

Design and Analysis of Composite Spur Gears for Weight reduction

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Abstract

Gears are one among the most critical components in mechanical power transmission system. They have major applications in fields like automotives, industrial rotational machines, watches, lifting devices, etc. Gears are usually subjected to fluctuating loads while in action. Gear tooth mainly fails due to excessive bending stress and excessive contact stress. Thus it is very important to analyze the stresses induced in gear, while designing it for the safety operation. Weight reduction of gear is also one of the most important design criteria as it has a great role in efficiency of the entire system.

Engineering components made of composite materials and plastics find increasing applications nowadays. The components made from composite materials provide reasonable mechanical properties with minimum weight. In this paper, the spur gear and pinion assembly is modeled in "PTC Creo" and imported to "ANSYS Workbench 15.0" for static structural analysis. Analysis is done by considering different materials for gears like Structural Steel, Polycarbonate and AlSiC(20%).

Keywords: *Gears, contact stress, Structural Steel, AlSiC-20%*

I. INTRODUCTION

Gears are one of the oldest of humanity's inventions which have same importance in nowadays also. Gears are machine

elements used to transmit rotary motion between any two shafts with a constant ratio. Nearly all the machines utilize gearing of one type or another. Thus

gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. The pinion is the smallest gear and the larger gear is called the gear wheel.

Gear design has evolved to such a level that throughout the motion of each contacting pair of teeth the velocity ratio of the gears is maintained fixed and the velocity ratio is still fixed as each subsequent pair of teeth come into contact. When pinion is the driver, it results in step down drive in which the output speed decreases and the torque increases. On the other hand, when the gear is the driver, it results in step up drive in which the output speed increases and the torque decreases.

Gears are classified according to the shape of the tooth pair and disposition into spur, helical, double helical, straight bevel, spiral bevel and hypoid bevel, rack and pinion, worm and spiral gears, etc. Spur gears have their teeth parallel to the axis and are used for transmitting power between two parallel shafts. They are used in high speed and high load application in all types of trains and a wide range of velocity ratios. Hence, they find wide applications right from clocks, household gadgets, motor cycles, industrial rotational

machines, automobiles, and railways to aircrafts.

A systematic literature survey provides an opportunity to, specifically review various methods used to solve problems similar to here. Robert Handschuh et.al, [3] from NASA Glenn Research Center designed, fabricated and tested a Composite spur gear. The Hybrid Gear was tested against an all-steel gear and against a mating Hybrid Gear for a specified number of cycles. Although the design was not optimized for weight, the composite gears were found to be 20 percent lighter than the all-steel gears.

Abhisek Panda, Prabhu Kalyan Mohapatra, [4] had an investigation describing about the wear characteristics of Al-Si alloys and Al-SiC composite using particle erosion test and pin-on-disc wear test at room temperature. Here Si and SiC, having 10% and 5% (weight percentages) are taken with Aluminium by stir casting method. It is found that addition of silicon/ silicon carbide improves the wear resistance, machinability, and corrosion resistance. It is observed, Al-SiC particulate composite bear's higher hardness than that of Al-10%Si alloy.

Ali Hubi Haleem, Newal Muhammad Dawood [5] prepared Silicon carbide particle reinforced aluminum matrix composite (AMCs) by stir-casting with different particle weight fraction 5, 7, & 10%. The hardness and material toughness were increased 1.84 and 2.16 times respectively at particles weight fraction (10%) that of the unreinforced aluminum based on the high hardness and deformation resistance of the silicon carbide particles. The finding was that mechanical properties improvements are mainly due to the highly hardness silicon carbide particles.

Habibur Rahman, Mamun Al Rashedb [6] purpose of work was to study about the microstructures, mechanical properties and wear characteristics of silicon carbide (SiC) reinforced aluminum matrix composites (AMCs). AMCs of varying SiC contents (0, 5, 10 and 20 wt. %) were prepared by stir casting process. The results showed that introducing SiC reinforcements in aluminum (Al) matrix increased hardness and tensile strength and 20 wt. % SiC reinforced AMC showed maximum hardness and tensile strength.

Manoj Singla et.al, [7] taken Al-SiC composites containing four different weight percentages 5%, 10%, 20% and

25% of SiC, which have been fabricated by liquid metallurgy method. It was found from the experimentation that the wear rate decreases linearly with increasing weight fraction of silicon carbide and average coefficient of friction decreases linearly with increasing normal load and weight fraction of SiC. The best results have been obtained at 20% weight fraction of 320 grit size SiC particles for minimum wear.

Maheub Vohra, Kevin Vyas [8] starts from the point that gears are generally made from metallic materials but recently advanced polymers were developed which have sufficient strength and properties similar to the metallic materials so they can easily replace the metallic gears. They also pointed that polymer gear gives extra benefits compared to metallic gears like less noise-vibration, low requirement of maintenance-lubrication, low cost, less weight and easy manufacturing. They also found that while increasing the face width and module, bending stress is decreased for polymer gears.

Samadhan Lande et.al, [9] advised to replace the metallic gear of sugarcane juice machine with plastic gears to reduce the weight as well as noise. For this purpose Nylon and Polycarbonate plastic

materials were considered and their feasibilities are checked with respect to metallic gear (Cast iron). They inferred that plastic gears are suitable for the application of sugarcane juice machine under only limited load conditions as compared to Cast Iron spur gears. It is also recommend that the best plastic material is Polycarbonate for safe and light weight design.

The Gears made from conventional materials such as structural steel withstand high torque and loads, but have a significant limitation that they are very heavy in weight as they are having high density. As a solution for this, gears made from a thermoplastic material can be used to reduce weight, but the thermoplastic gears cannot withstand high torque load forces without damaging the gear teeth, and are more susceptible to wear than metal gears.

To solve the respective problems of metal and thermoplastic gears, a number of attempts have been made to manufacture composite gears. In this paper, design and analysis of a spur gear made up of composite material AlSiC-20% is carried out. The contact stress results are compared with those results of structural steel gears, which are widely in use.

II. GEAR-PINION ASSEMBLY

The spur gear is simplest type of gear manufactured and is generally used for transmission of rotary motion between parallel shafts. The spur gear is the first choice option for gears except when high speeds, loads, and ratios direct towards other options. Other gear types may also be preferred to provide more silent low-vibration operation. A single spur gear is generally selected to have a ratio range of between 1:1 and 1:6 with a pitch line velocity up to 25 m/s. The spur gear has an operating efficiency of 98-99%.

An involute gear is based on an involute curve, which is a mathematical shape. To understand what an involute is, consider a simple cylinder and a string as shown below. Wrap the string around the cylinder.

While maintaining tension on the string, trace the path that the end of the string makes while un-wrapping it around the cylinder. This path is an involute curve. There are two key parameters that control the involute curve: the diameter of the cylinder and the angle that the string is un-wrapped around the cylinder.

A. Specifications of spur gears (pinion)

Table 1 Spur gear dimensions

S. No.	Parameter	Value
1	Profile	Involute
2	Pressure angle	20 degree
3	Pitch circle diameter	48 mm
4	Number of teeth	12
5	Module	4 mm
6	Addendum	4 mm
7	Dedendum	5 mm
8	Face width	22 mm
9	Root fillet radius	1.2 mm
10	Rim thickness	5 mm
11	Outside diameter	56 mm
12	Root diameter	38 mm
13	Base diameter	45.11 mm
15	Bore Diameter	14 mm
16	Keyway	5×5

B. Modeled Gear

The gear and pinion had been modeled separately as parts and assembling had been done afterwards. The modeling software used for this purpose is PTC creo 2.0. The assembled model is shown in fig.1.

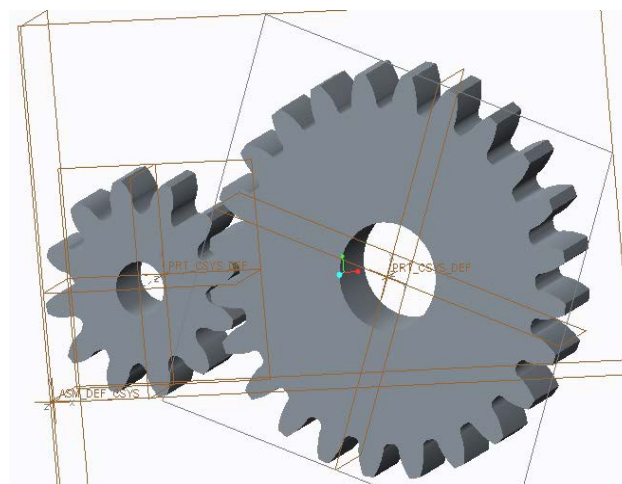


Fig.1. Gear-Pinion assembly

III. CONTACT STRESS

Contact Problem Despite the importance of contact in the mechanics of solids and its engineering applications, contact effects are not always taken seriously into account in conventional engineering analysis because of the extreme complexities involved in it. Mechanical problems involving contacts are inherently nonlinear. It is “nonlinear” in behavior is because usually the loading causes significant changes in stiffness, which results in a structure that is nonlinear. Nonlinear structural behavior arises for a number of reasons, which can be reduced to three main categories: Geometric Nonlinearities (Large Strains, Large Deflections), Material Nonlinearities (Plasticity) and Change in Status Nonlinearities (Contact). So the contact between two bodies belongs to the last case.

The modeling of friction is very difficult as the friction depends on the surface smoothness, the physical and chemical properties of the material, the properties of any lubricant that might be present in the motion, and the temperature of the contacting surfaces. There are several friction laws and models to choose from, and all are nonlinear. Frictional response can be chaotic, making solution

convergence difficult in ANSYS. With the rapid development of computational mechanics, however, great progress has been made in numerical analysis of the problem. Using the finite element method, many contact problems, ranging from relatively simple ones to quite complicated ones, can be solved with high accuracy. The Finite Element Method can be considered the favorite method to treat contact problems, because of its proven success in treating a wide range of engineering problem in areas of solid mechanics, fluid flow, heat transfer, and for electromagnetic field and coupled field problems.

A. Inputs for Analysis:

The material property values (Young's modulus, Poisson's ratio and Density) of different materials, which are considered here, are given in table 2.

B. Loads acting:

For a specific industrial application, we need to transmit a power of 7300 W. The force and torque requirements are 2406 N and 57.744Nm respectively, so that it will rotate at a speed of 1200rpm.

Table 2 Material properties

Material Property	Structural steel	Polycarbonate	AlSiC(20%)
Young's Modulus (N/mm ²)	200 x 10 ³	2.75 x 10 ³	200-230 x 10 ³
Poisson's Ratio	0.3	0.38	0.3
Density (Kg/mm ³)	7.85 x 10 ⁻⁶	1.1 x 10 ⁻⁶	2.95-3 x 10 ⁻⁶

Materials to be considered for contact stress analysis:

As the main analysis to be done here is contact stress analysis, we have to finalize the materials on which contact stress analysis is to be carried out. So bending stress has been found out using Lewis equation, for the gear dimension (Because analysis is to be carried out to materials which are able to bear the bending stress). Then the allowable bending stress value for each material is compared with the Lewis contact stress value.

Lewis equation: Tangential load $F = \sigma_b * y * P_c * b$

Where,

σ_b = Allowable stress

y = Lewis form factor

P_c = (Circular pitch)

$= \pi * \text{module}$

B = Face width of the gear

D = Pitch circle diameter of the gear

The results found from Lewis equation is that bending stress for the gear using Lewis equation is 37.85Mpa. So we have to compare it with allowable stress values of each material by taking, Allowable stress = UTS/3.

Thus Allowable stress for different materials can be found out using the equation. The allowable stress value for structural steel is 153.33Mpa, and hence it is safe to use as gear material in this particular application. The allowable stress

value for polycarbonate is found to be 21.66Mpa, and hence it is not safe to use as a material for gear here. But AlSiC-20% is safe to use as a gear material as it have a allowable stress value of 46.667Mpa,

which is greater than bending stress value obtained from Lewis equation.

Therefore structural steel and AlSiC-20% only have to be considered in contact stress analysis.

IV. CONTACT STRESS ANALYSIS

The contact analysis results, which are carried out using Ansys Workbench 15.0, is shown below:

A. Contact Stress Analysis Results:

I. Structural Steel

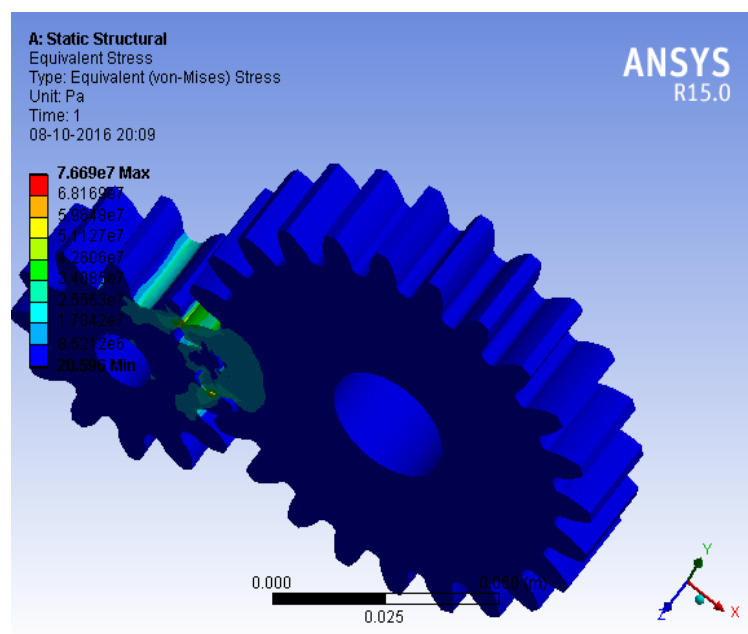


Fig.1. Contact stress for structural steel

The obtained value of Von- Mises stress from workbench is 76.69MPa (from fig.1). Allowable contact stress from equation is found to be 345MPa. Hence the design can be called as safe for required loading condition, if structural steel is used for manufacturing it.

II. AlSiC-20%

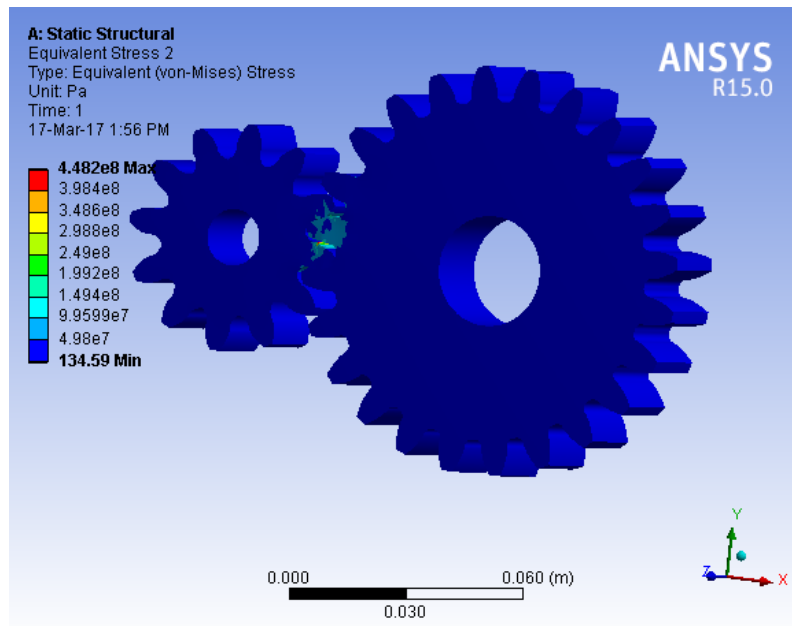


Fig.2. Contact stress for AlSiC-20%

The obtained value of Von- Mises stress from Ansys workbench is 448.2MPa. Allowable contact stress from equation is found to be 322.5MPa. Hence the design is not safe if AlSiC-20% is the gear material.

Therefore it is better to try the same analysis procedure with increasing face width from 22mm such that the value of contact stress is almost same as that of the structural steel.

For this design optimization process, the analysis is done as an iterative process by increasing the face width each time and carried out the same analysis up to a appoint when the satisfactory result came.

The satisfactory results of contact stress value are only shown here.

B. Analysis Results with increased face width:

I. AlSiC (20%)- Face width-31mm

The obtained value of Von- Mises stress from Ansys workbench, of AlSiC-20% with face width-31mm is 85.89MPa. Allowable contact stress from equation can be obtained as 322.5MPa. Hence the design can be said as a safe one.

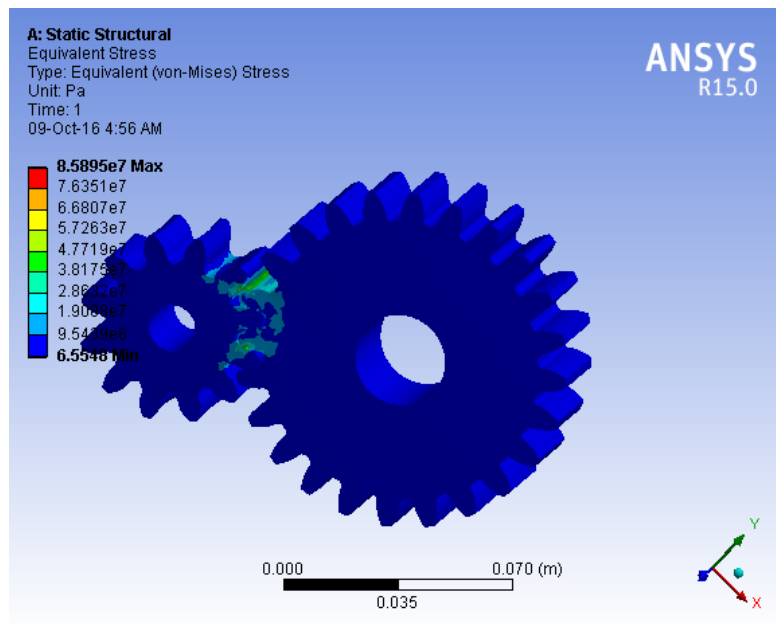


Fig.3. Contact stress for AISiC-20%

II. AISiC (20%)- Face width-32mm

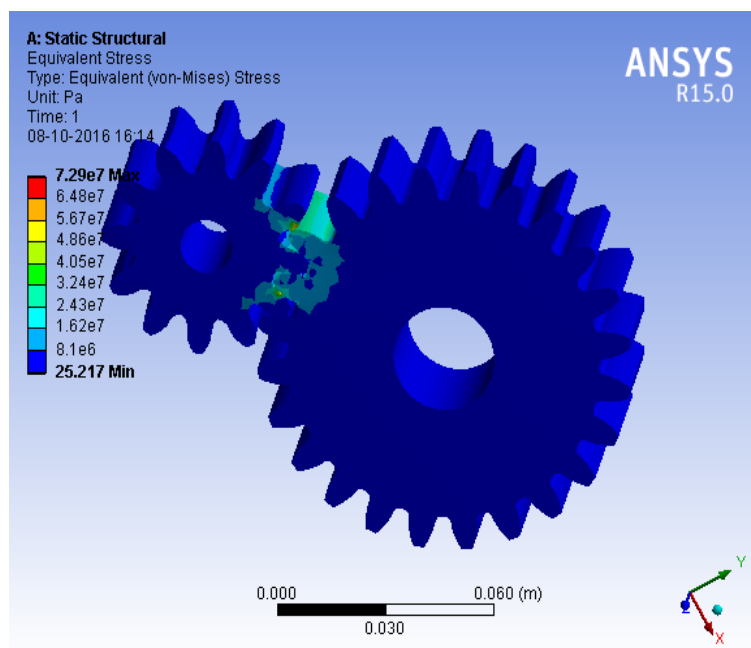


Fig.4. Contact stress for AISiC-20%

The obtained value of Von- Mises stress from Ansys workbench for AlSiC-20% with face width-32mm is 72.9 MPa. Allowable contact stress from equation is obtained as 322.5MPa. Hence the design can be called as a safe one. Value of contact stress for structural steel (76.69Mpa) with face width 22 mm, is closer to the contact stress value for AlSiC-20% with 32mm face width.

V. RESULT

Mass of Structural steel for face width 22mm is found to be 1.4086 kg. And the mass of AlSiC-20% for different face widths are shown in table 3.

Table 3. Mass and face widths for AlSiC-20%

FACE WIDTH (AlSiC) - mm	MASS - kg
31	0.75845
32	0.78292

Thus percentage reduction of mass (for same contact stress condition), while replacing structural steel with AlSiC-20%, is found to be 44.625%.

CONCLUSION

Numerical Investigation of spur gears made up of different materials are carried out to find the mass reduction that can be

obtained by replacing the structural steel gear by polycarbonate or AlSiC-20% composite. The polycarbonate material is found to be fail in bending stress and therefore did not considered for contact stress analysis. The contact stress developed for same dimension (face width=22mm) is more on composite (AlSiC-20%), while comparing with structural steel. For the same contact stress as structural steel gear with 22mm face width, AlSiC require about 32mm face width. Thus for same contact stress condition, AlSiC material have a mass reduction of 44.625% - which makes it suitable for light weight applications.

The works carried out up to this point can be extended in various areas. Theoretical calculation of contact stress and comparison with analysis result can be done. Also Manufacturing and testing of gears made up of AlSiC-20% and compare the results with that of structural steel (Validation) can be done. It will be useful if searching for more materials which will give improved results than AlSiC-20%.

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