# Long durability and tribology of polymer worm reducer for automobile electric power steering

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## 1. Introduction

Polymer worm reducer is used in electric power steering (EPS) with the characteristic of low noise and weight. Figure 1 presents the schematic of EPS and polymer worm reducer. Recent requirements for use under much severer conditions and downsizing need longer durability of polymer worm wheel (hereinafter gear) using engineering plastics including PA66. Tribology in the contact between polymer and steel under grease lubrication plays an important role to improve the performance of polymer worm reducer. In this study, measures to achieve longer durability were discussed from the viewpoint of improving the characteristics of polymer gear materials.

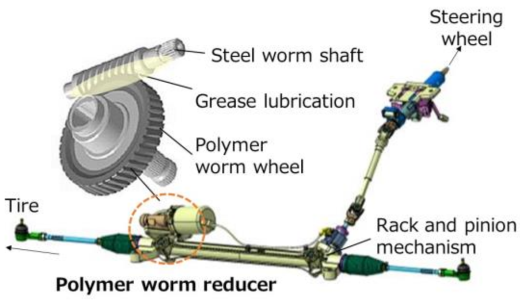


Fig.1 Schematic of electric power steering and polymer worm reducer.

## 2. Experimental

### 2.1 Basic sliding test

The tribological properties in the contact between PA66 and steel under urea grease lubrication were evaluated, using a basic sliding test which simulates the contact geometry of worm reducer in EPS [1]. Figure 2 presents the schematics of test specimens and sliding test setup. Table 1 lists the geometry of test specimen and table 2 lists test conditions.

### 2.2 Durability test of worm reducer

Wear/creep resistance and durability of polymer gear were evaluated with meshing steel worm shaft under grease lubrication. Tests were conducted under specific conditions of input torque, speed and temperature considering the environment of worm reducer.

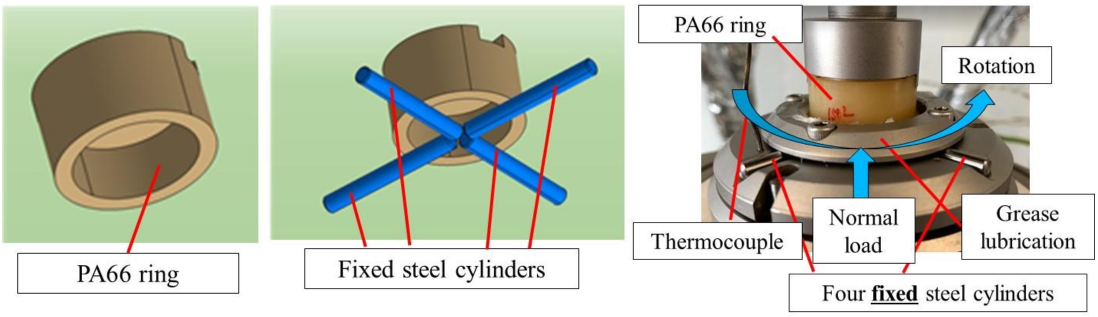


Fig. 2 Schematics of the test specimens and sliding test setup.

Table 1 Geometry of test specimen.

| | | |
|---|---|---|
| PA66 ring specimen | Outer diameter | 25.6 mm |
| | Inner diameter | 20 mm |
| | Height | 12 mm |
| Steel cylinder | Diameter | 3.5 mm |
| | Length | 30 mm |

Table 2 Test conditions for the sliding tests.

| | |
|---|---|
| Normal load | 350 N |
| Rotation speed | 790 rpm |
| Sliding speed | 1 m/s |
| Environment temperature | 25°C |
| Total sliding cycles | Max 130,000 cycles |

## 3. Results and discussion

### 3.1 Technology for long durability using unreinforced PA66 worm wheel

First, tribological properties and gear performance of unreinforced PA66 were evaluated. In the basic sliding test, little wear was observed on the PA66, and the main cause of the height reduction was creep. SEM observation of the gear surface after the durability test of the worm reducer shown in Fig. 3 exhibited little surface wear or peeling on the surface.

In the contact between the polymer and steel under grease lubrication, direct contact between the polymer and steel was reduced by the grease oil film, and adhesive wear, which normally causes polymer wear under dry conditions, was not observed. However, the unreinforced PA66 had a low Young's modulus, resulting in a large reduction in tooth thickness due to creep, which caused rattling noise and low durability of the polymer gears. Increase in the molecular mass of PA66 can improve the toughness and fatigue strength of PA66, thereby increasing durability. Figure 4 shows the relation between PA66 melt viscosity and polymer gear durability, which correlates with the molecular mass of PA66, indicating that increasing the molecular weight of PA66 is effective in improving durability.

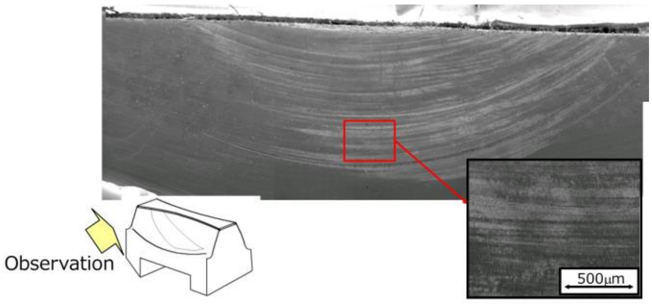


Fig.3 SEM observation of polymer gear sliding surface using unreinforced PA66 after durability test.

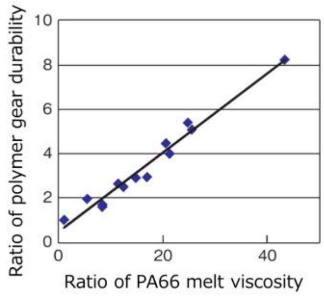


Fig.4 Relation between PA66 melt viscosity and polymer gear durability.

### 3.2 Technology for long durability using GF-reinforced PA66 worm wheel

Glass fiber (GF) reinforcement increases the strength of PA66, allowing polymer worm reducer to be used with higher input torque. On the other hand, GF induces tooth flank wear, resulting in tooth peeling and reducing the durability of polymer gears. GF also causes wear on steel worm shafts. Heat treatment to steel can increase hardness and reduce wear, however, it increases manufacturing costs and reduces meshing accuracy[2)]. Therefore, with the aim of using GF-reinforced PA66 as an EPS polymer gear material, the effects of GF-reinforced PA66 composition on wear resistance and tribological mechanisms were evaluated.

Figure 5 shows the effect of the molecular mass of PA66 on the displacement of GF composites and the change in steel wear during the basic sliding test. The number of cycles at the displacement inflection point increased as the viscosity number (VN), which correlates to the molecular mass of PA66, increased. The increase in molecular mass increases the toughness of PA66 and decreases the interface peeling between GF and PA66 due to shear stress. Thus, crack propagation and wear of the GF composite originated to the interface can be reduced. Furthermore, the increase in molecular mass can also improve the wear resistance of the steel. This is because exposure of GF edge originated to interfacial peeling which has higher aggression can be reduced. In addition, durability tests on a worm reducer using GF composite with increased molecular mass of PA66 showed less wear on the GF composite gear and non heat-trated steel worm shaft, and a longer durability compared to unreinforced PA66.

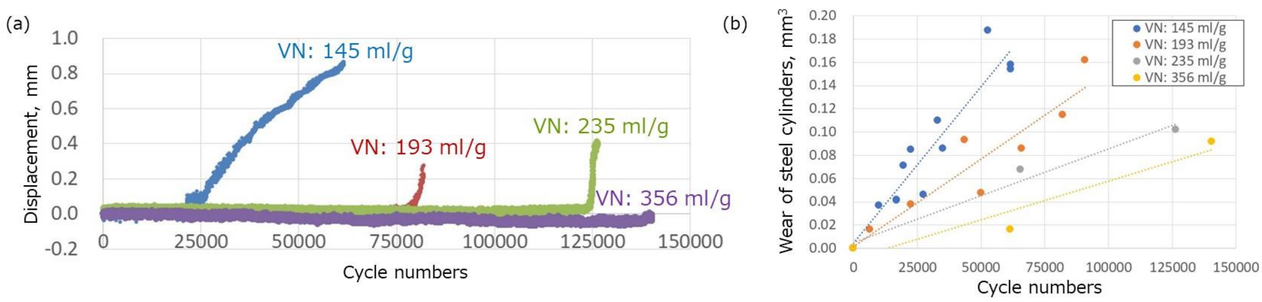


Figure 5: (a) Evolutions of GF composite displacement and (b) wear of steel counterpart during basic sliding tests.

## 4. Conclusions

This study presented the technology to increase the durability of polymer worm reducer of EPS through the improvement of the characteristics of polymer gear materials. Higher molecular mass can increase the durability of unreinforced and GF-reinforced PA66. These findings can contribute to the improvement of future EPS performance. For example, EPS can be used in large vehicles in which EPS could not be used so far due to insufficient strength of conventional polymer gears and is expected to improve fuel efficiency and contribute to autonomous driving through electrification. This basic tribological technologies of polymer gear is indispensable for the further expansion of high value-added EPS that can contribute to the global environment.

## Reference

1) T. Kunishima et al., Wear 456-457 (2020) 203383.
2) T. Kunishima et al., Wear 462–463 (2020) 203500.