Evaluating Fatigue Life of Injection-Molded-Plastic-Gear added with Carbon Particle made from Rice Hull

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Abstract

Injection-molded plastic gears are often used by adding some reinforcing materials, due to improvement in heat resistance, because the bulk temperature is easy to come close to the glass transition temperature of plastic materials. On the other hand, natural materials are utilized to focus on the ecological recycling. The rice hull is a residual product of rice and it contains natural silica about 20wt.%. Therefore, a carbonized rice hull; Rice-Hull-Silica-Carbon (RHSC) is focused as effective utilization of discarded rice hull. The RHSC is high strength and low frictional of porous carbon material. The authors have used the RHSC as a reinforcing material in plastic gear. In this study, some composite materials of a polyacetal and the RHSC-particle were prepared for the strengthen-injection-molded plastic gear. Test gears are the spur gear pair, helical gear pair and the crossed helical gears. Then, the fatigue test was carried out measuring the bulk temperature. Especially, the effects of RHSC were discussed to improve the fatigue strength of the injection-molded plastic gear.

Keywords: plastic gear, spur gear, helical gear, crossed helical gears, polyacetal, rice hull, porous carbon, silica, composite material

1 Introduction

Recently, plastic gears used in wide ranges of industrial products. Demands for plastic gears have increased for the purpose of weight saving, low cost, low noise, and clean environment. In Japan, Almost of all plastic gear have been produced by injection molding. The polyacetal (POM) is used as a gear material about 80% of them. Compared to other general-purpose engineering plastics, POM has a very good balance of price and performance.

The load-carrying capacity, wear and fatigue life of gears are affected by many factors [1to3]. In the case of injection-molded plastic gear, the plastic materials and the bulk temperature are the most important factors [1], [2]. The bulk temperature is easy to come close to the glass transition temperature of the plastic materials. Therefore, the plastic gears are added with reinforcing materials for keeping strength in high bulk temperature.

On the other hand, new utilizations of agricultural waste are focused on the ecological recycling, and the biomass has the characteristics of carbon offset. The rice is eaten all over the world. Especially, the consumption of rice becomes large in Asia. The rice hull is a residual product of rice, about 0.9 million tons of rice hulls are refused every year. Since the rice hull contains natural silica about 20wt.%, It has the potential for good frictional properties and high strength. Therefore, composite materials of biomass and plastic are reported [4to6]. Based on these backgrounds, the authors used carbon particles made from rice hull: Rice Hull Silica Carbon (RHSC) as a reinforcing material in plastic gear [7][8]. The RHSC is a porous carbon material. The effects of the median grain diameter and dopant ratio of RHSC-particle were discussed [7]. Then, the effect of RHSC particles on the frictional property and the fatigue mechanism were clarified [8].

In this study, test gears made from some composite material of POM and RHSC-particle. Test gears are spur gear pair, helical gear pair and crossed helical gears. The fatigue lives of these test gears were investigated. Based on results, the effects of RHSC particle were discussed to improve the fatigue strength of the injection molded plastic gear.

2 Experiments

2.1 Test gear

All test gears are injection molded gears, and geometrical dimensions are in same values. Therefore, the driving and driven gears were in same dimensions.

Table 1 shows materials for test gears. The polyacetal copolymer (POM) and the composite materials of POM and RHSC-particle were prepared for test gears. The dopant ratio of RHSC-particle is 7wt.%. The median grain diameters of RHSC-particle are 5μm and 60μm. Test gears are called POM, RHSC5 and RHSC60, respectively. Then, the both of RHSC5 and RHSC60 are called the RHSC-gear.

(1) Spur gear

Table 2 shows the dimensions of test spur gears.

(2) Helical gear

Table 3 shows the dimensions of test helical gears. The helix angle is 20 degree. In the case of crossed helical gears, the angle between shafts of crossed helical gears is 40 degrees, because the gears of same helix direction are used.

2.2 Experimental apparatus

The schematic representations of experimental apparatus are shown in **Fig. 1** and **Fig. 2**. The experimental apparatus used in this study is the power absorbing type. The synchronous speed of motor is 1500 rpm/50Hz. A transistor inverter is used to change the frequency of the electrical power source. The synchronous speed of the motor can be set at random within the range from 300 to 1800 rpm. The rotational speed of test gear is monitored by a tachometer. To set up the testing torque, a torque meter and a powder brake were added to this equipment. During the experiment, the bulk temperature of test gear was measured by a radiation thermometer.

(1) Spur gear pair and Helical gear pair

The experimental apparatus for spur gear pair and helical gear pair is shown in **Fig. 1**. The center distance between gear shafts can be set arbitrarily.

Table 1 Materials for test gears

Material		POM	RHSC5	RHSC60
Matrix		Polyacetal		
Filler		—	RHSC particle	
Median grain diameter	[μm]	—	5	60
Dopant ratio	wt.%	—	7	

Table 2 Dimensions of test spur gear

		Spur gear
Module	m [mm]	1.0
Pressure angle	α_c [deg.]	20
Number of teeth	z	48
Addendum Modification coefficient	x	0
Face width	b [mm]	8.0
Gear accuracy		JIS B 1702-3 Class P7

Table 3 Dimensions of test helical gear

		Helical gear
Module	m [mm]	1.0
Pressure angle	α_c [deg.]	20
Number of teeth	z	48
Addendum Modification coefficient	x	0
Face width	b [mm]	8.0
Helix angle	β [deg.]	20
Gear accuracy		JIS B 1702-3 Class P6

(2) Crossed helical gears

The experimental apparatus for crossed helical gears is shown in **Fig. 2**. The angle between gear shafts can be set arbitrarily.

2.3 Fatigue test

Test gear was operated at a constant rotational speed and transmitting torque, until the gear was broken. At this point the total number of rotation was counted as the fatigue life of test gear. In this study, lubricant was not used. In addition, the fatigue limit is defined as 10^7 revolutions, the total number of rotation.

The room temperature was kept at 23°C ± 2°C. To survey the conditions of test gear, the bulk temperature in the middle of tooth width was measured using a radiation thermometer during operation.

(1) Spur gear pair

The transmitting torque set up from 1.5 to 5.0Nm by a 0.5Nm unit. Test gear was operated at a constant rotational speed at 1000rpm. The backlash was set to 0.1 mm

(2) Helical gear pair

The transmitting torque set up from 1.5 to 3.5Nm by a 0.5Nm unit. Test gear was operated at a constant rotational speed at 1000rpm. The backlash was set to 0.1 mm

(3) Crossed helical gears

The transmitting torque set up from 0.2 to 0.6Nm by a 0.1Nm unit. The rotational speed of test gear was fixed at 500rpm and 1000rpm. The backlash was set to be 0.2mm.

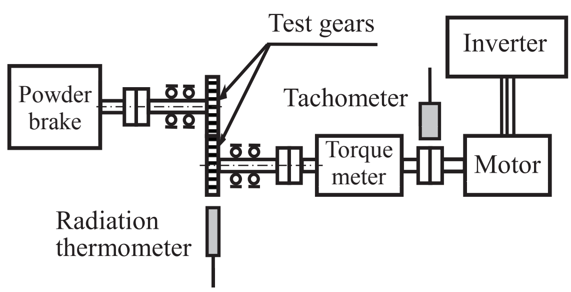


Fig. 1 Experimental apparatus and measuring system for spur gear pair and helical gear

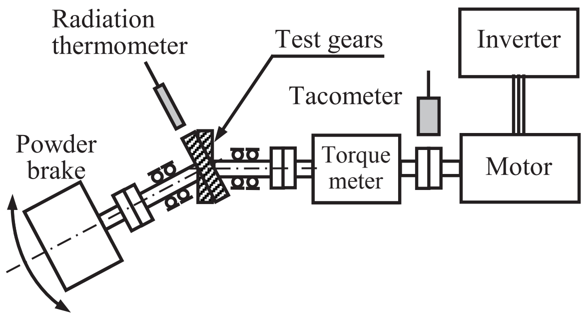


Fig. 2 Experimental apparatus and measuring system for crossed helical gears

3 Experimental results and discussions

3.1 Bulk temperature

Figures 3, 4 and **5** plot the bulk temperature vs the number of rotation.

In the case of spur gear pair shown in **Fig. 3**, the bulk temperature of RHSC gear increases over time and reaches equilibrium. However, the bulk temperature of POM rapidly increases after the start of rotation, peaks, and then decreases gradually, reaches equilibrium.

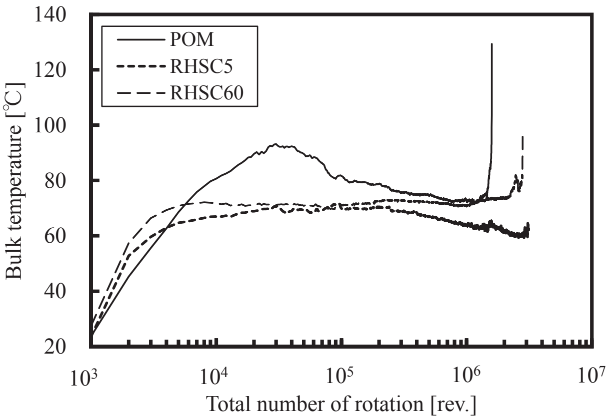


Fig. 3 Transition of bulk temperature with number of rotation (Spur gear pair, Torque 3.0Nm)

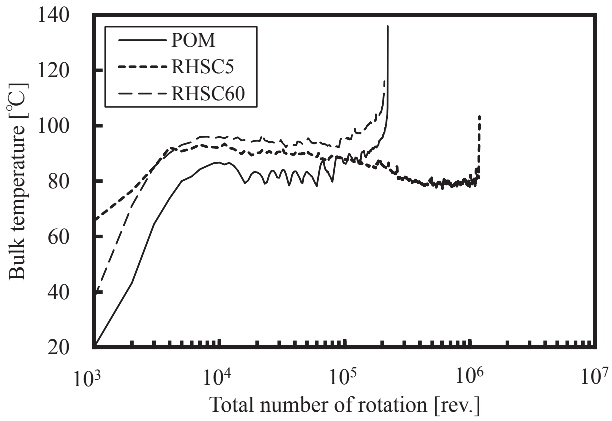


Fig. 4 Transition of bulk temperature with number of rotation (Helical gear pair, Torque 3.5Nm)

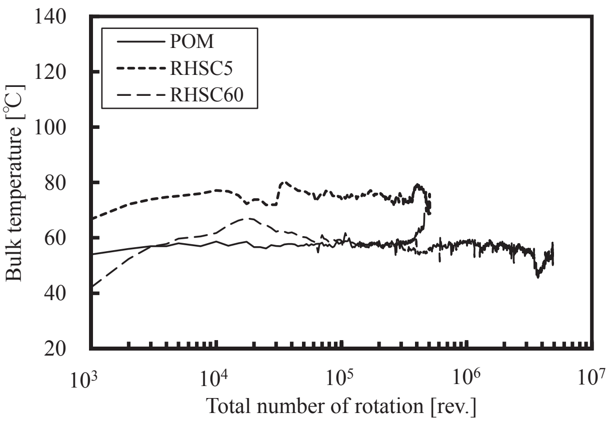


Fig. 5 Transition of bulk temperature with number of rotation (Crossed helical gears, Torque 0.5Nm)

Figure 4 shows the case of helical gear pair. The transition of bulk temperature of RHSC gear is similar to the spur gear pair. However, the case of POM, the bulk temperature of helical gear pair is lower than the RHSC gear.

In the case of crossed helical gears shown in **Fig. 5**, the bulk temperature gradually increases over time and reaches equilibrium soon, and keeps on equilibrium for a long time. From these results, it was found that the relationship between the bulk temperature and the rotation time differs according to the gear type. Because it is believed that the bulk temperature is approximately equal to the amount of tooth wear, it is believed that the tooth wear of crossed helical gears occur a constant volume per every rotation.

3.2 Fatigue life

Since plastic gears are affected by heat, the average value of the gear bulk temperature during operation (average bulk temperature) was used as an index to evaluate the fatigue life. The average bulk temperature represents the amount of fatigue work to the test gears during operation.

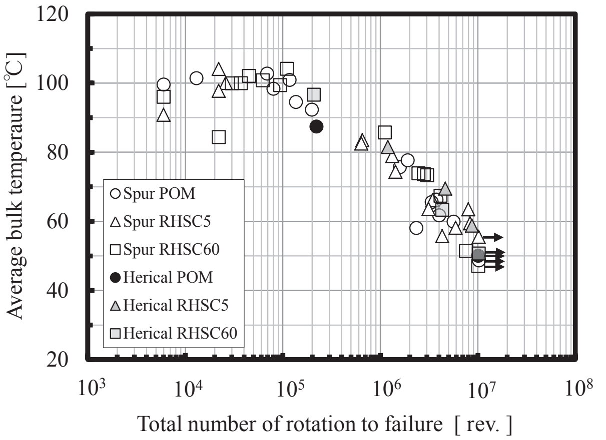


Fig. 6 Relationship between averaged bulk temperature and fatigue life (Spur gear pair and helical gear pair)

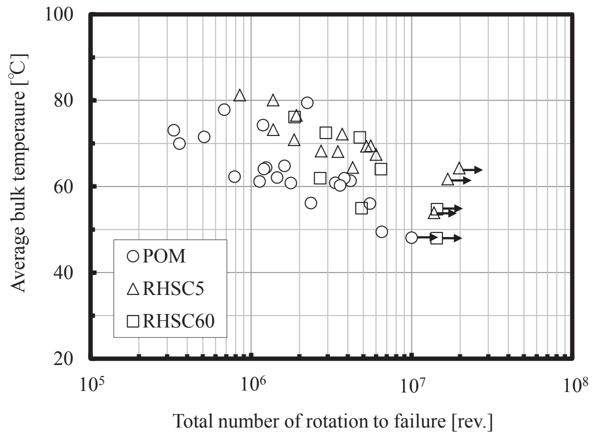


Fig. 7 Relationship between averaged bulk temperature and fatigue life (Crossed helical gears)

(1) Spur gear pair

The fatigue life of spur gear pair is shown in **Fig.6**. The fatigue life differs according to the median grain diameters of RHSC-particle. At the low temperature region, RHSC5 becomes a long life compared to POM and RHSC60. Therefore, the smaller median diameter of RHSC-particle is better for a reinforcing material in polyacetal. Furthermore, compared with other gear pair, the fatigue limit of RHSC5 is higher about 8°C. In other words, by the addition of RHSC-particle, a heat resistance of plastic gear is improved.

(2) Helical gear pair

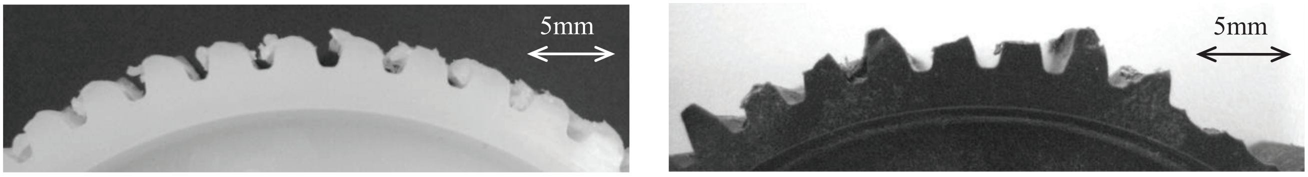
The fatigue life of helical gear pair is represented in **Fig. 6**, along with the case of the spur gear pair. The fatigue life slightly differs according to the median grain diameters of RHSC-particle. However the fatigue life of helical gear pair is approximately equal to the case of spur gear pair.

(3) Crossed helical gears

The fatigue life of crossed helical gears is shown in **Fig.7**. The variation in fatigue life is greater at higher temperatures also any gears. However, the variation in fatigue life is small at lower temperature. In the low temperature region, RHSC-gear becomes a long life compared to POM. Since the theoretical mesh is a point contact, the low frictional property of RHSC-particle affects the fatigue life.

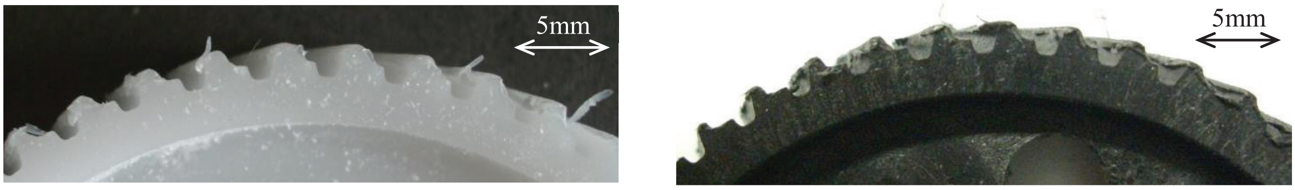
3.3 Damage form

The example of damage forms are shown in **Fig. 8** and **Fig.9**. In the case of spur gear pair, POM was melted for the frictional heat. However, RHSC-gear was breakage. The damage forms differ in existence of the RHSC particle. Also, the damage forms of helical gear pair are approximately equal to the case of spur gear pair.



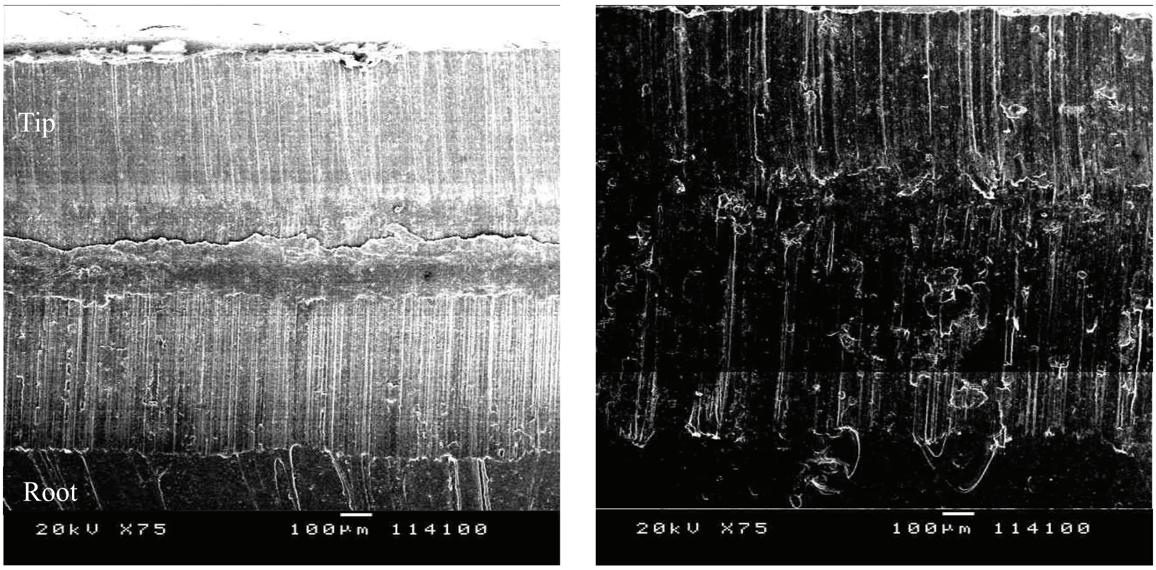
(a) POM (3.77×10^6rev.) (b) RHSC60 (2.56×10^6rev.)

Fig. 8 Damage forms of spur gear (Torque 3.0Nm)



(a) POM (1.24×10^6rev.) (b) RHSC5 (2.73×10^6rev.)

Fig. 9 Damage forms of crossed helical gears (Torque 0.5Nm, Rotational speed 500rpm)



(a) RHSC5, Initial wear (3.0×10^4 rev.) (b) RHSC60, Initial wear (3.0×10^4 rev.)

Fig. 10 Wear on tooth surface (Spur gear pair, Torque 3.5Nm)

In the case of crossed helical gears, the damage forms were tooth wear for all test gears. However, occurrence of wear particle is minimal in the RHSC gear. These results, adding the RHSC-particle to POM, it shows a possibility of improving the heat resistance or low heat generation due to decrease in friction. The long fatigue life of plastic gear is expected.

3.4 Tooth surface

The tooth surface of spur gear is shown in **Fig. 10**. The tooth surface of RHSC gear was worn, and the tooth became thin with increasing the operating time. The RHSC-particle scrapes against the tooth face. Then, the size of sheeted line is affected by the median grain diameter of RHSC-particle. When RHSC particles on the tooth surface shave the other tooth face, the projected area of RHSC particles is small, it become small frictional coefficient. In the case of RHSC60, since the RHSC-particle is large, damage to the tooth face is large. As the increase of rotational time, damage to the tooth surface becomes worse in any gear.

4 Conclusions

Based on the experimental results and discussions as given above, the following conclusions have been reached:

(1) The RHSC-particle existed on the tooth face shaves other tooth face, these trace depends on the size of RHSC-particle.

(2) In the case of RHSC-gear, the projected area of RHSC particles is small, it become small frictional coefficient. Therefore, the smaller median diameter of RHSC-particle is better for a reinforcing material in polyacetal gear.

(3) In the case of helical gear pair, the properties such as the bulk temperature and the fatigue life are approximately equal to the case of spur gear pair.

(4) In the case of crossed helical gears, since the theoretical mesh is a point contact, become to a high contact pressure. Therefore, the low frictional property of RHSC-particle affects the fatigue life.

Acknowledgement

Part of this work was supported by Grant in Aid for JST No. 04-095, and JSPS KAKENHI Grant Number 24560173. Before concluding, we wish to thank Mr. Takeshi Takahashi (Sanwa-Yushi Co.,Ltd., Higashine, Japan) for providing the experimental materials (RHSC-particle).

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Received on October 31, 2013
Accepted on January 28, 2014.