Short Communication

Friction and Wear of Polyamide 66 Composites Filled with RB Ceramics Particles under Dry Condition

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This study investigated the effect of a particle diameter and a mass fraction of RB ceramics particles on friction and wear of polyamide 66 composites filled with RB ceramics particles (PA66/RB ceramics composites) sliding against a bearing steel ball under dry condition. RB ceramics particles with a mean diameter of 3, 30, and 150 μm were used as the filler. Mass fractions of RB ceramics particles were 10, 30, and 50 mass% for the mean diameter of the particles of 3 μm, and 30, 50, and 70 mass% for the mean diameters of 30 and 150 μm. The smaller mean diameter and the higher mass fraction of RB ceramics particles provided lower friction coefficients and lower specific wear rates with the PA66/RB ceramics composites. The composite with a mean diameter and a mass fraction of RB ceramics particles of 30 μm and 70 mass% took the lowest friction coefficient of 0.27 among the composites. The composite with a mean diameter and a mass fraction of RB ceramics particles of 3 μm and 50 mass% took the lowest specific wear rate of 1.3×10⁻⁹ mm²/N among the composites, which was equivalent to the specific wear rate of RB ceramics disk.

Keywords: filler, friction, polyamide 66, polymer, RB ceramics, wear

1. Introduction

Polyamide 66 (PA66) has been widely used in mechanical components such as gear, bearing, and retainer, either filled or reinforced by graphite, PTFE (polytetrafluoroethylene), glass fibre, carbon fibre, and aramide fibre to improve tribological properties[1-3]. Recently, new polymer composites, filled with particulate RB (rice bran) ceramics, were developed[4]. RB ceramics are hard porous carbon materials made from rice bran[5,6]. Five kinds of thermoplastic resins, namely, PA66 (polyamide 66), PA11 (polyamide 11), POM (polyoxyxymethylene), PBT (polybutylene terephthalate), and PP (polypropylene) were used as matrix resins, compounded with RB ceramics particles with a mean diameter of 150 μm. The newly developed polymer composites showed lower friction and higher wear resistance than the neat resins, irrespective of matrix resins, sliding against steel ball under dry and di-ester oil lubricated conditions[4]. Particularly, it was revealed that the RB ceramics particles provided a significant improvement of wear resistance with the thermoplastic resins. The results indicate RB ceramics particles can be applied as filler which can provide both low friction and low wear. However, how the particle size and the mass fraction of RB ceramics particles affect the tribological properties of the polymer/RB ceramics composites remained unclear.

In this study, PA66 composites filled with RB ceramics particles with different mean diameters and mass fractions were prepared, and the effect of the mass fraction and the mean diameter of RB ceramics particles on the friction and wear properties was experimentally investigated under dry sliding condition.

2. Experimental

2.1. Sample preparation

Disk shaped (φ = 50 mm, t = 3 mm) PA66, and the PA66/RB ceramics composites with different mean diameters and mass fractions of RB ceramics particles were prepared by injection molding. RB ceramics particles with mean diameters d of 3, 30, and 150 μm were used as filler. Mass fractions of RB ceramics particles α were 10, 30, and 50 mass% for the mean
diameter of RB ceramics particles of 3 μm, and 30, 50, and 70 mass% for the mean diameters of 30 and 150 μm, respectively. RB ceramics particles with the mean diameters of 30 and 150 μm are porous particles featuring micrometer size pores. However, RB ceramics particles with the mean diameter of 3 μm don't include such pores. Thus, the apparent density of RB ceramics particles with the mean diameter of 3 μm is higher than that of RB ceramics particles with the mean diameters of 30 and 150 μm. The increased density causes lower fluidity of the compound during injection molding. That is why the maximum mass fraction of RB ceramics particles being capable of injection molding for the mean diameter of 3 μm (50 mass%) was lower than that for the mean diameters of 30 and 150 μm (70 mass%). Mechanical properties of these disk samples are listed in Table 1.

Figure 1 shows cross sectional BE (backscattered electron) images of the PA66/RB ceramics composites with different mean diameters of RB ceramics particles. As shown in Fig. 1, RB ceramics particles are dispersed homogeneously in the matrix PA66 without agglomeration. The relationship between mass fraction of RB ceramics particles and Vickers hardness of the composites, which was obtained using a load of 100 gf, is shown in Fig. 2. As can be seen in Fig. 2, the higher mass fraction and the smaller mean diameter of RB ceramics particles tend to increase Vickers hardness of the PA66/RB ceramics composites.

2.2. Experimental procedure

Friction tests were carried out using the linear reciprocating motion type friction apparatus. Bearing steel (JIS SUJ2) balls with a diameter of 2 mm were used as ball specimens. The neat PA66, the PA66/RB ceramics composites, and RB ceramics (size: 50 × 50 × 10 mm, surface roughness Ra: 1.1 μm, Vickers hardness HV: 4.4 GPa) were used as disk specimens. The sliding velocity (the sliding velocity is defined as a steady-state stage velocity not including the velocity at acceleration stage velocity not including the velocity at acceleration

![Cross sectional BE images of PA66/RB ceramics composites](image)

![Effect of mass fraction of RB ceramics particles on Vickers hardness of the specimens](image)

![The variation of the friction coefficients with number of repeat passages](image)
and deceleration periods) was 0.001 m/s. The normal load was 0.49 N, and the number of repeat passages was 1000 cycles. The friction coefficient used in this study was the average value during the period when the stage took steady state velocity.

Wear tests were conducted using the same friction apparatus as the friction tests. For the wear tests, the normal load was 0.49 N, the sliding velocity was 0.01 m/s, and the number of repeat passages of friction was $4 \times 10^4$ cycles. The wear rate of a disk specimen was measured using a surface profilometry across the wear track perpendicular to the sliding direction. All the tests were conducted at room temperature under dry sliding condition.

3. Results

3.1. Effect of mean diameter and mass fraction of RB ceramics particles on friction of PA66/RB ceramics composites

Figure 3 shows the variation of the friction coefficients for the neat PA66, the PA66/RB ceramics composite ($d = 30 \mu m$, $\alpha = 70$ mass%), and the RB ceramics with number of repeat passages. The friction coefficients for the PA66 significantly increased at the initial stage of friction, then took stable value around 0.6. The RB ceramics took low and stable value of friction coefficient of 0.16 irrespective of number of repeat passages. On the other hand, the friction coefficients for the PA66/RB ceramics composite slightly increased, then took stable value around 0.3.

Figure 4 shows the effect of mass fraction of RB ceramics particles on friction coefficients at 1000 cycles. It can also be seen in Fig. 6 that the specific wear rates of the PA66/RB ceramics composite was significantly lower than that of the neat PA66 (75 - 98% reduction). It can also be seen in Fig. 6 that the specific wear rates of the PA66/RB ceramics particles on the specific wear rate of the disk specimens. The specific wear rate of each PA66/RB ceramics composite was significantly lower than that of the neat PA66 (75 - 98% reduction). As can be seen in Fig. 4, the friction coefficients for the PA66/RB ceramics composites decreased with an increase of mass fraction of RB ceramics particles. The PA66/RB ceramics composite with $d = 30 \mu m$ and $\alpha$ of 70 mass% took the lowest friction coefficient of 0.27 among the composites.

Figure 5 shows the distribution of friction coefficients for the PA66/RB ceramics composites as a function of mean diameters and mass fractions of RB ceramics particles. As clearly shown in Fig. 5, smaller mean diameter and higher mass fraction of RB ceramics particles provided lower friction coefficients.

3.2. Effect of mean diameter and mass fraction of RB ceramics particles on wear of PA66/RB ceramics composites

Figure 6 shows the effect of mass fraction of RB ceramics particles on the specific wear rate of the disk specimens. The specific wear rate of each PA66/RB ceramics composite was significantly lower than that of the neat PA66 (75 - 98% reduction).
ceramics composites decreased with an increase of mass fraction of RB ceramics particles. Particularly, the composite with \( d \) of 3 \( \mu \)m and \( \alpha \) of 50 mass\% took the lowest specific wear rate of \( 1.3 \times 10^{-9} \text{ mm}^2/\text{N} \) among the composites, which was equivalent to that of RB ceramics disk \( (1.2 \times 10^{-9} \text{ mm}^2/\text{N}) \).

Figure 7 shows the distribution of the specific wear rate of the PA66/RB ceramics composites as a function of mean diameters and mass fractions of RB ceramics particles. As clearly shown in Fig. 7, smaller mean diameter and higher fraction of RB ceramics particles provided lower specific wear rate with the PA66/RB ceramics composites as well as lower friction coefficient.

4. Discussion
As shown in Fig. 2, the PA66/RB ceramics composites with the higher fraction and the smaller diameter of RB ceramics particles took higher Vickers hardness. Fig. 8 shows the effect of Vickers hardness of the disk specimens on friction coefficients and specific wear rates of the disk specimens. The friction coefficients decrease with an increase of Vickers hardness. It can be considered that the increased hardness of the composite materials due to small diameter and high fraction of RB ceramics particles results in smaller contact area. Furthermore, small diameter and high fraction of RB ceramics particles increase the number of the particles in the contact area, which will decrease the adhesion. Hence, small diameter and high fraction of RB ceramics particles provide lower friction coefficients with the composite materials. As also can be seen in Fig. 8, the specific wear rate of the disk specimens drastically decreased with an increase of Vickers hardness. It can be thought that the increased hardness of the composite materials due to small diameter and high fraction of RB ceramics particles increases the plastic flow pressure, which would prevent severe wear accompanied with the surface plastic flow. In addition, the reduced adhesion due to small diameter and high fraction of RB ceramics particles mentioned above will also contribute to the reduced specific wear rate.

5. Conclusions
This study investigated the effect of particle diameter and mass fraction of RB ceramics particles on friction and wear of the PA66/RB ceramics composites. The conclusions obtained in this study are summarized as follows;

(1) The PA66/RB ceramics composites prepared in this study showed the lower friction coefficients and the lower specific wear rates than the neat PA66 under dry condition.

(2) The smaller mean diameter and the higher mass fraction of RB ceramics particles provided the lower friction coefficients with the PA66/RB ceramics composites. The composite with the mean diameter and the mass fraction of RB ceramics particles of 30 \( \mu \)m and 70 mass\% took the lowest value of friction coefficient of 0.27 among the composites.

(3) The smaller mean diameter and the higher mass fraction of RB ceramics particles also provided the lower specific wear rates with the PA66/RB ceramics composites. The composite with the mean diameter and the mass fraction of RB ceramics particles of 3 \( \mu \)m and 50 mass\% took the lowest value of specific wear rate of \( 1.3 \times 10^{-9} \text{ mm}^2/\text{N} \) among the composites which was equivalent to the specific wear rate of RB ceramics disk.
6. References


