Stress Analysis of Spur Gear by using Different Materials: A Review

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ABSTRACT

Gears are machine elements used to transmit motion and power between rotating shafts by means of progressive engagements of projections. Gears have wide variety of applications. Their application varies from watches to very large mechanical units like the lifting devices and automotives. Engineering components made of composite materials find increasing applications ranging from space craft to small instruments. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. The main objective of the present work is to investigate Finite Element Analysis of the spur gear pair for different material in ANSYS software. In this paper A review has been taken for case-I purpose is to design the spur gear and study the weight reduction and stress distribution for cast steel and composite materials and results are observed. And in case-II Static analysis is performed to determine the deformation and Von-mises stresses. Analysis is done by considering different materials for gears like Structural Steel, Gray Cast Iron, Aluminium Alloy and Epoxy E Glass UD, and results are compared.

Keywords-*Spur Gear, ANSYS, Composite, Cast steel, Structural Steel, Gray Cast Iron, Aluminium Alloy, Epoxy E Glass UD*

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1. INTRODUCTION

1.1 Gear:

As per our mythological stories, Indian history is more than 12,000 years old. Since then people living here have been striving to improve the living conditions. They were living in the caves and the doors of the caves were opened and closed by none other than system with gear mechanism, wheel, lever and rope drives. The knowledge of gears has gone from India to east through some of the globe trotters from china as back as 2600 years BC. Primitive gears were first used in door drive mechanism in temples and caves and water lifting mechanism 2600BC in India and elsewhere.

Gears can be defined as toothed member which transmit power or motion between two shafts without any slip. Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness.

Gears will prevail as a critical machine element for transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology.

1.2 Classification Of Spur Gear

Gears can be classified into many types based on several criteria.

i) Gear with parallel axis
   a) Spur gear
   b) Helical gear
   c) Rack and pinion

ii) Gear with intersecting axis
   a) Bevel gear
   b) Angular Gear
   c) Miter Gear

iii) Gear with non-parallel and non-intersecting axis
   a) Worm and worm gear
   b) Hypoid gear
   c) Screw gear

1.3 Spur Gear

Spur gears are the most recognized and common type of gears. Spur gears have their teeth parallel to the axis and are used exclusively to transmit rotary motion between two parallel shafts, while maintaining uniform speed and torque. They have high efficiency and excellent precision rating.

Fig. 1 Spur Gear

Spur gears are also known as slow speed gears. The advantages of spur gears are their simplicity in design, economy of manufacture and maintenance and absence of end thrust. They are used in high speed and high load application in all types of trains and a wide range of velocity ratio. Hence they find wide application right from clocks, household gadgets, motorcycles, automobiles and railways to aircrafts.

1.4 Objective

When two gears are meshed with each other a definite velocity ratio is obtained. Gears are compact and have high transmission efficiency when compared to other power transmission system. Designing highly loaded spur gears for power transmission systems that are both strong and quiet requires analysis methods that can easily be implemented and also provide information on contact and bending stresses, along with transmission errors.

The finite element method is capable of providing this information, but the time needed to create such a model is large. In order to reduce the modeling time, a preprocessor method that creates the geometry needed for a finite element analysis may be used. So, analysis of spur gear is carried out for different material by using ANSYS and then the results are compared.

2. LITERATURE REVIEW

[1] M Jebran Khan et al. proposed ,Finite Element Analysis is one such method which has been extensively used in analysis of components used in various mechanical systems. He reported the contact stress analysis of 14.5 degree full depth involute stainless steel spur gears during the transmission of power of 10kW by theoretical method using Hertz theory and by FEA using ANSYS Workbench 14.0.He concluded that FEA provides results that are comparable with theoretical analysis results as was in the contact stress analysis of spur gears in the present study. FEA can predict whether a product will break, wear out, or work the way it was designed. Hence, FEA can prove very helpful in the product development process by forecasting its behaviour in operation.

[2] Putti Srinivasa Rao studied that The contact stress in the mating gears is the key parameter in gear design. Deformation of the gear is also another key parameter which is to be considered. The study in this paper shows that the complex design problem of spur gear which requires fine software skill for modeling and also for analyzing. The project aims at the minimization of both contact stress as well as deformation to arrive at the best possible combination of driver and driven gear.

In this process of spur gears mating, 3 different materials were selected and the software programme was performed for 9 different combinations to get the best result possible. The use of different materials in gear manufacturing provides a range of contact stresses. This range of contact stresses and deformation is useful in the selection of material in different applications. The values obtained by Hertz's equation and Ansys agree with each other with each other with a maximum error of 4% which is acceptable. The lowest contact stress is recorded when aluminum is used as both driver as well as driven gear.

[5] Bharat Gupta studied that the gear tooth failure take place if contact stresses in the gear are higher than the wear strength of the gear. For research purpose selecting one spur gear train for contact stress analysis. The contact stress can calculate by analytical method using hertz's contact stress theory for different value of module. The contact stresses can also calculated by FEA method. The model of gear train is formed in the Pro-E software and imported in the ANSYS for calculates the contact stresses. The result found by two methods are compared and concluded that difference is within reasonable limit. He observed the result and concluded that maximum contact stress decreases with increasing module of gear. The contact stresses are higher at the pitch point of the gear.

[6] Sachindra Kumar presented that Gears analysis in the past was performed using analytical methods, which required a number of assumptions and simplifications. In general, gear analyses are multidisciplinary, including calculations related to the tooth

stresses and to tribological failures such as like wear. Designing highly loaded spur gears for power transmission systems that are both strong and quiet requires analysis methods that can easily be implemented and also provide information on contact and bending stresses, along with transmission errors. The finite element method is capable of providing this information. The finite element method is very often used to analyze the stress state of an elastic body with complicated geometry, such as a gear. The finite element method with special techniques, such as the incremental technique of applying the external load in the input file, the deformation of the stiffness matrix, and the introduction of the contact element were used. It was found that initial loading using displacements as inputs was helpful in reducing numerical instabilities.

3. MODELING AND ANALYSIS OF SPUR GEAR PAIR

In this paper, analysis is carried out in two cases which are as follows:

3.1 Case-I

Analysis of spur gear for Cast Steel and composite material

3.1.1 Objective

In this case objectives are :

- To study the impact analysis for cast steel and composite materials.
- To study the torque loading for cast steel and composite materials.
- Finally, comparing and analyzing of the composite gear with existing cast steel gear is to be done.

3.1.2 Calculation of Gear tooth properties

Pitch circle diameter (p.c.d) = z*m = 18*10 = 180mm
Base circle diameter (Db) = D cos α
= 180*cos20
= 169.145mm
Outside circle diameter = (z+2)*m= (18+2)*10 = 200mm
Clearance = circular pitch/20 = 31.4/20 = 1.57mm
Dedendum = Addendum + Clearance = 10+1.57 = 11.57mm
Module = D/Z = 180/18 = 10mm
Dedendum circle diameter = P.C.D -2*dedendum
= 80-2*11.57= 156.86mm
Fillet radius = Circular pitch/8 = 31.4/8 = 3.9mm
Pitch circle diameter (Pc) = m*z = 10*18 = 180mm
Hole depth = 2.25*m = 2.25*10 = 22.5mm
Thickness of the tooth = 1.571*10 = 15.71mm
Face width (b) = 0.3*180= 54mm
Center distance between two gears = 180mm
Diametral pitch = Number of teeth/P.C.D= 18/180= 0.1mm

Properties of Cast Steel
Density = 7870 kg/m3
Young modulus = 200 GPa
Poisson's ratio = 0.29
Tensile strength = 518.8 MPa
Ultimate Tensile Strength = 540 MPa
Yield Tensile Strength = 415 MPa
Bulk modulus = 140 GPa

Properties of Composites (50% Carbon Fibers in Epoxy Resin Matrix)
Density = 1800 kg/m3
Young modulus = 450 GPa
Poisson's ratio = 0.30
Tensile strength = 52 MPa
Compressive strength = 600 MPa
The Spur Gear models are created by using Solid works software. The models are shown below.

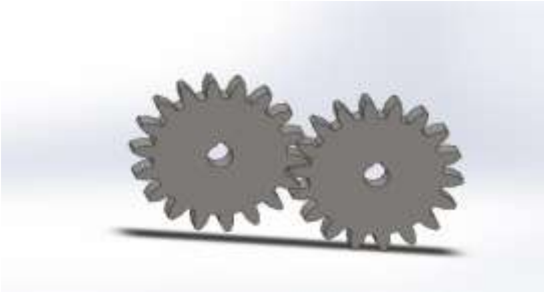

Fig. 2 Spur Gear Model

3.1.3 FE Analysis

Analysis Results for Spur Gear in ANSYS 13.0 in Various Materials are as follows: a) FE Analysis in Cast Steel
TORQUE T = 140N-m; SPEED N = 2500 rpm

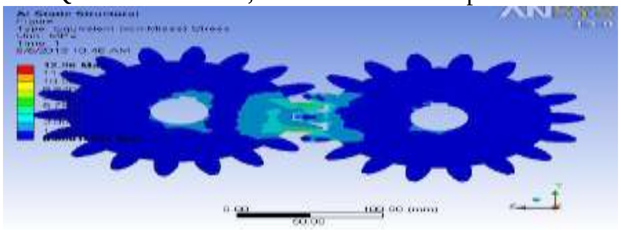

Fig. 3 Von-Mises Stress in cast steel

Maximum Von-mises stress Distribution of Spur Gear in Cast steel is 12.96 MPa

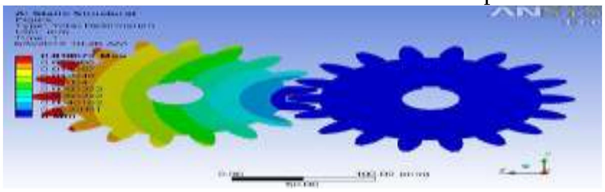

Fig.4 Total Deformation in Cast steel

Maximum deformation of spur gear in cast steel is 0.0180 mm.

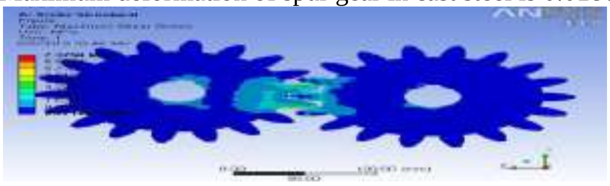

Fig 5 Maximum Shear Stress in Cast steel

Maximum Shear Stress of Spur Gear in Cast steel is 7.375 MPa
b)FE Analysis in Composite material in Various Torques TORQUE T = 140N-m; SPEED N = 2500 rpm

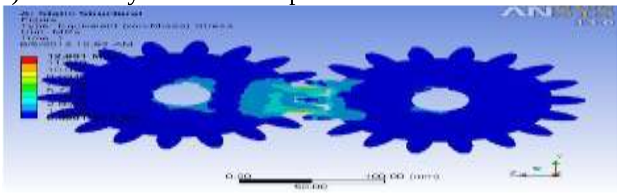

Fig. 6 Von-mises stress in Composite material

Maximum Von-Mises Stress Distribution of Spur Gear in Composite materials is 12.891 MPa

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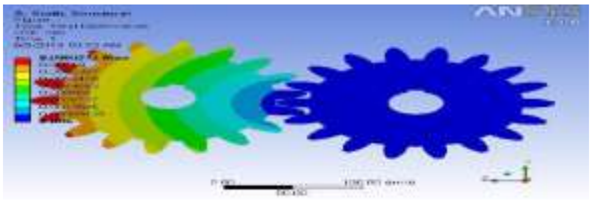

Fig.7 Total deformation in composite material

Maximum Deformation of Spur Gear in Composite materials is 0.00713 mm.

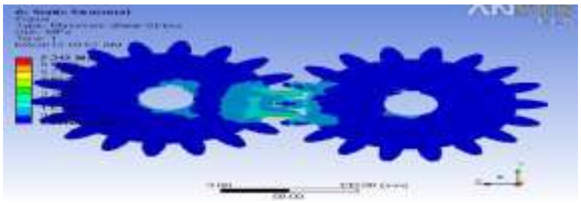

Fig. 8 Shear stress in composite materials

Maximum shear stress of Spur Gear in Composite materials is 7.342 Mpa

3.1.4 Result and discussion

	Cast steel	Composite materials	% Difference
Von-mises stress (MPa)	12.9 60	12.8 91	0.5324
Total deformation (mm)	18.073 e- 3	8.02 1 e- 3	55.619
Maximum shear stress (MPa)	7.37 6	7.34 2	0.4610

Table 1 Summary Of Result

3.2 Case-II

Analysis of spur gear for structural Steel, gray cast iron, aluminium alloys and and Epoxy E Glass UD

3.2.1Objective

In this case the objectives are :

- To reduce the stress distribution, deformation and weight of spur gear by using composite materials in the application of gear box.
- To compare the designed composites gear with the existing gear materials, such as structural steel, gray cast iron and aluminium alloy.

3.2.2 Calculations of Gear Tooth Properties:

Module = D/Z = 180/18 = 10mm
Pitch circle diameter (P.C.D) = Z×m = 18×10 = 180mm
Base circle diameter (Db) = D cos α
= 180×cos20 = 169.145mm
Outside circle diameter = (Z+2) ×m= (18+2) ×10 = 200mm
Clearance = circular pitch/20 = 31.4/20 = 1.57mm
Dedendum = Addendum + Clearance = 10+1.57 = 11.57mm
Dedendum circle diameter = (P.C.D -2)×dedendum = (80-2) ×11.57= 156.86mm
Fillet radius = Circular pitch/8 = 31.4/8 = 3.9mm
Hole depth = 2.25×m = 2.25×10 = 22.5mm
Thickness of the tooth = 1.571×10 = 15.71mm
Face width (b) = 0.3×180= 54mm
Center distance between two gears = 180mm
Diametral pitch = Number of teeth/P.C.D= 18/180= 0.1mm
Materials Selection:

Structural Steel:

Density = 7850 kg/m3
Young modulus = 200 GPa
Poisson's ratio = 0.3

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Ultimate Tensile Strength = 460 MPa
Yield Tensile Strength = 250 MPa
Bulk modulus = 166 GPa
Gray Cast Iron:
Density = 7200 kg/m3
Young modulus = 110 GPa
Poisson's ratio = 0.28
Ultimate Tensile Strength = 430 MPa
Ultimate Compressive Strength = 820MPa
Yield Tensile Strength = 276 MPa
Bulk modulus = 83.3 GPa
Aluminium Alloy:
Density = 2770 kg/m3
Young modulus = 71 GPa
Poisson's ratio = 0.33
Ultimate Tensile Strength = 310 MPa
Yield Tensile Strength = 280 MPa
Bulk modulus = 69.6 GPa
Epoxy E Glass UD:
Density = 2000 kg/m3
Young modulus = 450 GPa (X Direction)
= 100 GPa (Y& Z Directon)
Poisson's ratio = 0.3 (XY & XZ)
= 0.4 (YZ)
Ultimate Tensile Strength = 1100 MPa (X Direction)
= 35 MPa (Y&Z Direction)
The Spur Gear models are created by using Solid works software. The model is shown below:

Fig. 9 Spur Gear Model

This model is exported to HyperMesh to mesh the component with element size=0.001 and element type = trias
The Number of Nodes formed=309591
Number of Elements=68448
Then, the meshed model is imported into ANSYS Workbench to conduct static structural analysis, modal analysis.
3.2.3 FE Analysis
Analysis Results for Spur Gear in ANSYS 15.0 in Various Materials are as follows:
a) FE Analysis in Structural Steel

Torque =135 N.m

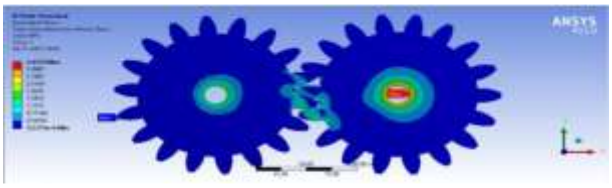

Fig.10 Von-mises stress
Maximum Von-mises stress in structural steel is 3.4724 MPa

Fig.11 Total deformation

Maximum deformation in structural steel at T=135 N.m is 0.0015 mm

b) FE Analysis in Gray Cast Iron

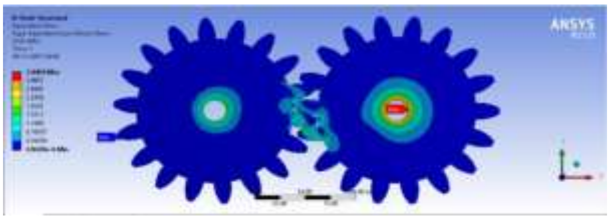

Fig. 12 Von mises stress

Von-mises stress in Gray Cast Iron at T=135 N.m is 3.4464 MPa

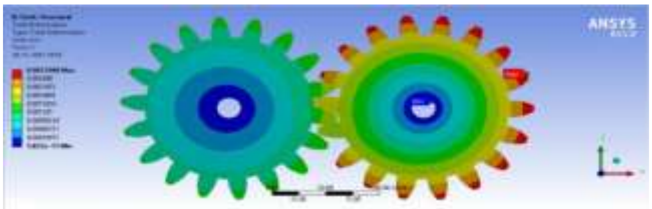

Fig. 13 Total Deformation

Total deformation in Gray Cast Iron at T=135 N.m is 0.0027 mm.

c) FE Analysis in Aluminium Alloy

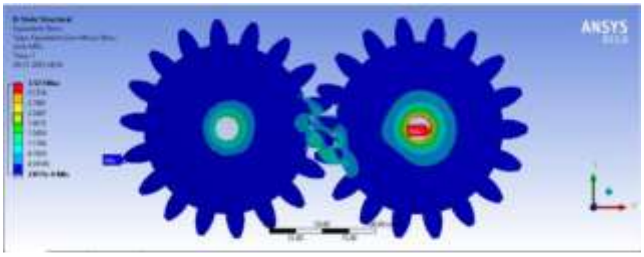

Fig. 14 Von mises stress

Maximum Von-mises stress in Aluminium Alloy at T=135 N.m is 3.5230 MPa

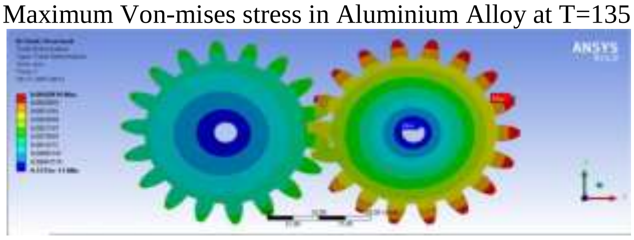

Fig. 15 Total deformation

Maximum deformation in Aluminium Alloy at T=135N.m

d) FE Analysis in Epoxy E Glass UD

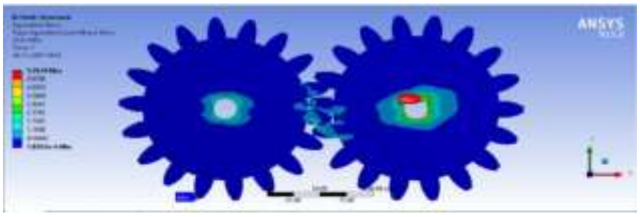

Fig. 16 Von mises stress

Maximum Von-mises stress in Epoxy E Glass UD at T=135 N.m is 5.2634 MPa.

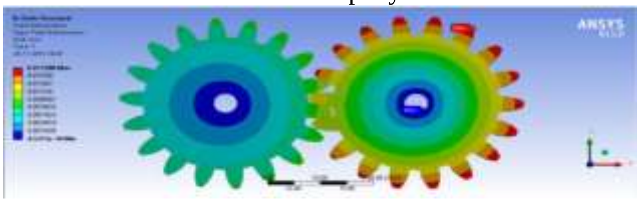

Fig. 17 Total Deformation

Maximum deformation in Epoxy E Glass UD at T=135 N.m is 0.0173 mm.

The above results are compared and shown in the following table:

	Structural steel		Gray cast iron		Aluminium alloys		Epoxy E Glass UD	
Torque	135	140	135	140	135	140	135	140
Deformation	0.0015	0.0015	0.0027	0.0028	0.0042	0.0044	0.0173	0.0179
Von mises stress	3.4724	3.6010	3.4464	3.5741	3.5230	3.6535	5.2634	5.4583

Table 2

4. CONCLUSION

Case-I

- On the basis of that study, the analysis of both cast steel and composite materials are analyzed in the application of gear box which is used in automobile vehicles.
- From these analysis it can be found that stress values for composite materials is less as compared to the cast steel spur gear.
- So from these analysis results, it can be conclude that, the stress induced, deformation and weight of the composite spur gear is less as compared to the cast steel spur gear.
- So, Composite materials are capable of using in automobile vehicle gear boxes up to 1.5KN in the application of Tata super ace model instead of existing cast steel gears with better results.

Case-II

- From the study it was concluded that the stress values are calculated for composite materials is approximately same as compared to the structural steel, gray cast iron and aluminium alloy.
- So from these analysis results, it can be conclude that, the stress induced, deformation and weight of the composite spur gear is almost same as compared to the structural steel spur gear, gray cast iron spur gear and aluminium alloy spur gear.
- So, Composite materials are capable of using in automobile vehicle gear boxes instead of existing cast steel gears with better results.

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