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Investigation of Wear Resistance and Torque Transmission Capacity of Glass Filled Polyamide and PEEK Composite Spur Gears

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Abstract: ***Polymer & polymer composite gears find increasing application because of the low material manufacturing cost, light weight & quiet operation compared with metal gears. Generally thermoplastic polymers like acetal polymer & nylon polymer are used for gear applications. But acetal and nylon gears have low load carrying capacity. To improve the performance of gears, geometry modification had been done like tooth width modification & cooling holes on tooth surface. But, for high power applications, these materials show poor performance. Therefore, it is necessary to select the polymer which has good mechanical properties & good thermal stability. Poly-ether-ether-Ketone (PEEK) has high strength & stiffness, low coefficient of thermal expansion which is required for gears. The comparative performance spur gears of 30% glass filled PA66 and 30% glass filled PEEK was investigated in this study. The results shows that 30% glass filled PEEK gears have high wear resistance and high torque transmission capacity as compare with 30% glass filled PA66 gears.***

Keywords: ***Poly-ether-ether-ketone (PEEK), Polyamide 66 (PA66), Scanning Electron Microscope (SEM).***

1. INTRODUCTION

Plastic gears have positioned themselves as serious alternatives to traditional metal gears in a wide variety of applications. The use of plastic gears has expanded from low power, precision motion transmission into more demanding power transmission applications. As designers push the limits of acceptable plastic gear applications, more is learned about the behaviour of plastics in gearing and how to take advantage of their unique characteristics. Plastic gears provide a number of advantages over metal gears. They have less weight, lower inertia and run much quieter than their metal counterparts. Plastic gears often require no lubrication or can be compounded with internal lubricants such as PTFE or silicone. Plastic gears usually have a lower unit cost than metal gears, and can be designed to incorporate other features needed in the assembly. These gears are also resistant to many corrosive environments. The polyamide gears have a number of disadvantages. These are of low load-carrying capacity, short running life and poor heat resistance, respectively. These advantages limit application of polyamide gears, especially in high speed, heavy load and high ambient temperature conditions [3]. Many methods for analysis and design of plastic gear are derived by using the steel gears with some modifications due to the characteristic low modules of elasticity and sensitivity temperatures of plastic materials [2]. Over the past few decades, a considerable number of studies were conducted on the performance of polyamide gears [4-13]. Strength of polymer gears depends on temperature, firstly. The polymer gear contact tooth surface temperature is so high resulting from local softening and surface wear is increased dramatically [14, 15]. Cooling operation must be applied or driver gear materials which have high heat transfer coefficient must be used for lessening the temperature and heat distribution of gear tooth surface during running time of plastic gears. Every time, these solutions, to increase the plastic gear running life, are not feasible at the different running conditions. Therefore, new base material was suggested having good mechanical and thermal properties for critical severe conditions.

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2. WORK METHODOLOGY

2.1 Specifications and materials

The mechanical and thermal properties of test gears [16] are shown in table 1. And specifications of the gear sets used in this study are summarized in Tables 2.

Table 1 Properties of Test Gear Materials

Parameter	PEEK GF30	PA66 GF30
Density	1320 Kg/m^3	1000-1400 Kg/m^3
Tensile modulus of Elasticity	4000-4200 MPa	1000-1300 MPa
Tensile yield strength	90-100 MPa	60-80 MPa
Glass Transition Temperature (T_g)	143 ^{O}C	110 ^{O}C
Melting Point (T_m)	343 ^{O}C	250 – 270 ^{O}C
Thermal Conductivity	0.2 W/ m.K	0.28 W/ m.K
Water Absorption, 24 Hrs	0.1 %	1.2 – 3.0%

2.2 Preparation of Sample

Commercially available 30% glass filled Polyamide 66 and 30% glass filled Poly-ether-ether- ketone materials were selected for the current study. The PEEK GF30 and PA66 GF30 granular materials were dried for 4 hrs prior to compression molding to remove the moisture content.

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Compression molded rod of 50 X 76 mm were made by using compression molding machine at the molding pressure of 124 MPa and melt temperature of 360 °C. After compression molding process, these rods were used as a raw material for manufacturing of gears. Gears were manufactured by machining process using hydraulic hobbing machine. Gears were made by gear hobbing process followed by compression molding process. Test polymer base spur gears were mated against the hobbed standard stainless steel spur gear (EN8).

2.3 Gear Test

Wear tests of the spur gear pairs and the experiment spur gear tooth were performed on a FZG (Figure 1). The FZG test machine is a power-circulating test machine with test spur gear tooth wear apparatus. The closed loop was changed with 7.5 kW DC electric motor of a driving vehicle. Gear loading was generated by FZG closed loop geared system. In this closed loop, the shaft number 5 was fixed with a pin and a twisting moment was generated in the shaft number 6 applying a gear loading with an arm. Experimental gears after and before experiments, were measured for weight loss with 0.0001 g sensitive weighing machine. Mean temperatures of PEEK GF30 and PA66 GF30 gear tooth were measured with Impact Infratherm Pyrometer 510-N infrared thermometer at a distance of 8 mm (Figure 2) from the meshing point of driver and pinion gears and recorded immediately [4,8]. 5 different experimental PEEK GF30 and PA66 GF30were tested at all experiment conditions. EN8 driver gear run versus the pinion gear was changed with new EN8 driver gear for each experiment. Therefore, heated steel gear was left being cooled down for another experiment after having been cleaned. The table 3 shows the test conditions of current investigation

Table 2 Specifications of Gears

Sr. No.	Parameters of Gears	Test Gears		Mating Gear EN8
		PEEK GF30	PA66 GF30	
1	Module, mm	1	1	1
2	No. of Teeth (Z)	45	45	45
3	Pressure Angle (Deg.)	20	20	20
4	Pitch circle Diameter, mm	45	45	45
5	Face width (b), mm	12	12	12
6	Centre distance, mm	45	45	45

Table 3 Test Conditions

Sr. No.	Parameter	Conditions
1	Applied Torque Nm	2, 3, 4, 4.5 N-m
2	Rotation Speed in rpm	257 & 494 rpm
3	Revolutions	1.8 x 10^5
4	Temperature	Room Temperature, 25°C
5	Environment	Air

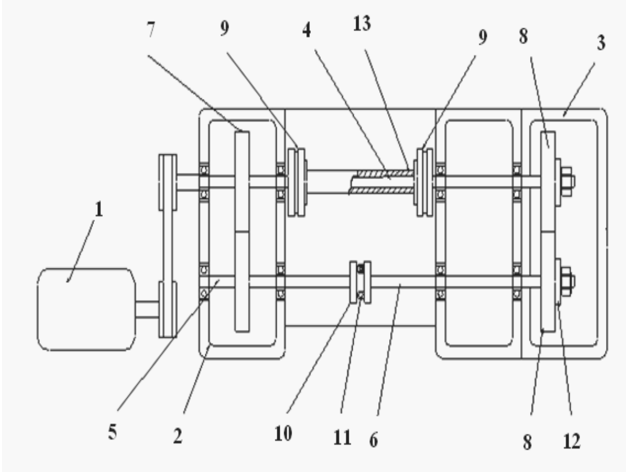

Figure 1. DC Motor, 2, 3: Gear box, 4, 5, 6: Shaft, 7: Circulating gears, 8: Pinion and gears (Test gears), 9: Coupling 10, 11: Load coupling 12: Washer, 13: Support tube

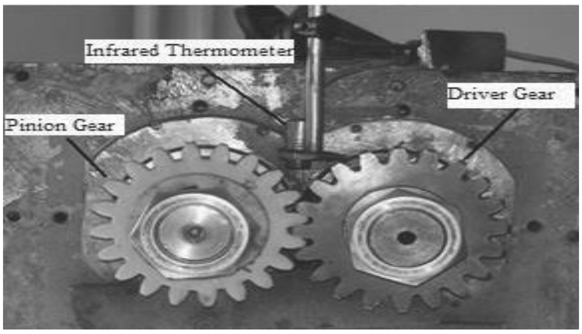

Figure 2. Impact Infratherm Pyrometer 510-N infrared thermometer

3. DISCUSSION ON EXPERIMENTAL RESULTS

All tests were conducted on FZG machine at different torque for PA66 GF30 and PEEK GF30. The following results were seen on average tooth temperature of test gears.

3.1 Tooth Temperature of PA66 GF30 Gears at Different Torque

The Figure 3 shows effect of torque on tooth temperature during the testing. It is observed that, the average tooth temperature of gear increases with increase in applied torque. The temperature of gear tooth was stabilized after 150000 revolutions. The increase in temperature for these gears was in the range of 62 °C to 74 °C for the applied toque of 2N-m to 4.5 N-m. These gears are more sensitive to torque variation and speed variation. As the applied torque on the gears was increased, the tooth temperature also increases drastically. The gear with high load & high speed was failed after 1 X 10^5 revolutions. After damages occurred, gear profiles could not mesh each other exactly, and tooth temperature decreased due to the failure of contacting.

3.2 Tooth Temperature of PA66 GF30 Gears at Different Torque

The PEEK composite gears with 30% wt. glass fibers are tested for different torque and speeds. The Figure 4 shows effect of torque on tooth temperature during the testing.

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It is observed that, as applied torque acting on gear teeth increases, the temperature of gear tooth at the pitch point is also increases. The increase in temperature for these gears is in the range of 54 °C to 59°C for the load toque of 2N-m to 4.5 N-m.

The Figure5 shows comparative average tooth temperature test gears. It was observed that the average tooth temperature of PA66GF30 was higher than the PEEK GF30 for all the torque levels. The average tooth temperature of PA66GF30 and PEEK GF30 were responsible for thermal softening at the pitch region. The wear at pitch region is more PA66 GF30 compared with PEEK GF30.

3.3 Specific Wear Rate

Weight losses of PA66 GF30 and PEEK GF30 experimented gears were measured after and before the experiment. In addition, wear volume (V) can be calculated dividing the measured wear loss by density. Then, the specific wear rate can be calculated by equation (1).

$$W_v = \frac{V}{z2mbN} \quad \text{------------------------------ (1)}$$

where Wv is the wear volume (mm^3), z the number of pinion teeth, m the module (mm), b the tooth width (mm) and N is the total number of revolutions (rev.)

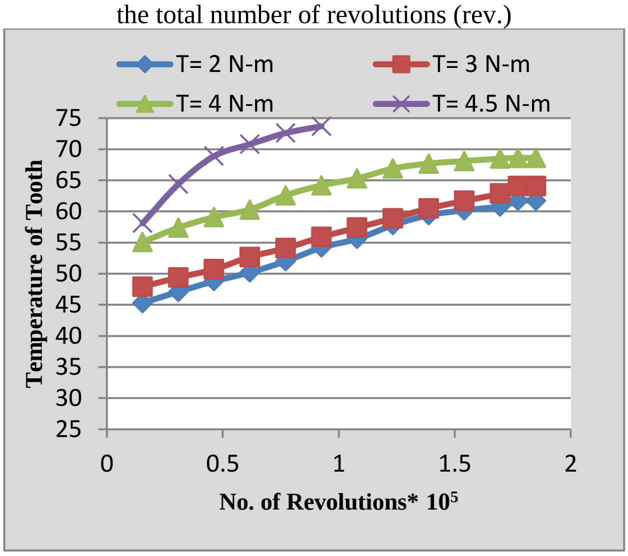

Figure 3. Plot of Temp. of tooth Vs No. Of revolutions of PA66GF30 Gears

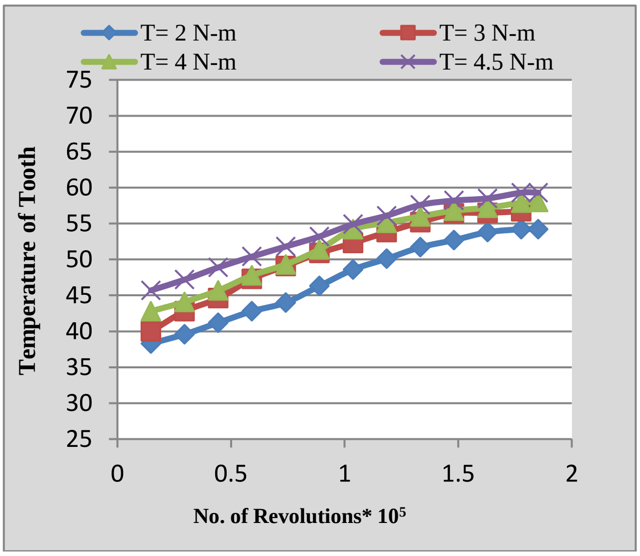

Figure 4. Plot of Temp. of tooth Vs No. Of revolutions of PEEK GF30 Gears

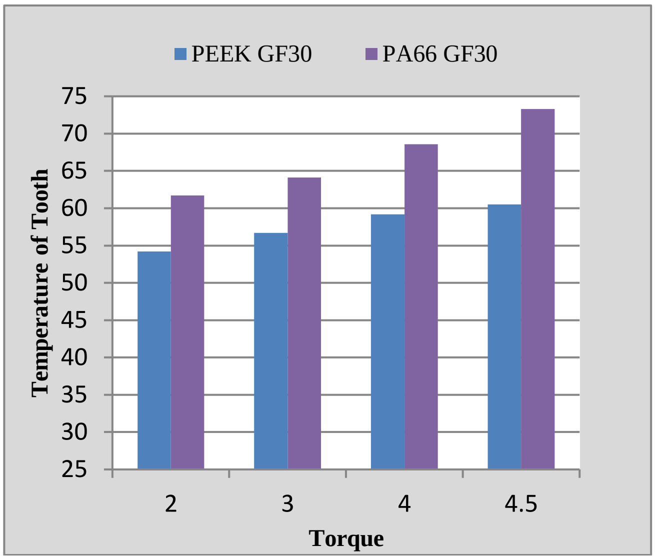

Figure 5. Plot of Temp. of tooth Vs Torque

Figure 6 shows the specific wear rate of PA66 GF30 and PEEK GF30 gears. The specific wear rate, the number of revolutions and the increasing torque changed each other directly proportional. Many materials separated from the contact surface of gear at nearly loading of all gears and due to effect of heat which were accumulated on the contact surface and softening of pitch line around. Hence, these reasons increase the specific wear rate. When the tooth load torque was 4.5 N-m, PA66 GF30 gear tooth was melted by the effect of heat or tooth fractures were seen, as a result of the effect of thermal damages. For high revolutions, specific wear rate increased with rising torque. But it was observed that this sudden increase was lower than other numbers of revolutions.

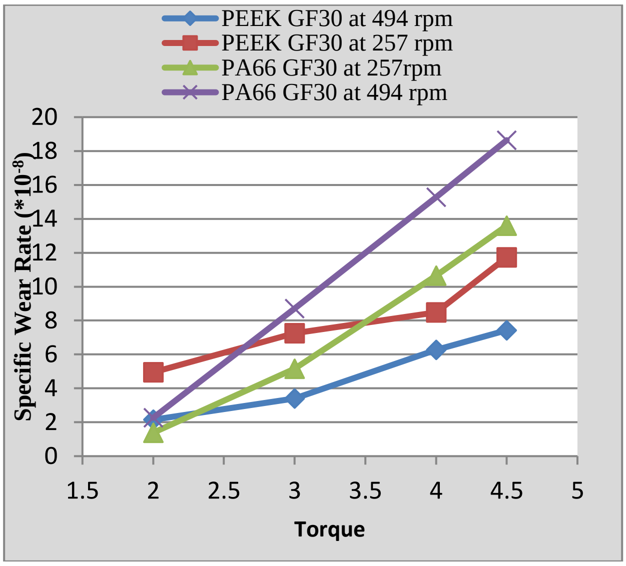

Figure 6. Specific Wear Rate Vs Torque at different Speeds

The Figure 7, 8 and 9 shows the SEM image of gear tooth surface before experimentation and after experimentation respectively. The Figure 8 shows the image of damaged gear tooth at high torque.

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The damaged occurred due to the thermal cycle fatigue at critical load. The load carrying capacity of this material is less. When load was increased beyond the endurance limit of material, it resulted into the breakage of tooth. It is also observed that the tooth surface is plain before the test and yielding of material is seen on the tip of tooth after the test. This is happened due to the increase of tooth temperature which resulted into plastic flow of material in radial direction. The yielding is resulted into creep of tooth.

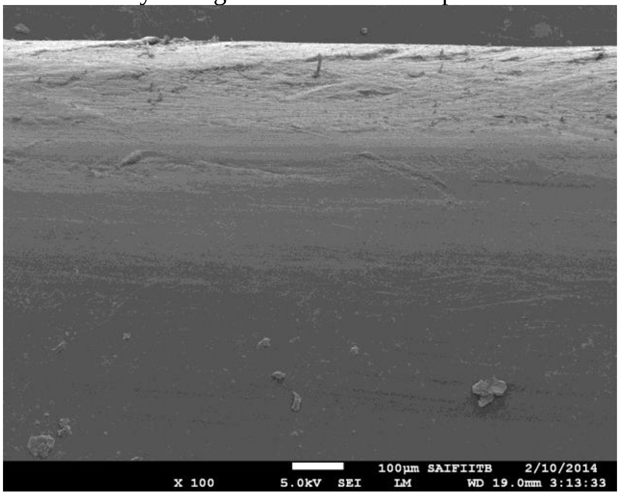

Figure 7. Image of Tooth before Experimentation of PA66 GF30

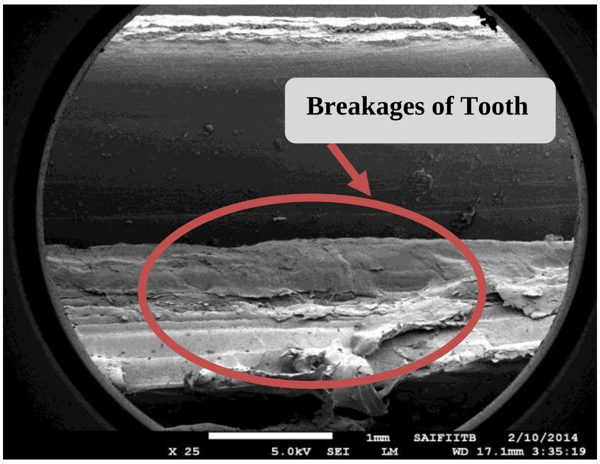

Figure 8. Image of Failed Tooth after Experimentation of PA66 GF30

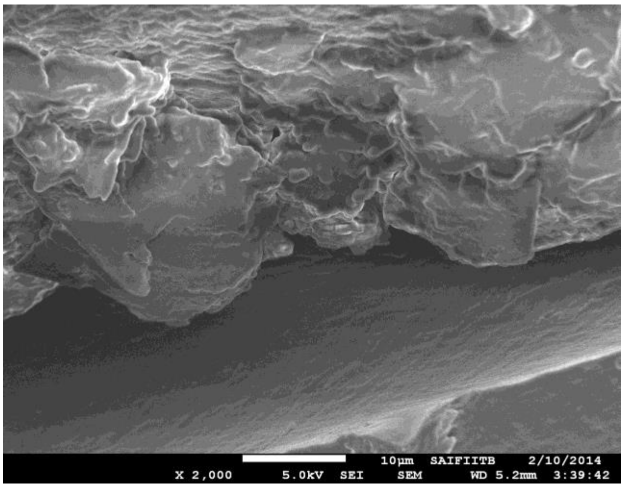

Figure 9. SEM Image of Failed Tooth after Experimentation of PA66 GF30

The Figure 9 & 10 shows the SEM image of gear tooth surface before test and after test respectively. These images are taken at 100X magnification. It is observed that the tooth surface is plain before the test and after the test flakes are observed due wear of pitch surface. These flakes are nothing but the subsurface formation which further increases the wear rate and reduces the cross section of tooth at the pitch region.

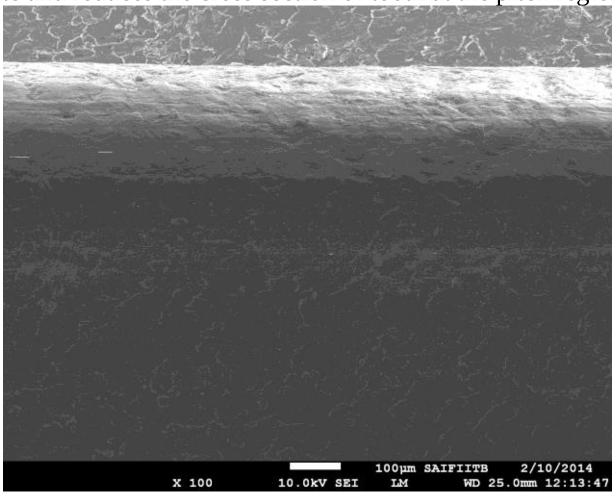

Figure 10. Image of Tooth before Experimentation of PEEK GF30

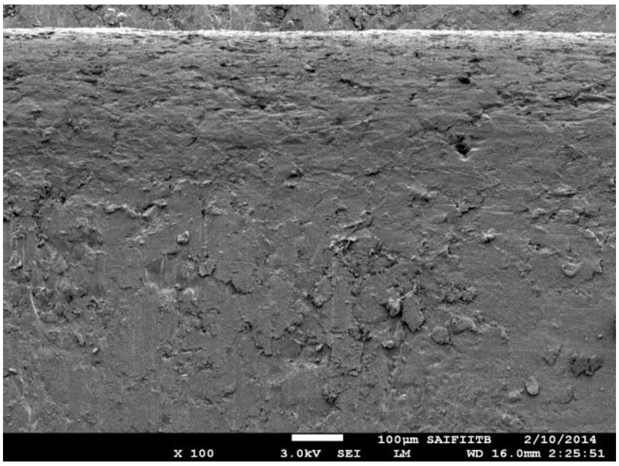

Figure 11. Image of Tooth after Experimentation of PEEK GF30

CONCLUSION

The experimental results of PA66 GF30 and PEEK GF30 gears at different torque and numbers of revolutions were summarized below. It is observed that, the tooth temperature increases with increase in torque and increased temperature resulted into thermal softening of gear tooth which further increases specific wear rate. At high torque and high speed, the gears of PA66 GF30 material are failed. The comparative results of PA66 GF30 and PEEKGF30 gears shows that, the specific wear rate of PA66 GF30 is much higher than PEEK GF30 at all torques and speeds. Therefore, the torque transmission capacity of PEEK GF30 is higher than PA66 GF30. The results of SEM of all the composite gears also show that, the formation of subsurface pattern or surface fracture are responsible for increased wear rates. The failure mechanism in PA66 GF30 was thermal cycle fatigue which occurred due to high temperature & repeated stress on pitch surface of gear tooth.

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