Analysis of Performance of Polyamide 66 Reinforced Carbon Fiber Composite Spur Gears using FEA

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Abstract - *The carbon-fiber reinforced polymer composite used for spur gears are light in weight having high tensile strength to weight ratio and corrosion resistant. The Polyamide66 (PA 66) with carbon fiber (CF) reinforced gear is in great demand in many light duty applications as replacement of steel gears. By using varying percentage of CF/PA 66 composite specimens and spur gears are manufactured on injection moulding machine. The specimens are prepared as per ASTM and ISO standards and then tested in the laboratory to get the mechanical properties like tensile strength, tensile modulus, poison's ratio and density. The spur gear CAD modeled using CATIA V5 CADD software. In the present work Finite Element Analysis of the spur gear pair using ANSYS software is carried out by varying percentage of CF/PA 66 composite material. In the investigation it is found that the deformation, Von-Mises, Maximum Principal stress and Minimum Principal stress of composite material is better than Polyamide and almost equal or better than steel for optimum mixture of CF/PA 66 composites.*

Key Words: Carbon fiber, Polyamide, Composite, Finite Element Analysis.

1. INTRODUCTION

In order to overcome limitation of conventional spur gears, carbon fiber reinforced polyamide composite materials are preferred in many industries. Now a days metallic gears are replaced by polymer composite gear due to their light weight, good strength, reducing noise, and increasing wear and corrosion resistance. By percentage variation in carbon fiber and polyamide material superior properties are developed in composite material as good as steel material. By reinforcement of carbon fiber the tensile, flexural, compressive strength found to be better in some of polyamides. The composite gears find their special applications in pharmaceutical equipment, food processing machinery and also in chemical plant as they do not react with product.

When CF content in PA6/CF composite is increased, increases the tensile strength, modulus and hardness but decreases strain at break point of PA6/CF composites [1]. Composite material provides adequate strength with weight reduction and they have emerged as a better alternative for replacing metallic gears [2]. However, the ultimate tensile strength, elastic modulus, and elongation of the composites decreased with increasing polypropylene [3]. The short graphite fibers reinforcement improves the friction and wear properties of PA11. addition of powder bronze and copper improves the friction and wear properties of PA/CF composite [4]. It is observed that the gear made of PA12/CF has excellent wear properties with added grease at the meshing region, higher load capability, excellent noise property, lesser water absorption as compared to PA6, PA66 and PA46 [5]. Wear rate increases drastically when the load reaches a critical value for a specific geometry and running speed and finally gear failures are mainly at root and pitch fractures instead of surface wear [6-8]. When contact stresses increase, wear rate increases which can be measured on coordinate measurement machine [9-10]. use of nano composites spur gears for different rotational speeds and applied torque on the transmission efficiency of PA6 is reported [11-12]. Temperature has a critical influence on all polymer gears, much more than on metal gears [13]. The result shows in single tooth contact zone the maximum chance of contact/bending fatigue failure occurs. When plastic gear functioning and damages are observed, the contact fatigue life is less than the bending fatigue life [14-15]. It is noticed that failure of spur gear is associated with bending strength and contact surfaces, it start from one tooth to all teeth [16, 17] and Hertzian surface pressure decrease [18]. Advanced FEM software has been used to simulate the spur gear analysis and validated with the experimental results [19-21].

The authors contributions are carbon fiber reinforced polyamide composite spur gears can be manufactured having adequate strength, weight reduction and friction reduction. It shows that PA12/CF has excellent wear property in polymer family. When the gear load reaches a critical value for a specific geometry then wear rate increases. Spur gear fails under bending strength, wear and dynamic load conditions.

2. MATERIAL

2.1 Polyamide 66

Polyamide 66 has a high melting point, a great abrasion resistance and high water absorption. Hence it is preferred in making parts of machines. It is the most popularly used thermoplastic material due to its extreme heat resistance and strength. It is used in making carpet fibers, electro-insulating elements, bearings, gears and conveyor belts etc. Polyamide 66 is supplied by Solvay Chemical, Korea in pellets form having the size, length 2.0 mm and diameter 1.5 mm. as shown in Fig.1.

Fig -1: Pellets Polyamide 66

2.2 Carbon Fiber

Carbon fiber is usually combined with other materials to form a composite. When impregnated with a plastic resin and baked it forms carbon fiber reinforced polymer which has a very high strength-to-weight ratio and is extremely rigid although somewhat brittle. Carbon fibers are also mixed with other materials, such as graphite to form reinforced carbon carbon composites, which have a very high heat tolerance properties. Carbon fiber is supplied by Formosa plastics, Taiwan having mean length 6 mm and filament diameter 6 micron as shown in Fig.2.

Fig -2: Short Carbon Fiber

2.3 Carbon Steel

Carbon steel is steel with carbon content varies from 0.05% to 2.1% by weight. as carbon percentage increases, steel has ability become stronger and harder; however it becomes less brittle. High carbon contain reduces weld ability and lowers the melting point. They are higher in weight, complex in processing, more costly, higher corrosion, more vibration and noise as compared to polymer.

3. PROCEDURE OF DIFFERENT TYPES OF MECHANICAL TESTS

Preparation of samples- The specimens are manufactured by varying CF content in steps of 0, 10, 20, 30, 40, 50,60 % in PA. Tensile modulus, Poisson's Ratio and density are found by conducting the tests in laboratory. The density is calculated from mass and volume ratio. The mass is measured in electronic balance machine and volume is calculated by water displacement method. The tensile test specimen is as shown in Fig.3.

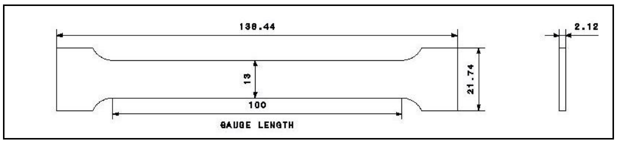


Fig -3: Test specimen

4. DESIGN OF COMPOSITE MATERIAL SPUR GEARS.

4.1 Design of spur gear in CAD software.

STEP 1: START the CATIA V518 software.
STEP 2: Start – Mechanical design – part design - click ok.
STEP 3: Select plane XY- sketch – Draw the sketch.
STEP 4: Draw the tooth profile using line & circle commands then trim the unnecessary part by using trim option.
STEP 5: Make it to constraint with pressure angle is 22.5°. Select that tooth profile click on rotate command then instance-24 – from origin of circle –angle is (360/24)
STEP 6: Exit to workbench –select the PAD command. It gives the thickness as 10.62mm
STEP 7: Similarly design pinion and make assembly to form gear pair.

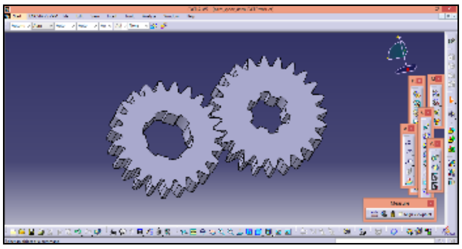


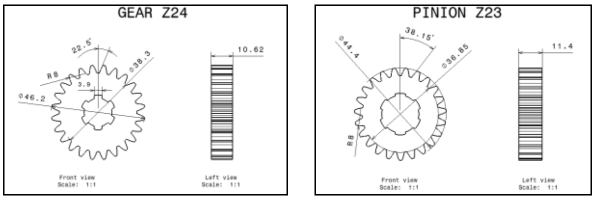
Fig -4: CAD model assembly of spur gear and spur pinion

4.2 Dimensions of Spur Gear and Pinion

Table -1: Spur Gear Dimensions

Parameters	Spur Gear	Spur Pinion
No. of teeth, Z	24	23
Module, m (mm)	1.7780	1.7780
Width of the gear tooth, b (mm)	10.000	7.00
Pressure angle, αn (degree)	22.5	22.5
Root circle diameter, df (mm)	39.4238	36.85
Tip circle diameter, da (mm)	38.3	44.4

Base circle diameter, db (mm)	46.2	37.78
Pitch circle diameter, dp (mm)	42.65	42.68



(a)Spur Gear (b) Spur pinion

Fig -5: Geometric dimension of a) Spur Gear b) Spur pinion

4.3 Dimensional Measurement of steel spur gear using Coordinate Measuring Machine (CMM):

The Coordinate Measuring Machine (CMM) plays a vital role in the mechanization of the inspection process. Coordinate measuring machine is relatively recent development in measurement technology. Basically, it consists of a platform on which the work piece being measured is placed and moved linearly or rotated. A probe attached to a head capable of lateral and vertical movements records all measurements.

5. FINITE ELEMENT ANALYSIS

An analytical solution is a mathematical expression that gives values of the desired unknown quantity at any location in the body, as the consequence it is valid for infinite number of location in the body. For problem involving complex material properties and bounder conditions, the engineer resource to numerical method that provides approximate that enables solution.

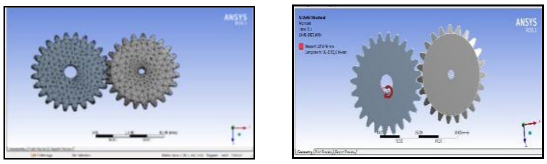
A meshing and boundary conditions of the spur gear model has been generated according to geometric dimensions obtained by calculations. Meshing density is properly checked and refined in meshing area for optimal finite analysis. In this analysis boundary conditions are applied at the centre of spur gear as shown in fig.6.

5.1 Analysis Procedure

Step 1: Static structure->Engineering Data->Material Add ->Add Properties -> Geometry
Step 2: File-> Import the solid model from CATIA V5
Step 3: Model->Geometry->Mesh->Default Mesh 0.5 size->Refinement
Step 4: Structural-> Fixed support-> Select Cylindrical support
Step 5: Structural-> Frictionless support-> Select Cylindrical support
Step 6: Structural-> Moment-> Select Cylindrical support
Step 7: Select Phase-> Solution-> Von-mises stresses
Step 8: Select Phase-> Solution-> Total Deformation
Step 9: Select Static Structure-> Solve.

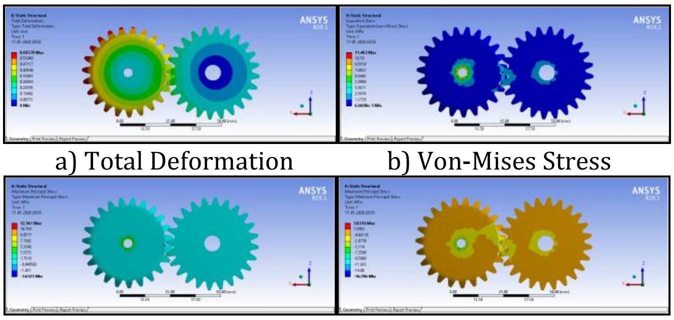
5.2 Results of analysis

After model is prepared in CATIA V5 R20 it is imported to ANSYS 19.1 for static analysis. In this analysis proper meshing and boundary conditions are applied. A moment in terms of torque 2.05 N-m is applied to gear geometry. The material property values like tensile modulus, Poisson's ratio and density are taken from specimens test results. In static analysis, total deformation, Von-Mises, Maximum and Minimum Principal Stresses are calculated for 0% CF and 60% CF and are as shown in Fig.7, 8, 9.



a) Meshing b) Boundary Conditions

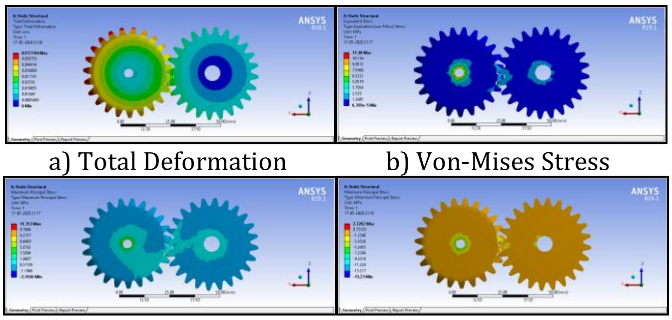
Fig-6: Meshing and a boundary Condition of spur gear



a) Total Deformation b) Von-Mises Stress

c) Maximum Principal Stress d) Minimum Principal Stress

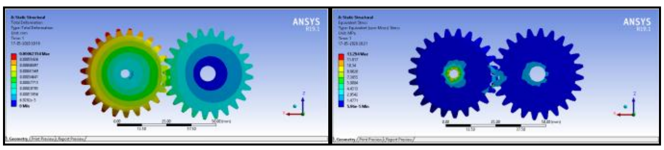
Fig-7: Static FEA of spur gear pair of PA (0% CF)



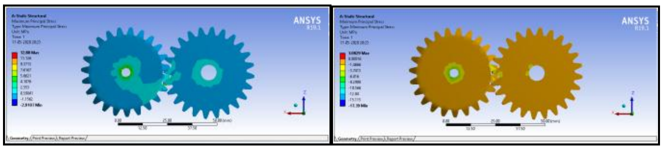
a) Total Deformation b) Von-Mises Stress

c) Maximum Principal Stress d) Minimum Principal Stress

Fig -8: Static FEA of spur gear pair of PA/CF composite material (60% CF)



a) Total Deformation b) Von-Mises Stress



c) Maximum Principal Stress d) Minimum Principal Stress
Fig -9: Static FEA of spur gear pair of steel

a)Total Deformation b)Von-Mises Stress c)Maximum Principal Stress d)Minimum Principal Stress

6. RESULT AND DISCUSSION

In order to investigate the effect of different volume fraction analysis is performed on PA and PA/CF specimens. The tensile modulus, Poisson's ratios were determined from tensile test and density measured of specimens from density measurement technique. Finite Element Analysis determine the total deformation, Von-Mises, Maximum and Minimum Principal stresses for a PA/CF spur gears of different volume fraction and their results are given below.

Table -2: Specimen test results

Test specimen material	% of CF in CF/ PA 66 composite							steel	% diff.
	00	10	20	30	40	50	60		
Tensile modulus	179.40	785.20	2347.8	2510.4	3908.8	3040.2	1878.57	2.05 x10^5	98.09
Poisson's ratio	0.400	0.388	0.376	0.364	0.352	0.340	0.328	0.300	8.82
Density	1032	1154	1180	1267	1349	1361	1412	7860	82.83

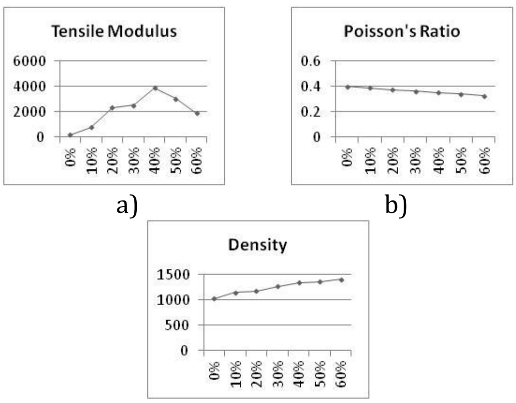


Chart -1: a) Tensile Modulus, b) Poisson's Ratio and c) Density Vs % of CF in CF/PA66 Composite.

Table -3: Static finite element analysis of gears results.

Test specimen material	% of CF in CF/ PA 66 composite							steel	% diff.
	00	10	20	30	40	50	60		
Deformation (mm)	0.605	0.138	0.046	0.043	0.027	0.015	0.057	0.0006	97.703
Von-mises Stress	11.4	11.4	11.4	11.4	11.4	11.3	11.3	13.9	14.39
Max. Principal Stress	12.5	12.3	12.0	11.8	11.6	11.5	11.5	12.8	2.47
Min. Principal Stress	3.83	3.60	3.40	3.21	3.04	2.87	2.72	3.08	11.56

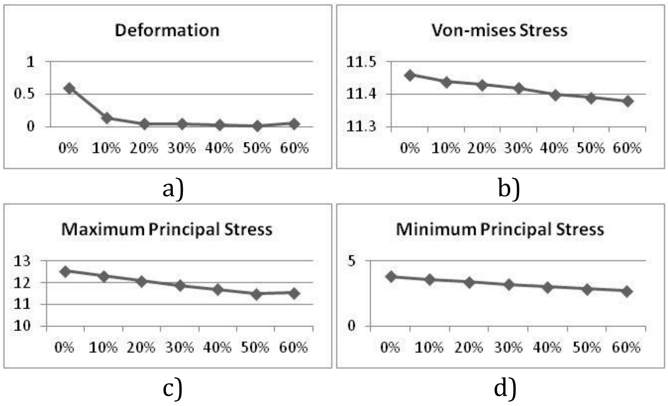


Chart -2: a) Deformation, b) Von-Mises stress c) Maximum Principal stress and d) Minimum Principal stress Vs % of CF in CF/PA66 Composite.

7. CONCLUSIONS

By various volumetric fraction of CF reinforced PA 66 samples tensile strength, Poisson's ratio and density properties are calculated. The result shows that tensile modulus, Poisson's ratio and density of steel is more than CF/ PA 66 composite material. Minimum Poisson's ratio of CF/ PA 66 composite material is 8.82% less than steel. Hence the performance of steel is better than CF/ PA 66 composite material. Overall weight of CF/ PA 66 composite material spur gear is 5 times less than steel.

In static analysis results, the total deformation steel is less than CF/ PA 66 composites. Furthermore, the total deformation of CF/ PA 66 composites is less than PA 66. The Von-Mises, Maximum Principal and Minimum Principal stresses of CF/ PA 66 composites are less than the steel and PA 66. From the analysis the stresses induced in CF/ PA 66 composites spur gear pair is significantly less than steel and pure polyamide spur gear. Hence CF/ PA 66 composites spur gear are capable to withstand more stress than PA 66 material and have potential to replace steel gears in certain high precision motion with low power transmission applications.

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