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The load capacity of PC/ABS spur gears and investigation of gear damage

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ABSTRACT

Purpose: Recently, Polyamide 66 and Teflon as plastic materials have been widely used at the manufacturing of gear mechanism. The purpose of the paper is to examinee the load capacity of PC/ABS spur gears and investigation of gear damage.

Design/methodology/approach: In this study, usability of PC/ABS composite plastic materials as spur gear was investigated. PC/ABS gears were tested by applying three different loading at two different numbers of revolutions on the FZG experiment set.

Findings: As a result of the experiments, load capability of PC/ABS materials was seen rather high, if one of the spur gear pair was steel (AISI 8620).

Practical implications: In fact that, PC/ABS materials are durable against flame, air, ultraviolet lights and holding lower moisture than PA66 GFR 30 materials, the usage of them brings an advantage in many industrial areas.

Originality/value: Using PC/ ABC materials provides many advantages due to fire, air and ultraviolet light durability and low moisture holding properties.

Keywords: PC/ABS; Wear; Spur gear

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PROPERTIES

1. Introduction

Polymers and polymer composites which are used for gear materials, represent and are interesting development hence they facilitate easy manufacture and low costs [1]. They are widely used in automotive and household appliances, business and printing machinery, computer peripherals, textile machinery [2]. Plastic gears have many advantages like: low noise, light weight and self lubrication. However, 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 [4-14].

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 [15, 16]. 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, reinforcement materials as glass, carbon and aramid are added to polymer materials to overcome these obstacles. The composite polymers having reinforced the carbon, glass, aramid, graphite fibres have well mechanical properties as many as steel materials and they are widely used in the industrial areas [17].

PC/ABS alloys are engineering thermoplastics based on mechanical blends of polycarbonate 90–60% with ABS 10–40%. PC/ABS combines the greater heat resistance of polycarbonate with improved processibility of ABS [18].

In this study, load carrying capacity and occurring damages of gears which are made of PC/ABS blends were investigated. PC is hard material and ABS is soft material. The usage of materials limits these drawbacks. However PC and ABS polymers combine each other, the PC/ABS blends have suitable mechanical properties for gear applications in the industrial areas [18].

2. Work methodology

2.1. Specification and materials

The specification and material properties of the gear sets used in this study are summarized in Tables 1 and 2, respectively.

Table 1.
Specification of the test gears

	Pinion gears	Driver Gears
Material	PC/ABS	AISI 8620
Module	3.5	
Number of teeth	26	
Pressure angle (deg.)	20	
Operation meshing angle (deg)	20.84	
Profile shift coefficient	0.073	
Diameter of pitch circle (mm)	90	
Diameter of tip circle (mm)	98.511	
Tooth width (mm)	14	18
Centre distance (mm)	91.5	
Contact ratio	1.592	

Table 2.
Properties of the plastic materials

	PC/ABS	AISI 8620
Density (g/cm^3)	1.1	7.85
Tensile modulus of elasticity (MPa)	1827	205000
Thermal conductivity W/(K.m)	0.28	46.6
Hardness	R110	56 HRC
Tensile Strength, Yield (N/mm^2)	35	560

2.2. Preparation of specimen

Experimental spur gears were produced with plastic injection method. PC/ABS (% 60/40) granular materials were dried and blended using a mixer in time shown in Table 3. After this process, the wedge channel of gears was cut with a wedge machine. Then, the PC/ABS pinion and steel gear were dipped in ethyl alcohol and acetone, respectively. Subsequently, they were dried in a dehumidifier at 35°C for 10 h and then used for the test. The weight of the plastic pinion was measured before and after testing to evaluate the wear loss.

Table 3.
Injection process values by Windsor HSI 80 plastic injection machine

Materials	ABS/PC
Module (m) mm	3.5
Drying time	240 min. 110^{o}C
Machine Capacity	180 gr
Machine Closing Force	80 Ton
Injection Pressure	20 bar, 3 s. (Pressure in room 300 Bar)
Ironing Pressure	12 Bar, 6 s. (Pressure in furnace 150 Bar)
Press Temperature	210 ^{o}C
Mould Temperature	40 ^{o}C
Waiting time in mould	50 s.
Total cycle time	70 s

2.3. Gear test

The test conditions are shown in Table 4.

Table 4.
Test conditions

Applied Load (N/mm)	16.07, 20.5 and 29.36
Rotation speed (rpm)	750, 1000 and 1500
Pitch Line velocity (m/s)	3.57, 4.76 and 7.14 (PC/ABS gears)
Revolution	1.8x10^5
Environment, Temperature	Air, 19-22 °C
Humidity	30-45%

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 PC/ABS gear tooth were measured with Impact Infratherm Pyrometer 510-N infrared thermometer at a distance of 7 mm (Figure 2) from the meshing point of driver and pinion gears and recorded immediately [4,8,18]. 5 different experimental PC/ABS were tested at all experiment conditions. AISI 8620 driver gear run versus the pinion gear was changed with new AISI 8620 driver gear for each experiment. Therefore, heated steel gear was left being cooled down for another experiment after having been cleaned.

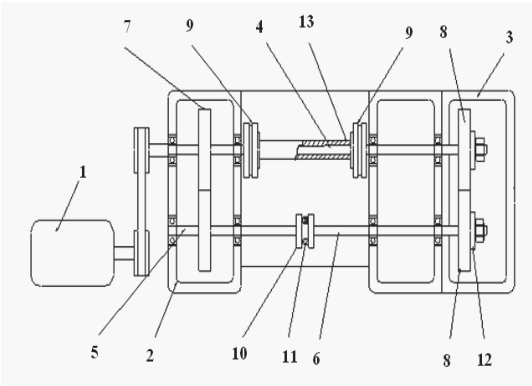

Fig. 1. DC Motor, 2, 3: Gear box, 4, 5, 6: Shaft, 7: Circulating gears, 8: Pinion and gears (Test gears), 9: Coupling 10, 11: Load coupling 12: Washer, 13: Support tube

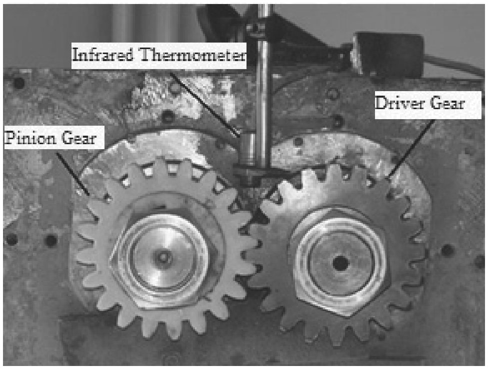

Fig. 2. Impact Infratherm Pyrometer 510-N infrared thermometer

Firstly, the surfaces of damaged gears were taken with a digital photo machine. Scanning Electron Microscope (SEM) was used for taking pictures of wearing surfaces of the PC/ABS gear teeth.

3. Discussion of the experimental results

3.1. Specific wear rate

Weight losses of PC/ABS 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 as follows [4, 16].

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

where W_v 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 shows the specific wear rate of PC/ABS. The specific wear rate, the number of revolutions and the increasing load changed each other directly proportional. Many materials separated from the contact surface of gear at nearly loading of all gears and 1500 numbers of revolutions 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 was 29.36 N/mm, PC/ABS gear tooth was melted by the effect of heat or tooth fractures were seen, as a result of the effect of thermal damages. For low revolutions, specific wear rate increased, rising load but it was observed that this sudden increase was lower than other numbers of revolutions.

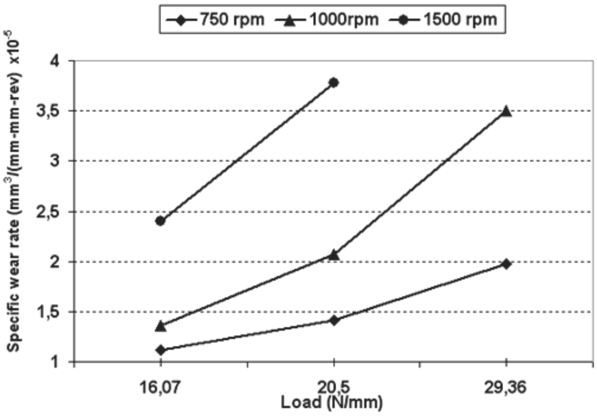

Fig. 3. Variation in specific wear rate of PC/ABS

Variation in temperatures occurred at contact surface of gear tooth at different gear load and the number of revolutions were shown in Figure 4a. The accumulated heat on the tooth surface at 750 rpm and 3 different loads, shown in Figure 4 did not occur at high levels by means of driver gear AISI 8620. The accumulated heat which occurred upon the PC/ABS gears was captured by steel gear and spread out. Consequently, thermal balance of gear pairs was provided with steel gear.

When tooth temperature gradually increased at 1000 rpm, 16.07 N/mm and 20.5 N/mm tooth loads given in Figure 4b and AISI 8620 steel driver gear reached the thermal equilibrium at the defined temperature, thermal damage was not observed. Only, wear occurred at the tooth profile. However, more heat which occurred at repeated loads due to low PC/ABS material thermal conductivity with increasing tooth load was not distributed out and the accumulated heat occurred at every repeated load. Strength of materials and its rigid lessened under the effect of temperature and the fractures of gear teeth were found later.

The variation in temperature which occurred upon the contact surface of gear tooth at 1500 rpm and different loads was shown in Figure 4c. While tooth temperature increased 16.07 N/mm tooth load during the defined time, gear tooth temperature reached the thermal equilibrium by means of driver steel gear. However, tooth temperature suddenly increased with the effect of friction force that occurred on gear surface at other tooth loads. Tooth exposed the thermal damages without thermal equilibrium temperature.

PC/ABS materials are brittle above defined temperature. When they suddenly increased this temperature, material structure showed the glassing properties. This caused the fracture of tooth immediately. The viscoelastic behaviour materials caused a damage like creeping and slacking. The temperature on the tooth surface with load effect increased at the contact points and thermal damages occurred at the PC/ABS materials. After damages occurred, gear profiles could not mesh each other exactly, and tooth temperature decreased due to the failure of contacting. Temperature of PA 66 GFR30 materials which occurred on the tooth surface at the same loading conditions and wear depth of gear profile PC/ABS higher than PA 66 GFR30 were found in the Yakut study [18].

Wear depth of PC/ABS gear profile was given in Figure 5. Ideal wear of PC/ABS gear was observed at the 20.5 N/mm tooth load and 750 rpm. But, wear depth of gear profile with raising a number of revolutions increased and lost profile properties. The wear depth of PC/ABS gear occurred at the root circle of gear. Sliding permanently, it was performed at the root and tip of tooth, because side and surface size of driver and pinion gear are different from each other. Sliding rate changed during the gear period, but, pitch line reached zero rolling velocity at the contact point.

PC/ABS pinion gear damages were shown in Figures 6, 7, Figure 8 and Figure 9 at the different numbers of revolutions and under different tooth load. As it was shown in Figures 6a-c, 16.07 N/mm tooth load, any thermal damage was not found at the tooth surface.

It was observed that the tooth gear temperature did not suddenly rise at 16.07 N/mm tooth load and the accumulated heat on the pinion gear was spread out by AISI 8620 driver gear, and the equilibrium of gear pair reached under 50°C for all numbers of revolutions. Therefore, thermal damages did not occur on the gear tooth surfaces. If the thermal damages were shown, the wear rate would be found at low levels 29.36 N/mm load (Figures 8a, c). In addition, the tooth gear temperature did not rise speedily at 20.5 N/mm tooth load and 750 rpm and the thermal equilibrium reached about 50°C and the thermal damages did not occur on the gear tooth surface but, wearing formed at the gear profile. However, when the gear specimens run 1000 rpm and 1500 rpm, the gear tooth temperature suddenly increased at the initial periods of tests and the accumulated heat on this surface could not be spread out by driver gear. Consequently, the beginning of thermal damages was formed at this test conditions. Any pinion gear tooth was not broken during this test conditions.

a)

b)

c)

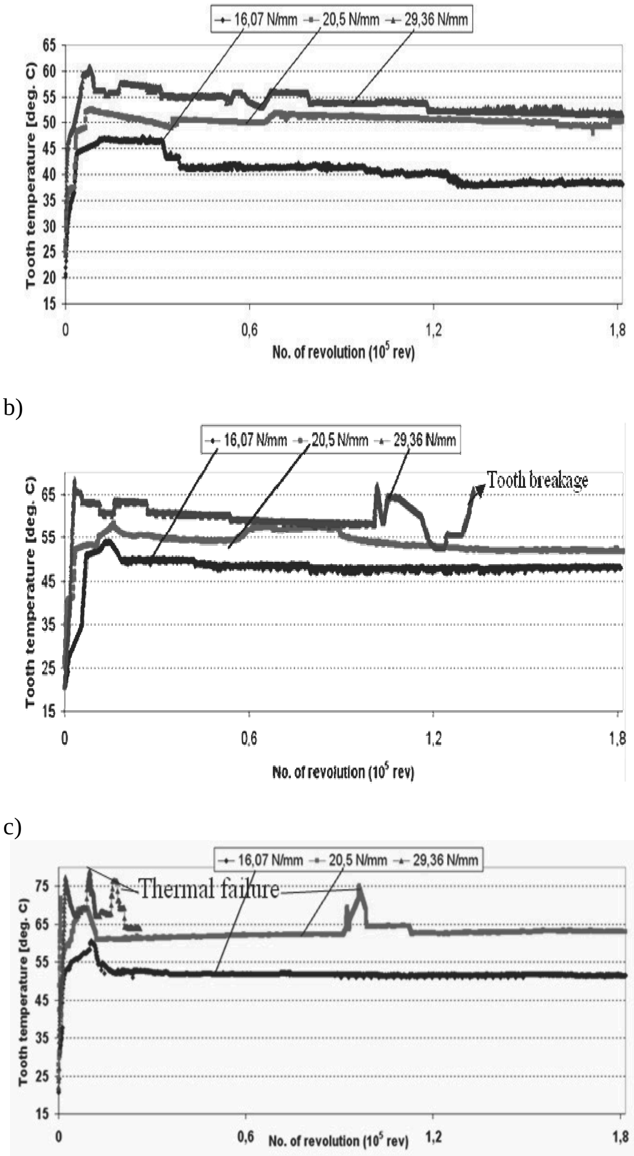

Fig. 4. PC/ABS- AISI 8620 tooth temperature variation of gear pair, a) 750 rpm, b) 1000 rpm, c) 1500 rpm

a) b) c)

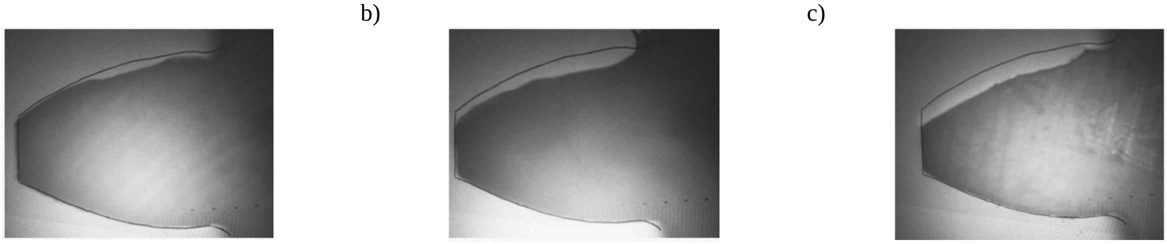

Fig. 5. Wear depth of PC/ABS-AISI 8620 gear profiles at 20.5 N/mm tooth load, a) 750 rpm, b) 1000 rpm, c) 1500 rpm

a) b) c)

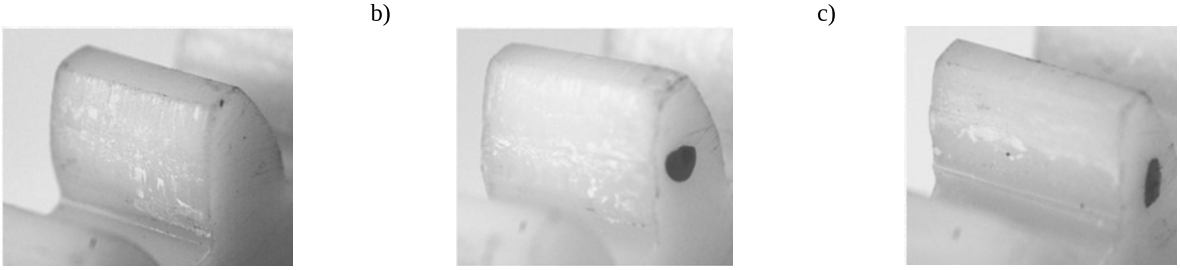

Fig. 6. Tooth damages at 16.07 N/mm load, a) 750 rpm, b) 1000 rpm, c) 1500 rpm

a) b) c)

Fig. 7. Tooth damages at 20.05 N/mm load, a) 750 rpm, b) 1000 rpm, c) 1500 rpm

a) b) c)

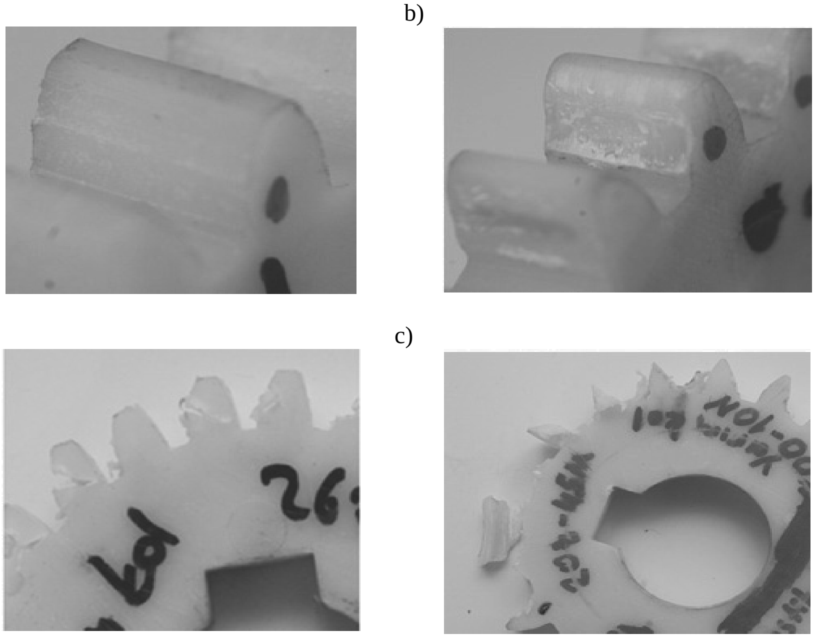

Fig. 8. Tooth damages at 29.36 N/mm load, a) 750 rpm, b) 1000 rpm, c) 1500 rpm

The thermal damages on the tooth surface did not occur at 750 rpm but wear pitch line around was observed with the effects of steel gear and accumulated heat. When the specimens were run at the 1000 rpm test conditions, mechanical properties of PC/ABS gear decreased with sudden increasing of tooth temperature and thermal damages on the tooth surface were investigated, and also, gear teeth were broken in two test periods (see Figure 4b). These results show us that gear pairs could not be cooled enough. However, the accumulated heat in this area occurred with the effects of Hertz surface pressure and increase of tooth load, and extremely wear depths were observed. The properties of PC/ABS gears materials with accumulated heat at the tooth surface lessened and damages at the pitch line around like fractures were observed at the 1500 rpm (Figure 8c).

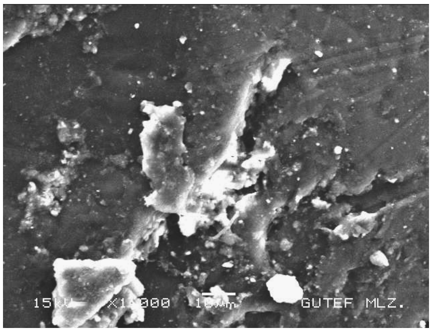

Fig. 9. SEM images of tooth damages on the surface at 20.5 N/mm tooth load and 1000 rpm

Scanning electron microscope (SEM) observation of PC/ABS tooth surface in present tests, Fig. 9, after it has had a run of 1.8x105 numbers of revolutions revealed an evidence of surface transverse cracks, formed after a short period of running, and the crack formation would lead to premature failure.

4. Conclusions

The experiment results of PC/ABS tested at different tooth load and numbers of revolutions gears were summarized below.

In fact that, PC/ABS materials are durable against flame, air, ultraviolet lights and holding lower moisture than PA66 GFR 30 materials, the usage of them brings an advantage in many industrial areas. Particularly, gear materials like PC/ABS should be provided to widely used, open and moisture environmental conditions. In this study, it was found that good operating conditions are comprised at low numbers of revolutions and the tooth loads. If the driver gear was AISI 8620, the accumulated heat on the steel gear spread out easily. However, when tooth load increased, thermal damages occurred and the fracture of tooth and the surface melting was formed due to an immediate increase of temperature. Additive materials should be added to PC/ABS materials for rising durability. Suitable environmental conditions must be determined by defining the number of revolutions and the tooth load for gears [18]. PC/ABS gear should be preferred at low tooth and unwanted high power transmission.

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Additional information

The paper was published also in the Archives of Materials Science.

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