# Influence of groove shape on rolling contact fatigue of PEEK-PTFE hybrid radial bearings in dry conditions

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**Abstract.** In this study, rolling contact fatigue (RCF) tests were performed in order to investigate the effect of groove radius on the life of PEEK-PTFE hybrid radial bearings. Furthermore, solid state NMR spectroscopy was performed in order to investigate the molecular structure of PEEK. It was found that groove radius shape was related to limitations of the bearings, and the molecular structure of the PEEK was not changed by the temperature rise in this test. Furthermore, thermal failure of the PEEK was not affected by oxidation during RCF test.

## 1 Introduction

PEEK (Poly-Ether-Ether-Ketone) and PTFE (Poly-Tetra-Fluoro-Ethylene) have good mechanical features such as heat and corrosion resistance. In our previous studies on PEEK radial bearings [1-4], the effect of radial load on bearing life in dry conditions was investigated. Mizobe et al. found that the wear resistance of the PEEK hybrid thrust bearing with a PTFE retainer was superior to that without the PTFE retainer [5]. Koike et al. reported that the radial load capacity of the PPS-PTFE hybrid radial bearing was improved by the groove radius shape [6]. The failure pattern of these bearings was thermal deformation.

Solid state NMR spectroscopy is used for studies of polymers in order to investigate their properties [7-9]. For example, the solid state NMR spectra can examine the change in the molecular structure of polymer basing on the assignment of the carbon signals. However, the effect of rolling contact fatigue on the molecular structure of PEEK is unclear.

In this study, rolling contact fatigue tests were performed in order to investigate the effect of groove shape on bearing life of PEEK-PTFE hybrid radial bearings. Furthermore, solid state NMR spectroscopy was performed in order to investigate the effect of the rolling contact fatigue tests on the molecular structure of PEEK.

## 2 Test method

### 2.1 Specimens

Our bearing specimens (PEEK outer race, PEEK inner race, PTFE retainer, and nine alumina ceramic balls) were designed based on the Japanese Industrial Standards (JIS) B 1512-1 2011 (Rolling bearings - Boundary dimensions - Part1: Radial bearings) and 1521 2012 (Rolling bearings - Deep groove ball bearings, #6205). Figure 1 is a photograph of the bearing specimen. The outer diameter, inside diameter, and ball diameter were 52 mm, 25 mm, and 7.14 mm (9/32 inch), respectively. Two inner races were designed, with groove radii that were 101% and 112% of the alumina ball radius. The effect of contact radius on bearings features [10] and theoretical technique for calculation of fatigue life [11] were investigated for steel bearings. However, these techniques were not investigated for polymers. In this present work, two values of 101% and 112% are selected to investigate the effect of groove curvature on contact problem in polymer bearings. Figure 2 shows an illustration of the groove radius shape of the inner races. The inner race of 101% and 112% curvature radii have been labelled as “1.0r” inner race and “1.1r” inner race. Table 1 shows the material properties of PEEK and PTFE [12-14].

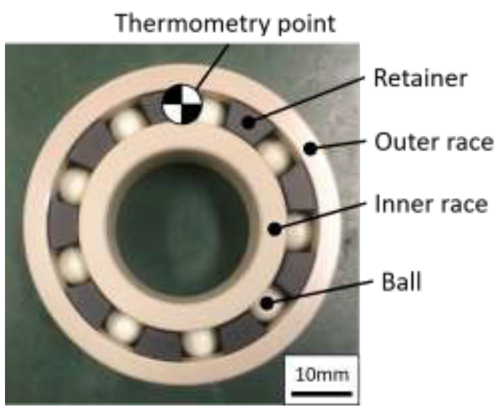


**Figure 1.** PEEK - PTFE radial bearing.

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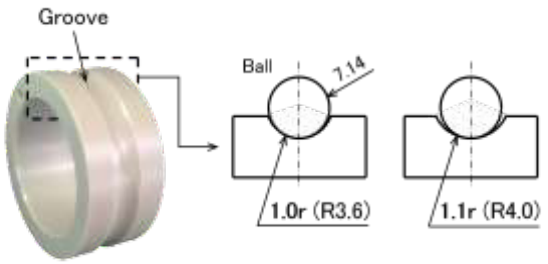



**Figure 2.** Curvature radius of groove of inner races.

**Table 1.** Material properties of PEEK and PTFE [12-14].

| | Melting point [°C] | Glass transition point [°C] | Density [g/cm$^3$] | Tensile modulus [GPa] |
|---|---|---|---|---|
| PEEK | 343 | 143 | 1.30 | 4.0 |
| PTFE | 327 | 115 | 2.16 | 0.4 |

### 2.2 Rolling contact fatigue (RCF) test

The RCF tests of PEEK-PTFE radial bearings were done using the RCF test machine which was developed by Kida's group [1-4,6]. Figure 3 shows a schematic illustration of the RCF testing machine. All tests were performed under dry conditions. Fatigue cycles were $1.0\times10^6$. The RCF tests were stopped when the specimens were broken by thermal deformation. Temperature and wear loss were measured using a thermal infrared sensor (Fluke Corporation, Fluke 59 Mini) and an electronic balance (A&D Company, BM-252).

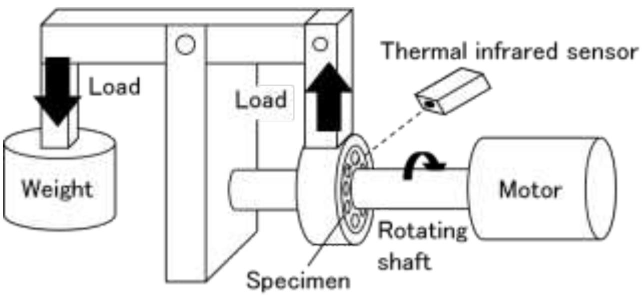



**Figure 3.** Schematic illustration of RCF testing machine.

### 2.3 Solid state $^{13}$C nuclear magnetic resonance (NMR) spectroscopy

A solid state NMR spectroscopy (JEOL Ltd., JNM-ECX500) was used in order to investigate the effect of rolling contact fatigue tests on the molecular structure of the PEEK bearing. Table 2 shows the analysis conditions of the spectroscopy. A $ZrO_2$ file was used in order to assemble the powder samples.

**Table 2.** Analysis condition of solid state $^{13}$C NMR spectroscopy.

| | |
|---|---|
| Analysis method | CP/MAS |
| Rotational speed | 10 kHz |
| Resonant frequency | 125 MHz |
| Scan number | 5000 |

## 3 Results and discussion

### 3.1 Relation between rotation speed and radial load

Figure 4 shows the failure conditions of the specimen. Failures are plotted as "×". They were caused by thermal deformation. Figure 5 shows photographs of the thermal deformation of the specimens. In the case of the thermal deformation, the inner race was melted more compared to the outer race. The thermal deformation was caused by the frictional heat. The load capacities of 1.0r and 1.1r specimens were 380 N and 476 N at 600 rpm. The 1.1r specimens did not break when the load was less than 284 N at 3000 rpm. The limit load of 1.1r specimens was higher than that of the 1.0r specimens. These results indicate that groove radius shape is related to the limitations of the bearings.

### 3.2 Wear loss

Figure 6 shows the relation between wear loss and radial load in four parts (inner race, outer race, ball, and retainer). In this test, wear loss of 1.0r was highest among all samples, whereas the wear loss of 1.1r specimens was less than that of 1.0r specimens. This indicates that the increase of the groove radius decreases wear loss.

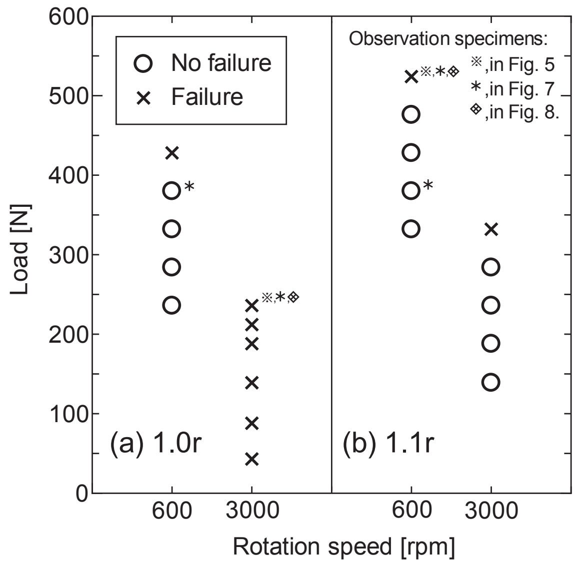
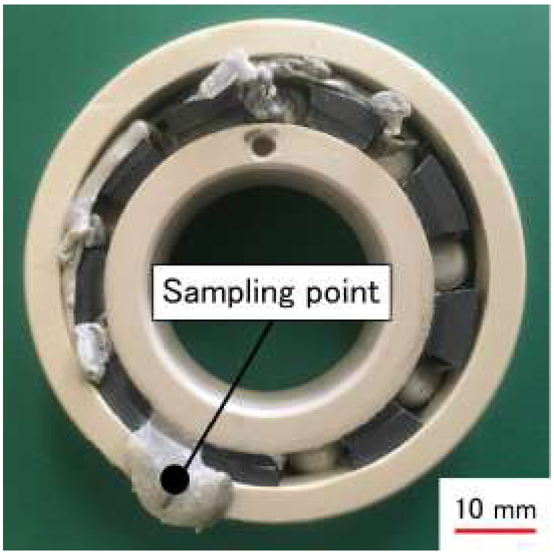


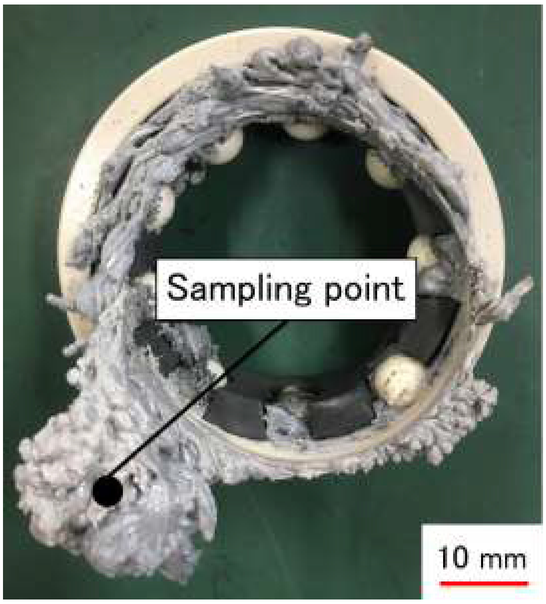

**Figure 4.** Relation between rotation speed and radial load. (a) is for 1.0r, and (b) is for 1.1r.

### 3.3 Thermometry

Figure 7 shows the relationship between temperature and the number of cycles. Temperature was measured until $1.0\times10^6$ cycles or thermal deformation. The thermal deformation occurred within $0.25\times10^6$ cycles when the temperature was over 60 °C. The feature operation temperature of the 1.1r specimens was similar to that of the 1.0r specimens. This indicates the thermal deformation occurred within $0.25\times10^6$ cycles irrespective of the groove radius.




(a)At 600 rpm and 524 N




(b)At 3000 rpm and 236 N

**Figure 5.** Photographs of the thermal deformation specimens.

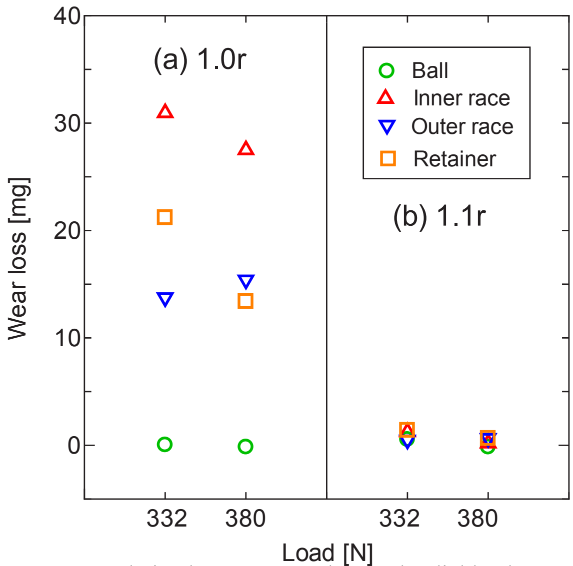



**Figure 6.** Relation between wear loss and radial load at 600 rpm. (a) is for 1.0r, and (b) is for 1.1r.

### 3.4 Analysis of solid state $^{13}C$ NMR spectroscopy

Figure 8 shows the solid state $^{13}C$ CP/MAS NMR spectra of PEEK bearings. Powder samples were assembled from the sampling points of Figures 5. Fig. 8 shows the spectrum before the test was similar to that after the test. All peaks can conform to the carbon positions in the literature [7, 8]. This indicates that the molecular structure of the PEEK is not changed by the temperature rise in this test. Therefore, it was found that the thermal failure of the PEEK bearing was not affected by oxidation during the RCF test.

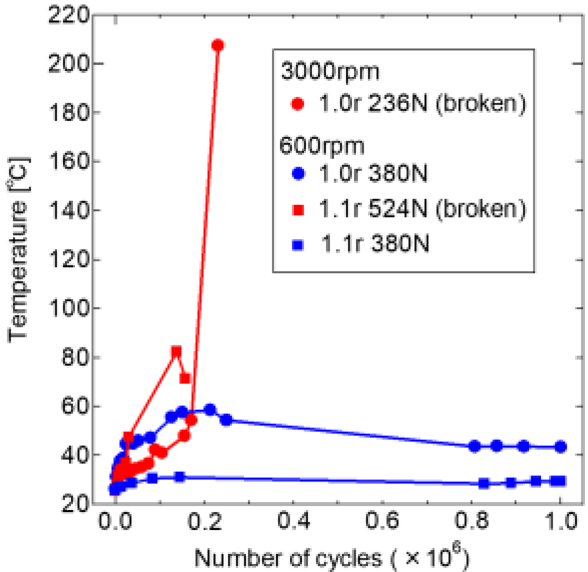



**Figure 7.** Relation between temperature and number of cycles.

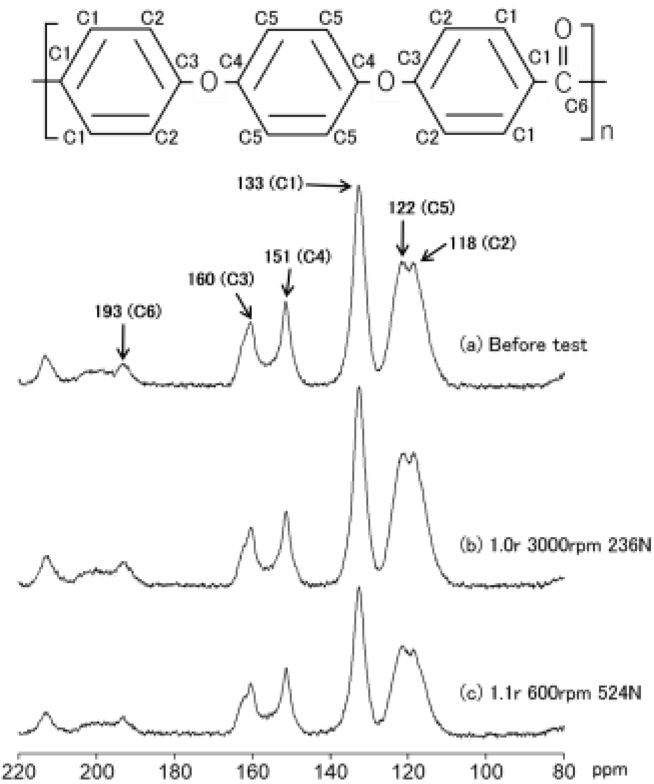



**Figure 8.** Solid state $^{13}C$ CP/MAS NMR spectra.

## 4 Conclusion

In this study, RCF tests and solid state NMR spectroscopy of PEEK-PTFE radial bearings were performed. The effect of radial load on life was examined. Furthermore, the effect of RCF tests on the molecular structure was studied. The following conclusions were obtained:

(1) Groove radius is related to the limitations of the bearings.

(2) Increase of groove radius decreases the wear loss.

(3) Thermal deformation occurs within $0.25\times10^6$ cycles irrespective of the groove radius.

(4) Molecular structure of the PEEK does not change due to temperature rise in this test.

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