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Analysis of Composite Material Spur Gear under Static Loading Condition

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Abstract

Spur gears are the simplest and widely used in power transmission. 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 metallic gears of steel alloy and Aluminium Silicon carbide composite have been manufactured. Composites provide much improved mechanical properties such as better strength to weight ratio, more hardness, and hence less chances of failure. So this work is concerned with replacing metallic gear with composite material so as to improve performance of machine and to have longer working life. Efforts have also been carried out for modeling and finite element analysis of gears using ANSYS 14.0. Composite gears have been manufactured by stir casting, which is economical method. Composite gears offer improved properties over steel alloys and these can be used as better alternative for replacing metallic gears.

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*Keywords:*Spur Gear,MMC,Finite Element Analysis,Gear teeth bending test

1. Introduction

Gears are the most common means of transmitting power in mechanical engineering. With the moving wheel of science and technology the use of gears has become more common in all the upcoming industries. The advantages of spur gear are their simplicity in design, can be manufactured economically and less maintenance and absence of end thrust.

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[1] Gear is a component within a transmission device that transmits rotational torque by applying a force to the teeth of another gear or device.[2] Recently metal matrix composite (MMC) materials are used to manufacture a number of engineering components, due to their unique advantages, such as light weight, high strength, higher dimensional stability and corrosion resistance, when compared with polymer-based composite materials, though the cost of MMCs are very high.[3,5] Power transmission gears are one such area able to make use of MMC materials. [4]

Al- SiC composite can be produced by powder metallurgy or stir casting and it provides improve hardness and tensile strength with much reduction in weight.[10,11,12]Some wetting agent is required to be added for improving wettability of SiC particles onto the molten aluminum. Sometimes Fly ash, Borax powder or magnesium is added to improve the wettability. There are various standards available for gear design and numbers of factors are required to be considered for designing a gear. [6,8] 3D modeling software CATIA has been used for modeling and Finite Element analysis is done in ANSYS 13.0

It is required to operate gears under oil less condition in many modern types of machinery. 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.

Nomenclature

κ - Fibre area correction factor
N-RPM of gear
V- Linear Velocity of Gear
Y-Lewis Form Factor
m- Module
C_s- Service factor
C_v- Velocity factor
E_1,E_2- Young’s modulus of gear material
Ec - Young's modulus of the composite
Ef -Young's modulus of the fibre
Em - Young's modulus of the matrix
P_{eff} −Effective Load on gear teeth
P_t-Tangential Component of resultant force
S_b − Bending Strength
S_{ut}- Ultimate Tensile strength of gear material
Vf - fibre volume fraction
Vm - matrix volume fraction (1-Vf-Vv)
Vv = void volume fraction
Y_m-Material coefficient
Z_p- Number of Teeth on pinion
σ_b − Bending stress
ηd - fibre diameter distribution factor (set at unity for man-made fibers)
ηl- fibre length distribution factor
ηo - fibre orientation distribution factor
α- pressure angle

2. Power Rating Of Spur Gear As Per Is:4460

Method for rating spur and helical power transmitting gears connecting parallel shafts and meant for general engineering applications has been specified in IS: 4460. The Method primarily deals with checking of power transmitting capabilities of a gear set when the relevant parameters, such as material, gear dimensions, speed, are known so as to ensure whether the particular drive meets with the requirements. For this purpose, a set of formulae along with the values of the basic stress factor s for common gear materials as well as other relevant factors, e.g. speed factors, zone factors, pitch factors, has been specified.

The power rating of spur and helical gears is divided into

(i) horse power for strength, and

(ii) Horse power for wear. These are given by

Horse power for strength

$$PS=\frac{X_b \times Y \times S_b \times b \times m^2 \times n \times z}{25.4} \times \frac{1774}{10^8} \quad (1)$$

Horse power for wear

$$PS=\frac{X_b \times Y_f \times S_b \times b \times m \quad \times n \times z}{K} \times \frac{1774}{10^8} \quad (2)$$

3. Preparation of Composite

Aluminium based SiC particulate metal matrix composite has been prepared by stir casting. For preparing Aluminium silicon carbide composite by using stir casting mass basis ratios of 100:3, 100:6, 100:9,100:12,10:15 and 100:18 have been taken. Figure 1 shows the stir casting device used for preparing composite. The raw material for composite preparation has been used in the form of aluminium ingots. These metal ingots have been cleaned and melted to the temperature of 750ºC in graphite crucibles. A three-phase electrical resistance furnace with temperature controlling device has been used for melting. For each melting 300 - 400 g of alloy has been used. SiC particles, preheated to around 500ºC, have been then added and stirred continuously by a mechanical stirrer at 720ºC. The stirring has been carried out for 5 to 8 minutes. During stirring, Magnesium have been added in small quantities to increase the wettability of SiC particles.

"Cover all" powder has been added to flux impurities and degasifier tablets have been used for removing air bubbles from molten metal.

Spur gears have been manufactured by cutting teeth on gear blanks by form cutter on milling machine. A semi permanent sand mould prepared for making test samples having 110mm diameter. Gears have been designed for transmitting 5HP power at 1440 rpm according to Lewis theory.

Fig.1 Stir Casting Set Up

Fig. 2 Specimen for Tension Test

4. Mechanical Testing Of Samples

The mould has been prepared for casting specimen for various mechanical tests. Hardness test of composite samples have been conducted on Automatic Optical Brinell Hardness Tester (Make FIE India, Range 250kg to 3000 kg). Hardness values have been found to be increasing with increase in SiC content. Tensile testing has been carried out on UTM (Make FIE, Range up to 600 kN).Results of these tests are have been mentioned in Table 1.The microstructure has been observed on optical microscope (make Olympus, Japan, Range 1000X max). The samples have been round in cross section having 18mm diameter and gauge length has been kept 90mm.

Hardness values have been taken at three different sections and it has been found that hardness is increasing with increase in SiC percentage. Highest value of 91 BHN has been obtained at 15% SiC content and maximum tensile stress of 151 N/mm^2 has been obtained for 18% SiC content. So Al+18% SiC has been selected for designing spur gear. A sudden rise in hardness value has been observed when SiC percentage increased from 12% to 15%. Chemical analysis revealed the reason for same, as highest percentage of Silicon has been retained in sample. Table 2 shows chemical analysis results.

Table 1 Test Results

Specimen	Composition		Results	
Sample No	Al(%) gm	SiC(%)gm	Average Hardness (BHN)	Tensile strength (N/mm^2)
01	100	3	41.33	105.4
02	100	6	42.66	99.2
03	100	12	46.66	132.62
04	100	15	91.66	129.16
05	100	18	59.33	151.94

Table 2 Chemical Analysis Results

Element	**Si**	**Ni**	**Cu**	**Al**	**Mg**
Sample 1	1.32	0.01	0.099	97.26	0.040
Sample 2	2.06	0.071	0.060	95.12	0.067
Sample 3	1.38	0.012	0.091	97.35	0.150
Sample 4	8.55	0.034	1.080	84.48	0.091
Sample 5	3.33	0.010	0.650	94.08	0.079

5. Design Of Gears

Lewis formula and Hertz Equation have been derived to account for various factors which have influence on gear rating. Gear design engineering is not an exact science; it is a mixture of art and science. Two criterions have been considered for designing spur gear i.e Bending strength and contact stress. According to these two theoretical formulas have been used for designing gears.

a) Lewis Formula
b) Hertz Theory

Lewis Formula is used for designing gear. Some of the equations used in design of gear are mentioned here.

$$P=\frac{2\pi n_1\times M_t}{60} \tag{3}$$

$$m=\left\{\frac{60\times10^6}{\Pi}\left[\frac{Kw\times C_s\times F.S.}{Z_p\times n_1\times\frac{S_{ut}}{3}\times\left(\frac{b}{m}\right)\times Y\times C_v}\right]\right\}^{\frac{1}{3}} \tag{4}$$

$\phi_m=\frac{b}{m}$ =10(Initially assumed)

$$\sigma b=\frac{(i\pm1)*[M_t]}{a*m*b*y} \tag{5}$$

Here y=form factor for corrected Z_1

6. Finite Modeling of Spur Gears

Models for numerical analysis have been prepared in CATIA v5 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.

Young's modulus of a composite material is anisotropic (varies with direction) and can be estimated using the rule-of-mixtures

$$E=(\eta_d \times k \times \eta_l \times \eta_o \times V_f \times E_f) + (V_m \times E_m) \quad (6)$$

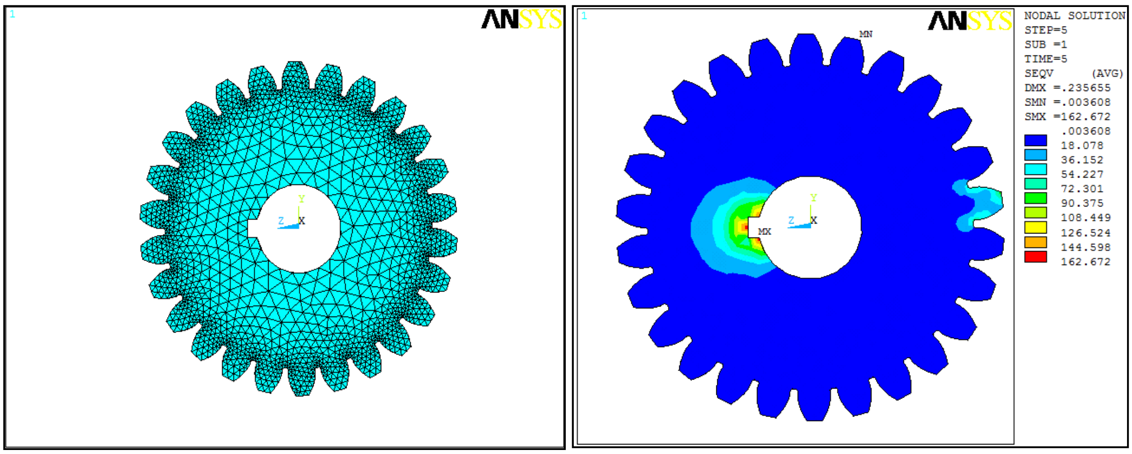
Table 3 Material Properties of Gear Materials

Material Property	Alloy Steel	Nylon	Al-SiC
Young's Modulus	210 Gpa	2.25Gpa	150 Gpa
Poisson's ration	0.3	0.30	0.3
Ultimate Tensile Strength N/mm^2	200	82	151

Bending stress in gear can be calculated theoretically from Eq. 7.

$$\sigma = \frac{W_t \times P_d \times K_t}{b \times Y} \quad (7)$$

Following results have been obtained for both the materials. Von Misses Stress Plots for different Forces But it should same because of area and BC's are same for all three materials. Von mises stress and displacement values have been obtained for different values of tangential force and Meshing used for FEM and von mises stress plot for 750N force has been shown in Fig.3. Tangential force has been applied at the tip of tooth and von mises stress, displacement has been obtained for different force magnitudes. Von misses stress plots have been obtained for different forces but its magnitude should same because of area and boundary conditions are same for all three materials



(a) (b)

Fig. 3 FEM of Spur gear (a) Meshing (b) von mises stress plot for 750N tangential force

Table 4 Bending Stress

Sr. No	Force (N)	Von mises stress (N/mm^2)	Displacement (mm)		
			Steel	Nylon	Al-SiC
01	150	32.53	0.02244	0.047137	0.02094
02	300	65.06	0.04488	0.09426	0.04189
03	450	97.60	0.06733	0.14139	0.06284
04	600	130.13	0.08977	0.18852	0.08378
05	750	162.67	0.11221	0.23565	0.10473

7. Gear Teeth Bending Test

Gear tooth bending test has been performed by single tooth fatigue as show in Fig. 4 as per SAE J1619. This tests gives the bending strength of gear which is useful in deciding the power rating of gear as mentioned in Eq. 1 and Eq. 2.Tests have been conducted on two samples each of steel and Al-SiC respectively.

Fig. 4 Gear teeth bending test

Table 5 Gear tooth Bending Test Results

Sample No.	Bending Strength(S_b) kN		
	Nylon	Steel	Al-Sic
Gear 1	4.64	64.2	34
Gear 2	4.6	65	35

8. Conclusion

In the present work Al-SiC composite have been prepared by stir casting and various mechanical tests are conducted for evaluating properties of composite. Following conclusions are drawn from the experimental work and numerical analysis done on gears,

- Al-SiC composite prepared by stir casting provides improved hardness, Tensile strength over base metal. Better results have been obtained at 18% SiC is added.
- Gears manufactured from composite provides almost 60% less weight compared to steel gear, while power rating of both gears remains almost same.
- FE Analysis also shows less chances of failure in Al-SiC gear. Almost 3-4% difference has been observed between theoretical and FEA values of bending stress.
- These gears can be used for transmitting almost 24kW power.

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