_p+Z_g} = 1.1$

$$F_w = \frac{d_p*b*Q*K}{\cos^2\varphi}$$

where $K = 0.16\left[\dfrac{BHN}{100}\right]^2$

$$Fw = 249\left[\frac{BHN}{100}\right]^2$$

Also,

$$F_w = N * F_{eff} \quad \text{where } N = 2.5$$

$$249\left[\frac{BHN}{100}\right]^2 = 2.5 * 4100$$

$$BHN = 641$$

Bending Stress(σ_b)

$$\sigma_b = \frac{F_{eff} * K_v * K_o * (0.93K_m)}{b * m_n * J}$$

where, K_o =Overload Factor

J = Multiplier factor = $0.42 * 0.96 = 0.4032$

$\sigma_b = 321MPa$

Tensile Strength =321 MPa

5. Material Selection

Structural Steel

Density = 7850kg/m^3
Young Modulus = 200 GPa
Poisson's Ratio = 0.3
Ultimate Tensile Strength = 460 MPa
Yield Tensile Strength = 250 MPa
Bulk Modulus = 166 MPa

Aluminium Alloy

Density = 2770 kg/m^3
Young Modulus = 71 GPa
Poisson's Ratio = 0.33
Ultimate Tensile Strength = 310 MPa
Yield Tensile Strength = 280 MPa
Bulk Modulus = 69.6 MPa

EN-24

Density = kg/m^3
Young Modulus = 193 GPa
Poisson's Ratio = 0.31
Ultimate Tensile Strength = 900 MPa
Yield Tensile Strength = 750 MPa
Bulk Modulus = 166 MPa

Epoxy E Glass UD

Density = 2000 kg/m^3
Young Modulus = 450 GPa(X Direction)
= 100 GPa(Y& Z Direction)
Poisson's Ratio = 0.3(XY & XZ)
= 0.4 (YZ)
Ultimate Tensile Strength = 1100 MPa(X Direction)
= 35 MPa(Y & Z Direction)

The Helical gear models are created by using Solidworks software. The models are then imported to ANSYS to conduct static and dynamic analysis.

6. Result and Conclusion

Analysis Results for Helical Gear in Various Materials.

Reports for Structural Steel Helical Gear

Torque = 140N-m

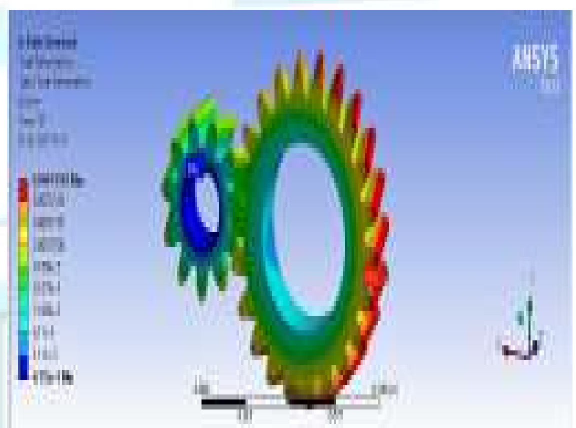

Fig 4 Total Deformation in Structural Steel

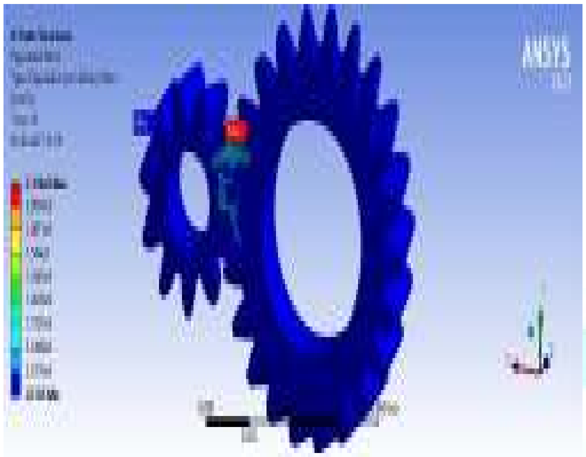

Fig 5 Von- Mises Stress in Structural Steel

Reports for Aluminium Alloy Helical Gear
Torque = 140N-m

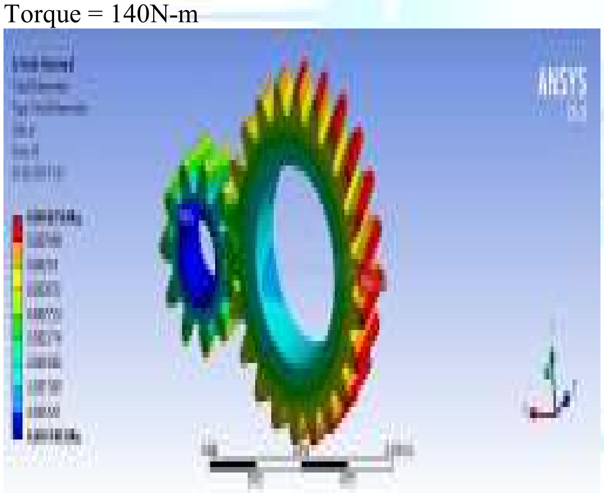

Fig 6 Total Deformation in Aluminium Alloy

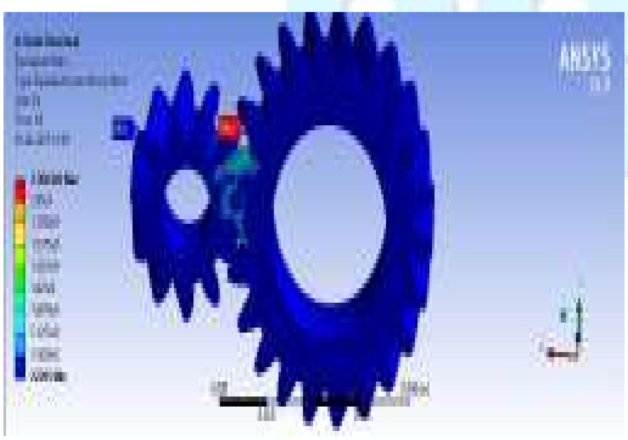

Fig 7 Von- Mises Stress in Aluminimum Alloy

Reports for EN-24 Helical Gear
Torque = 140N-m

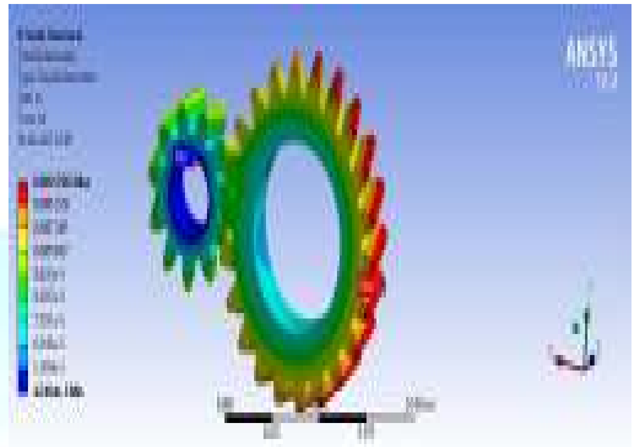

Fig 8 Total Deformation in EN-24

Fig 9 Von- Mises Stress in EN-24

Reports for Epoxy E Glass UD Helical Gear
Torque = 140N-m

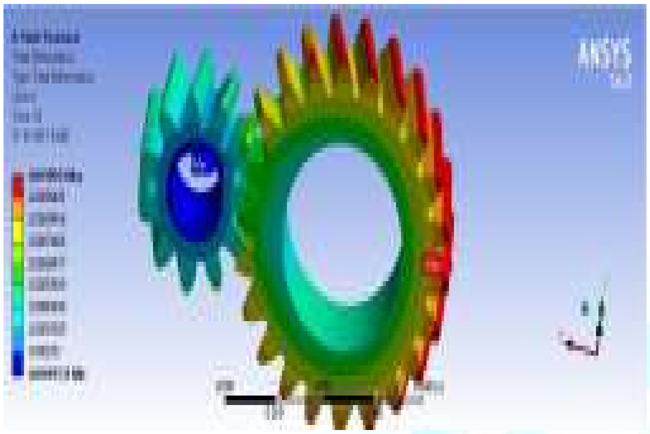

Fig 10 Total Deformation in Epoxy E Glass UD

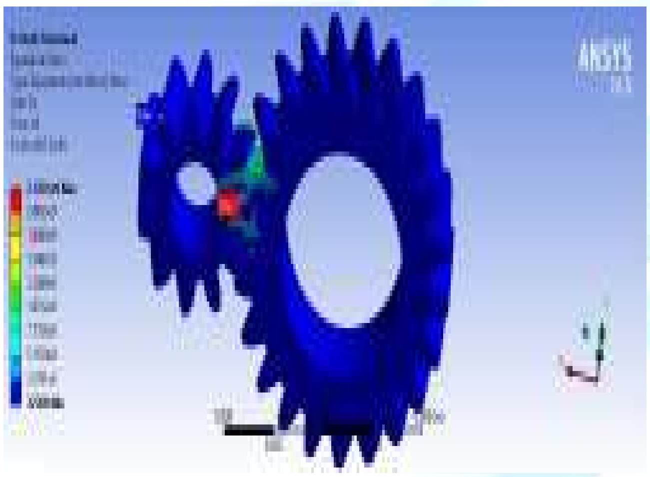

Fig 11 Von- Mises Stress in Epoxy E Glass UD

Table 1 Comparison Table for Different Materials

Material	Torque(Nm)	Total Deformation(mm)	Von Mises Stress(MPa)
Structural Steel	140	0.00013	2.31
Aluminium Alloy	140	0.0003	2.30
EN-24	140	0.00013	2.31
Epoxy E Glass UD	140	0.0019	2.32

7. Conclusion

The following conclusion can be drawn from the analysis conducted in the study.
It was concluded that the stress values calculated for all the materials are same as the existing material. Also the stress induced, deformation and weight of the alternative materials are approximately similar to the existing material. So, these materials are capable to replace the existing material in gear box to obtain better results. Amongst all the materials EN-24 is the best to replace the existing 20MnCr5 material of helical gear.

8. Acknowledgement

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