Effects of load and rotational speed on the friction and wear properties of PTFE composites

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Abstract. PTFE composites has a lower hardness and shear strength than steel. Therefore, wear mainly occurs in PTFE composites itself when rubs with steel. For studying the friction and wear properties of PTFE composites, a series of experimental tests were conducted under different sliding velocities and load pressures using block-on-ring testing machine. Through weighting PTFE composites specimens before and after the experiment, we can get the wear mass losses of specimens, then the wear rate of PTFE composites is obtained by combining material density, loading pressure and wear length. At the same time, the friction coefficient is recorded in real time by the monitoring system of the testing machine. The analysis results are as follows: at constant sliding velocities, the wear rate of PTFE composites gradually decreases with the increase of loading pressure; at constant loading pressure, the wear rate of PTFE composites decreases gradually with the increase of sliding speed. This leads to further conclusions that motor should not run in low speed range for a long time when PTFE composites is used as motor bearing material.

1. Introduction
Polytetrafluoroethylene (PTFE) material has the advantages of non-viscosity, heat resistance, wear resistance and self-lubricating, etc., which is widely used in bearing bush [1, 2]. Motor bearing, as the main component of supporting shaft rotation, is greatly affected by motor speed and load. Bearing bush is directly in contact with the shaft. It will directly affect the working conditions of bearing bush when the motor speed and load is changing [3]. Therefore, it is necessary to explore the friction and wear characteristics of bearing bush material (PTFE material is selected in this paper) under different rotating speeds and loading conditions [4, 5].

A test block of PTFE material is made and then brought into contact with the test ring on a ring-block friction machine to simulate the contact friction of the rotating shaft and the bearing bush. Because the hardness and shear strength of PTFE is lower than that of metal, wear occurs mainly in PTFE material itself when it is rubbed against steel [6]. Therefore, we can obtain the wear amount of PTFE test block by weighing before and after the experiment, and then obtain the wear rate [7]. At the same time, the friction coefficient is recorded in real time by the monitoring system of the testing machine.

2. The test platform
Ring-block friction and wear test platform is composed of Rtec friction machine and PTFE composite material friction test block. Rtec friction and wear testing machine is shown in “Fig 1”. The friction machine is equipped with three modules: rotary friction module, reciprocating friction module and ring block friction module. The working principle of the ring-block friction module is the closest to
the actual running condition of the rotating shaft and bearing bush, so the ring block friction module of the Rtec friction wear machine is selected.

![Rtec friction and wear testing machine](image)

**Figure 1.** Rtec friction and wear testing machine

In actual operating condition, the rotor is rotating and the bearing is stationary. Therefore, in the laboratory friction test machine, we still let the test ring under the servo motor drive rotation. The speed of the motor is set by the industrial computer before the test, while the analogy of the bearing, the test block, remains stationary and a force perpendicular to the cutting plane of the sliding ring is applied by the jacking rod. At the same time, an oil pool can be installed in which lubricating oil is added, and the test block friction system is soaked in lubricating oil to simulate the working state of motor bearing under lubrication conditions.

![Schematic diagram of ring block friction test](image)

**Figure 2.** Schematic diagram of ring block friction test

Fig.2 is a schematic diagram of ring-block friction test. The rotating test ring shown in the figure can be regarded as the rotor shaft of the motor and the test block can be regarded as the bearing of the motor. In terms of materials, 25Cr2Ni4MoV is used for the test ring and PTFE is used for the test block. Because the study of the effect of filling material on PTFE material is not involved in this paper, the PTFE material has not been modified \([8, 9, 10]\). The wearing particles filled in material will not be taken into account.

### 3. Experimental methods and procedures

#### 3.1 Material parameters of the test block and ring

The tested material block is the PTFE which is provided by manufactor of the bearing. Then material is cut into small test blocks. Rtec friction machine test ring material using 45# stainless steel. The
overall surface hardness is about HRC 50 ~ 60, the surface roughness Ra is 0.1~0.4 microns. Table 1 shows some mechanical performance parameters of the test block and ring.

Table 1. Mechanical Performance Parameters of Test Block and Ring

| Material    | Elastic modulus/Gpa | Coefficient of linear expansion /°C$^{-1}$ | Poisson's ratio | Compressive strength /Mpa |
|-------------|---------------------|-------------------------------------------|----------------|--------------------------|
| Test block  | PTFE                | 1.7~2.4                                   | 9.3x10$^{-5}$   | 0.4                      | 35                       |
| Test ring   | 45° steel           | 200                                        | 1.2x10$^{-5}$   | 0.3                      | /                        |

3.2 Experimental procedure

This paper uses the weighing method to obtain the wear amount of the test block. Before and after experiment, the test block shall be weighed by a precise electronic balance and the weight of the test block shall be recorded. Then according to the weight difference between the test block before and after the test, we can calculate the wear amount and the wear rate of the test block [11]. It should be noticed that before and after testing the test ring and the test block should be wiped clean and placed in ethanol solution and then cleaned with ultrasonic cleaning instrument, so as to remove the dirty stuffs attached to the surface of the test block and the test ring. After drying the solution on the surface of the material with clean paper and oven, we weigh the test block by putting it on the electronic balance tray and record the weight. According to the recorded data, the wear amount and wear rate of PTFE composites under different rotating speed and loading conditions were obtained. The specific experimental steps are as follows:

1. Use a polishing machine to polish the test block and test ring surface, and then use the solution to clean the surface and dry;
2. Before the friction test, the test block is weighed by a precise electronic balance and data are recorded;
3. Friction tests were conducted under load pressure of 22.96N, 28.70N, 34.44N and motor speed of 108r/min, 228r/min and 248r/min, respectively;
4. After the experiment, the sample is washed with ethanol solution and dried;
5. Using the Precision electronic balance to weigh the test block and recording the data;

At the same time, the friction coefficient is recorded in real time by the monitoring system of the testing machine.

4. Experimental results and analysis

According to the above operation steps, friction and wear tests were carried out on the test blocks, and the wear amount of the test blocks under different rotating speeds and load pressures is shown in table 2.

Table 2. Wear Amount of Test Block

| Speed(r/min) | Wear amount (g) |
|--------------|-----------------|
| Pressure(N)  | 108  | 228  | 248  |
| 34.44        | 0.0347          | 0.0288 | 0.0279 |
| 28.70        | 0.0303          | 0.0263 | 0.0250 |
| 22.96        | 0.0261          | 0.0241 | 0.0213 |

On the basis of the above wear amount, combined with the material density, loading pressure and wear stroke, formula (1) is used to calculate the material wear rate, as shown in table 3.

$$w = \frac{\Delta m}{\rho ES}$$  (1)
In the formula, \( w \) is the wear rate, \( \text{mm}^3/(N\cdot m) \); \( \Delta m \) is the amount of wear, g; \( \rho \) is the material density, \( g/\text{mm}^3 \); \( E \) is the test loading pressure, N; \( S \) is the wear stroke, m.

**Table 3. Wear rate of test blocks**

| Pressure (N)  | Wear rate \((\text{mm}^3/Nm) \times 10^{-5}\) |
|--------------|------------------------------------------|
|              | Speed (r/min)   | 108          | 228          | 248          |
| 34.44        | 14.14           | 5.56         | 4.95         |
| 28.70        | 14.82           | 6.09         | 5.32         |
| 22.96        | 15.95           | 6.98         | 5.67         |

According to Table 3, the following conclusions can be drawn: When the relative rotating speed is constant, the material wear rate decreases with the increase of loading pressure; when the loading pressure is constant, the wear rate decreases with the increase of relative speed. During the test, the friction coefficient during the test is recorded in real time by the monitoring system of the test machine, as shown in Fig. 3.
Loading pressure 22.96N, Speed 248rpm

Loading pressure 28.70N, Speed 108rpm

Loading pressure 28.70N, Speed 228rpm
Loading pressure 28.70N, Speed 248rpm

Loading pressure 34.44N, Speed 108rpm

Loading pressure 34.44N, Speed 228rpm
As can be seen from figure 3, at the early stage of the test, the friction coefficient is large, reaching 0.11 at the highest. The friction coefficient gradually decreases and finally tends to be stable. The value of the final stable friction coefficients are listed in Table 4.

Table 4. Average Friction Coefficient

| Speed (r/min) | 108   | 228   | 248   |
|--------------|-------|-------|-------|
| Pressure (N) | 34.44 | 0.055 | 0.055 | 0.025 |
|              | 28.70 | 0.068 | 0.055 | 0.035 |
|              | 22.96 | 0.075 | 0.070 | 0.035 |

As can be seen from table 4, during the interaction between test block (PTFE composite material) and test ring (25Cr2Ni4MoV) friction pair, the variation of friction coefficient with loading pressure and relative speed goes the same way as wear rate test above.

The above phenomenon is closely related to the molecular chain characteristics of PTFE composites. The molecular formula of PTFE is (C2F4)n, in which, c-c and c-f are connected by covalent bond, which is relatively firm, but the molecular chains are connected by Van der Waals force, and the binding force is relatively weak compared with the covalent bond, so PTFE material has poor wear resistance and is easy to form transfer film. In the process of interaction with steel test ring, with the increase of loading pressure, the contact area between the two gradually increases, and the friction heat generated per unit time increases, resulting in more PTFE molecular chains falling off, sliding, adhesion to the shaft surface, and the formation of transfer film [12]. After that, the friction between the steel shaft and PTFE composite material is transformed into the friction between PTFE composite transfer film and PTFE composite material test block, and the friction coefficient decreases. Similarly, when the relative speed of rotation gradually increases, the friction heat generated between friction pairs per unit time increases, which is conducive to the formation of PTFE composite transfer film and the reduction of friction coefficient.

5. Conclusion
As for the experiments that have been done in this paper, some conclusions can be obtained as follows:

(1) When the relative rotating speed is constant, the material wear rate decreases with the increase of loading pressure;

(2) When the loading pressure is constant, the wear rate decreases with the increase of relative speed.
According to the above conclusions, it is suggested that when the bearing bush material is PTFE composite material, the motor should not operate in the low speed range for a long time, because the dynamic pressure lubricating oil effect of such lubricating oil cannot be reflected, which may lead to dry grinding between the bearing and the shaft. But the rotating shaft speed should not be too high, which will produce a lot of friction heat and is harmful to the bearing if the cooling is not timely.

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