Wear and friction of PEEK composites, dry or lubricated

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1. Introduction

Polyetheretherketon (PEEK) is a semi-crystalline thermoplastic polymer with high glass transition temperature and high melting point and high mechanical strength. This makes it attractive as rubbing material and a candidate for metal replacement. In hydro power bearings, water lubrication would be preferred to avoid oil leaks from traditional bearings. The literature indicates though that polymers can wear more when lubricated by water compared to dry sliding [1,2]. In the present study we will investigate the wear and friction of PEEK composites dry or lubricated with water and n-heptane.

2. Materials and experimental setup

Four PEEK variants have been tested against stainless steel AISI316L. The polymers are PEEK, PEEK with 10% PTFE (polytetrafluorethylene), PEEK with 30% carbon fibres (CF) and PEEK with 30% glass fibres (GF). Some of their properties are shown in table 1.

Table 1. The tested PEEK variants

<table>
<thead>
<tr>
<th>PEEK with</th>
<th>E modulus (MPa)</th>
<th>Stress at yield (MPa)</th>
<th>Strain at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>4200</td>
<td>116</td>
<td>15</td>
</tr>
<tr>
<td>10% PTFE</td>
<td>3600</td>
<td>96</td>
<td>7</td>
</tr>
<tr>
<td>30% CF</td>
<td>6000</td>
<td>112</td>
<td>10</td>
</tr>
<tr>
<td>30% GF</td>
<td>6300</td>
<td>113</td>
<td>5</td>
</tr>
</tbody>
</table>

The principle of the experimental setup is shown in figure 1.

Figure 1: The pin on cylinder test setup.

The 8 mm diameter polymer pin is sled against a rotating contact wheel (cylinder) made of stainless steel. The sliding velocity is 30 mm/s and the load is 200 N. The pressure velocity PV value is 1 to 1.3 which is much lower than in other studies [3] but similar to the settings in another [4]. According to engineering brochures this value is acceptable [5]. The duration is 2.5 hours which gives a sliding distance of 270 m. The wear extend is evaluated by measuring the wear scar through a microscope as it is shown in figure 2 for a test with neat PEEK.

Figure 2: The wear scar on the pin after a test with neat PEEK.

The width of the wear scar is expressed as a wear volume so that the specific wear is given in $m^3/(N.m)$. The coefficient of friction is measured during the test by dividing the friction force by the normal force. After each test the cylinder is machined to cut off 0.1 mm of metal. This is to ensure that no polymer is left on the surfaces.

3. Results

The specific wear of the polymers is shown in figure 3

Figure 3: Specific wear of the polymers dry and lubricated with water and n-heptane respectively.

The CoFs are shown in figure 4.
4. Discussion

It can be noticed in table 1 that all the polymers have the same strength except for the one with PTFE, which has a lower one. The fibres are added to increase the E-modulus which means that, in the case of carbon, the fibres are of type I. If the strength would have been higher the strain at break would have been 1-2 percent.

Lancaster [6] showed in the 1960s, very much inspired by Ratner [7], that the abrasive wear rate of a polymer is a function of the reciprocal of the product of the strength and strain at break (the RL relation). Figure 3 confirms this theory as the fibre filled PEEKs have higher RL relations than the neat PEEK and show higher specific wear than this latter one. In the case of the PTFE filled PEEK the RL relation does not apply as the sliding occurs in a transfer film on the metal. For this reason Lancaster used a single pass experiment.

Figure 3 shows that the specific wear increases with a factor of 10 or more when water lubrication is introduced. This is not true for carbon filled PEEK where the specific wear is reduced by a factor of two compared to dry sliding. These results are the main reason for not using water lubricated in hydro power bearings. Most studies find an increase in wear with water lubricated carbon fibre filled polymers [1,2,4,8].

If n-heptane is used as lubricant the wear decreases for PEEK and carbon fibre filled PEEK compared to dry sliding. For PTFE and glass fibre filled PEEK it is the opposite. The surface energy of n-heptane is three times lower than the one of water. This seems to be an advantage when it comes to preserving the transferred polymer layer. This is clear for the PTFE filled PEEK. Whether the lubricating mechanism in the other PEEK variants is different is not known.

The viscosity of n-heptane is half that of water. This does not seem to influence the friction much except in the case of glass fibre filled PEEK. This indicates that the experiments are run in the boundary lubrication regime. This is confirmed by calculations of film thickness which is less than one nanometer in all of the experiments.

5. Conclusions

In this study, a pin-on-cylinder apparatus was used to examine the wear friction properties of PEEK and some of its composites in dry and lubricated conditions. In terms of wear and friction properties, the sought-after properties of PEEK and its composites generally include low wear and low friction. Hence, a single material cannot be said to be superior in all lubricating conditions in this regard. When the sliding is not lubricated, PEEK with 10 wt% PTFE is superior in terms of wear and friction. When lubricated with water, PEEK with 30 wt% CF shows the best properties in terms of wear and friction. Moreover, CF-filled PEEK is the best choice in n-heptane lubrication. The wear is lower than in water lubrication at the expense of higher friction.

4. References