Tribological behavior of fiber reinforced PA66 material under high surface pressure, sliding and grease lubricated conditions

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MOTS CLES
Polyamide, Glass fiber, Grease, Steel, molecular mass, hardness of metal

INTRODUCTION

Polyamide66 (hereinafter PA66) material is widely used for sliding parts, such as worm gear and bearing retainer. Recently, there are great demands of downsizing and high-power driving for sliding parts, and it is required to reduce the deformation of parts and ensure durability life by improving the strength and stiffness of resin material. Reinforcement by fibers such as glass fibers (GF) or carbon fibers (CF) is an effective way to meet the above challenge. There are various conventional researches on the tribology of fiber reinforced polyamide in contact with metallic material [1]. However, these researches are mostly carried out in dry conditions. In addition, there are only few reports on the effects of parameters such as molecular mass of resin or hardness of metallic counterbody on the tribological properties under sliding conditions in grease. In this work, we investigated the tribological mechanisms of fiber reinforced PA66 material in contact with metallic material under grease lubrication.

TESTING METHOD

Each testing specimens were obtained by injection molding process. Table 1 shows the details of tested materials. Viscosity number (hereinafter VN which is related to the molecular mass of resin) of each specimen was measured by relative viscosity method in conformity with ISO 307. Tribological properties were evaluated in sliding test under grease lubricated conditions, with a rotating resin ring in contact with 4 metal cylinders. Figure 1 shows a schematic view of the testing device. It is possible to obtain high contact pressure, similar to the one observed in worm gear. Table 2 shows test conditions. Effects of counterpart metal hardness was also studied, and different values of hardness of steel material were obtained by different conditions of heat treatment.

Table 1: Evaluated material

No.	Resin	Fiber	VN
1	PA66	GF15%	145 ml/g
2	PA66	GF15%	193 ml/g
3	PA66	GF15%	230 ml/g
4	PA66	CF10%	150 ml/g
5	PA66	CF10%	220 ml/g

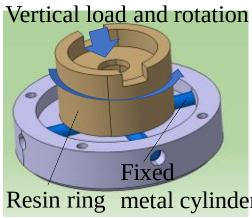

Figure 1: Schematic view of testing

Table 2: Test conditions

Item		Value	Item	Value
Resin ring	Outer diameter	25.6 mm	Grease	Urea grease
	Inner diameter	20 mm	Normal load	220-350 N
	Height	12 mm	Surface pressure	156-198 MPa
	Young's modulus	6 GPa (PA66+GF15%) 9.5 GPa (PA66+CF10%)	Rotation speed	1 m/s
Metal cylinder	Material	S45C (Fe+0.45% C)	Temperature	RT
	Diameter	φ3.5 mm	Testing time	Total: 4 hr in which 10sec driving and 20sec stopping are repeated
	Hardness	HV311-HV660		
	Young's modulus	205 GPa		

RESULTS AND DISCUSSION

Figure 2 shows the evolutions of friction coefficient (μ) and vertical displacement of the sample No.1 (normal molecular mass). Both average and max values of μ in each 1 second were recorded respectively. Displacement did not increase in the initial stage of testing (indicated that neither wear nor creep did occur); however, after this initial stage, an inflection point of displacement was observed. In addition, rapid increase of μ also occurred at the time of inflection point, accompanied by severe noise. The process of deformation during testing was clarified by detailed observation and analysis as follow.

At first, breakage and dropping of GF occurred due to the initial contact pressure and sliding. Then, micro cracks related to the damaged GF were generated. Then, μ increased due to the deterioration of surface conditions and finally large peeling occurred. The effect of creep deformation was higher just after the peeling, but the effects of wear increased by increasing sliding time. On the other hand, in the case of unreinforced PA66 material, the abrasion wear or large-scale peeling like GF reinforced PA66 was not confirmed, and only creep deformation in initial stage of testing occurred.

Fig.3 shows the results in the sample No.3 (high molecular mass). It took longer time to come to the inflection point of displacement compared to the normal molecular mass sample, and the speed of increasing displacement after the inflection point was slower. The reason for peeling was studied with experiments during which the stopping time between sliding periods was changed. The effect of fatigue properties related to the repeated contacts on the peeling occurrence was supposed to be much higher than the thermal properties such as glass transition temperature of PA66. The results of tensile testing showed that the breakage energy (integral value of stress-strain curve) was increased by increasing molecular mass related to the increase of elongation at break. Therefore, fatigue properties related to repeated stress were supposed to be increased and high wear resistance properties were obtained.

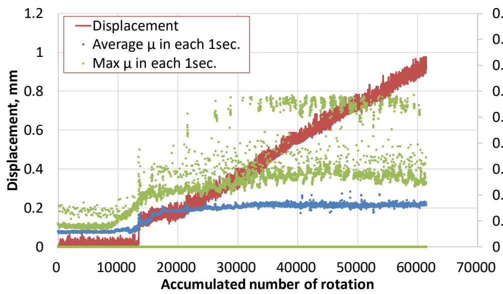

Figure 2: Testing chart (No.1)

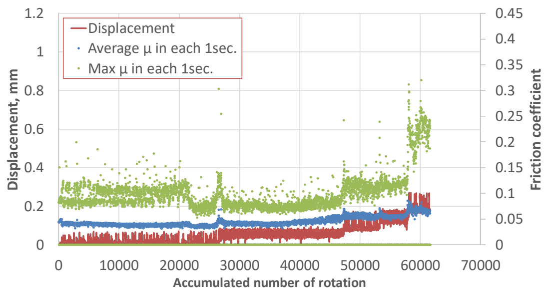

Figure 3: Testing chart (No.3)

Wear of metallic cylinders and the effect of metal hardness on wear resistance properties of metal and resin were also investigated. A decrease of wear for both resin and counterpart metal are observed when increasing molecular mass of resin. This was because wear of resin was reduced by increasing molecular mass, and exposure of reinforcement fiber in resin surface or mixture of wear debris into grease were reduced; therefore abrasive wear of metal could be reduced. In addition, the effects of metal hardness on the wear of PA66 was also evaluated. There was an inflection point of height deformation of resin in both GF and CF reinforced material as shown in Figure 4. We also confirmed that the hardness in the inflection point coincides with the hardness of fiber itself measured by nano-indentation and converted to Vickers hardness. Thus, it was supposed that when the hardness of fiber is lower than the hardness of metal, wear of fibers in surface occurred and resin was worn in abrasive wear mode. On the other hand, when the hardness of metal was lower than the hardness of fiber, the wear of fiber and damage of fiber was reduced and wear of resin was decreased.

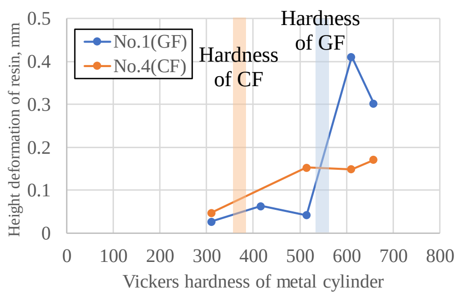

Figure 4: Relation between hardness of metal and deformation of resin

CONCLUSION

Tribological mechanism of fiber reinforced polyamide 66 material which slides against metal material under grease lubrication was clarified. There was an inflection point of deformation during testing which is related to the peeling of resin, and this is attributed to microcracks which is related to GF which was damaged and dropped from sliding surface. In addition, this deformation was reduced by increasing molecular mass. Furthermore, the effects of hardness of counterpart metal on wear of fiber reinforced PA66 was possible to be explained by the relative hardness of metal and fibers.

Références

[1] Shin, M. W., Kim, S. S., & Jang, H. (2011). Friction and wear of polyamide 66 with different weight average molar mass. *Tribology Letters*, *44*(2), 151–158.A.