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Investigations of Contact Temperature in Disc-on-Disc Tribotesting under Boundary Lubrication

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Abstract **-** For the wet friction pair, the UMT disc-disc test was carried out to study the temperature distribution of the friction interface. The influence of relative rotational speed, applied load, and lubricating oil flow rate on the temperature change of the friction interface was analyzed. It was found that the temperature field of the contact surface can be measured by drilling temperature measuring holes of different depths in the friction lining and arranging temperature sensors. During the sliding friction process, the temperature distribution of the friction interface is not uniform. Different radial depths have different temperature values. Near the radial midpoint of the inner diameter, the temperature value is the highest, and the temperature rise rate is the largest. Next is the radial midpoint position near the outer diameter. The temperature is lowest near the edges of the inner and outer diameters of the friction linings. The temperature value of the friction interface increases with the increase of relative rotational speed and applied pressure. When the friction pair working conditions are constant, the lubricating oil flow has a certain influence on the decrease of the friction interface temperature.

Keywords**:** wet friction pair; disc-disc test; temperature distribution; boundary lubrication

1. Introduction

Wet friction pairs are widely found in high-power transmission components, such as wet clutches, wet brakes and hydro viscous speed control clutches [1]. During the sliding friction process of the friction pair, a large amount of friction heat is generated at the friction interface in a short time, which makes the temperature of the friction surface increase instantaneously. Higher temperatures can easily lead to ablation and severe wear of the friction surfaces, resulting in a sharp change in the coefficient of friction [2]. A larger temperature gradient will cause warping and thermal deformation of the friction element, thereby shortening the service life of the friction element and reducing the working reliability of the friction pair. The wet friction pair is mainly cooled by the continuously circulating lubricating oil [3]. During the working process of the wet friction pair, the lubricating oil is pressed into the gap of the friction pair through the oil passage, and conducts convective heat exchange with the surface of the friction pair, thereby playing the role of heat dissipation. Lubricating oil not only affects the lubrication state of the friction pair, but also greatly affects the effective heat dissipation, local high temperature and force transmission characteristics of the friction pair.

Scholars have done a lot of research on the temperature field distribution of wet friction pairs. [4] studied the groove pattern of the friction plate so that more transmission fluid flows through the contact gap of the clutch plate to increase the cooling effect, and selected three groove designs, according to the gap outlet The flow rate is used to judge the cooling effect of the fluid [5]. [6] studied the influence of grid radial grooves on wet clutch performance on the basis of considering fluid thermal-viscous properties and heat conduction, and proposed a comprehensive expression of governing equations, boundary conditions and numerical solution techniques, to simulate the thermal effects of the meshing process in a wet clutch [7]. [8] studied boundary lubrication friction by pin-on-disk test and solved the Reynolds equation to simulate the flow of cooling oil. Przemyslaw and Todd analyzed the changes in temperature and stress of wet friction plates due to thermally induced contact pressure changes [5], and jointly studied with Samuel [9] hot spots during short-term engagement of multi-plate wet clutches The generation mechanism of the phenomenon; [10] conducted a thermodynamic simulation analysis on the temperature field characteristics of the wet clutch engagement under constant energy; [11] took the wet multi-disc brake as the research object, and simulated its high energy. In terms of thermoselasticity and wear during sliding contact, it is believed that increasing the physical parameters (specific heat capacity, thermal coefficient, etc.) of the friction material can effectively reduce the surface temperature of the friction pair.

In this paper, disc-disc friction tests were carried out on the UMT test machine for the wet friction pair to study the distribution law of the temperature field on the friction surface. The influence of different relative speeds, pressures and lubricating oil flow on the temperature were analyzed. Friction materials are commonly used copper-based powder metallurgy materials. This paper provides a reference for the analysis of the temperature distribution of the wet friction interface.

2. Experimental procedure

2.1. Equipment

The friction and wear test machine UMT-5 used in the experiment is shown in Figure 1, which is mainly composed of a friction and wear test working chamber, a lubricating oil cooling circulation system, and a data acquisition and storage system. The wet disc friction pair module is selected for the test. The friction plate is installed on the upper fixture as the upper sample, and the load is applied from the upper part. The steel plate is installed in the oil pool fixed with the lower fixture, and the lower part is mainly responsible for applying the rotational speed. During the experiment, the friction plate does not rotate, and the steel plate rotates together with the lower clamp and the oil pool. At the same time, the working chamber has the function of heating up, which can raise the friction pair to the required experimental temperature.

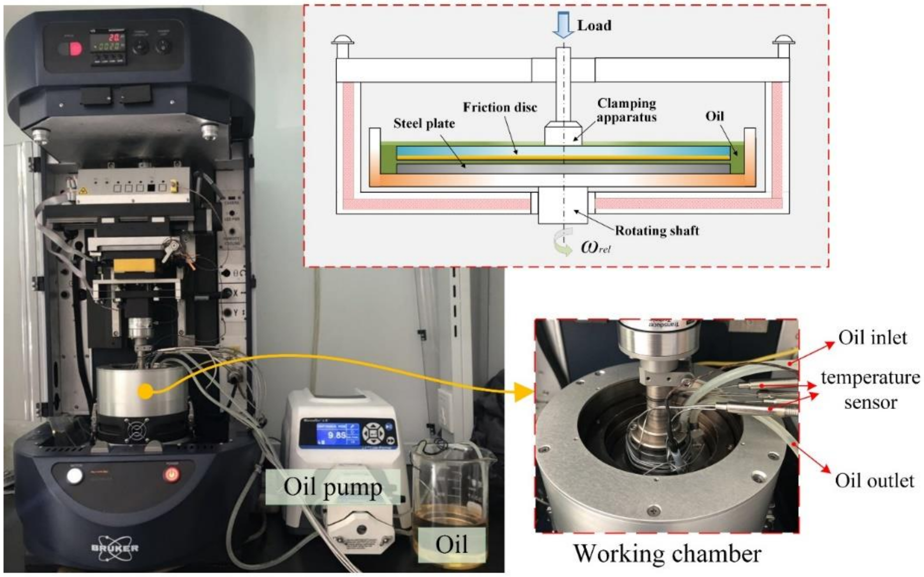


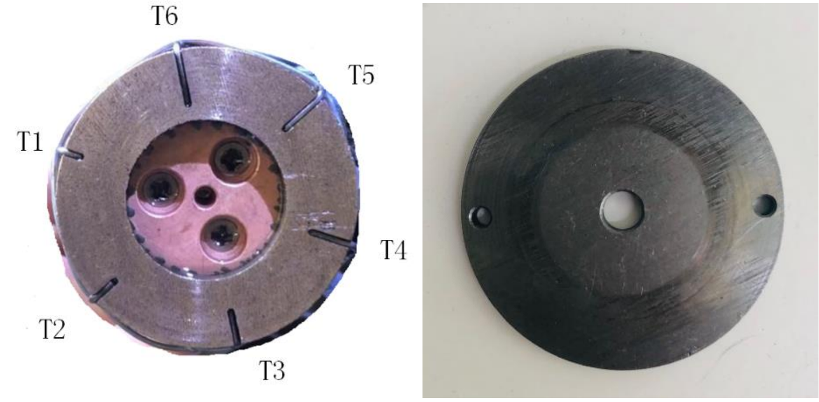
Fig. 1: UMT tester.

The lubricating oil is extracted from the oil container through the action of the oil pump, and flows into the friction interface gap between the friction plate and the steel plate after passing through the oil channel inlet of the upper clamp. Then, it is extracted from the oil pool and flows into the oil container to form a lubricating oil circulating cooling system. In order to test the temperature change of the friction interface, grooves were made on the friction interface of the friction plate and a temperature sensor was arranged. The collected temperature signal is converted into a temperature value through the conditioning module. The temperature acquisition system used in this paper is built on the LabView platform. The data acquisition system also includes a pressure sensor and a torque sensor, to test the changes of pressure and torque during the experiment, and to collect and save the experimental data through the data acquisition module. The pressure sensor model used is DFH-200 with a rated load of 2000N, and the torque sensor model is TRT-100 with a range of 0-15.4N·m. The temperature sensor uses a filament K-type (nickel-chromium-nickel-silicon) armored thermocouple, as shown in Figure 5.3. The thermocouple output signal is 4~20mA current, and the response time is 5ms. The maximum temperature of the thermocouple is 1300℃.

In order to eliminate the influence of the rough surface of the newly machined friction element on the experimental results, the friction surface was fully run-in before the experiment. During the experiment, first adjust each experimental module to the normal standby state, add an appropriate amount of lubricating oil to the oil pool, and then carry out the test.

2.2. Friction components

Figure 2 shows a physical view of the friction element. The inner diameter of the friction material of the friction plate is 22 mm, and the outer diameter is 40.6 mm. The friction plate is made of copper-based powder metallurgy friction material, and the components mainly include Cu, Sn, Zn and SiO2; the steel plate is made of 65Mn steel material. In order to detect the temperature changes at different radial depths of the friction interface in real time during the sliding friction process, grooves with different depths are opened in the friction layer to arrange temperature sensors. The depths of the grooves are 3, 4, 5, 6, 7 and 8 mm and are numbered T1, T2, T3, T4, T5 and T6 respectively.



(1) friction disc (2) steel plate

Fig. 2: Real picture of friction element.

3. Temperature distribution of the interface3 Analysis of Influencing Factors

In order to study the real-time temperature distribution of the friction interface during the friction process, several experiments were carried out in common working conditions, and the average value was taken for analysis. The initial temperature for this experiment was room temperature. The selected working condition pressure is 440N, the relative speed is 1000r/min, and the cooling flow of lubricating oil is 30mL/min. During the experiment, first apply the target load to the test sample, namely the friction plate, after standing for two seconds, set the speed of the test sample, namely the steel plate, and keep the friction pair for 10 minutes for relative sliding friction. After the sliding is over, lift the friction plate 1mm, and the lubricating oil starts to circulate and cool at the same time.

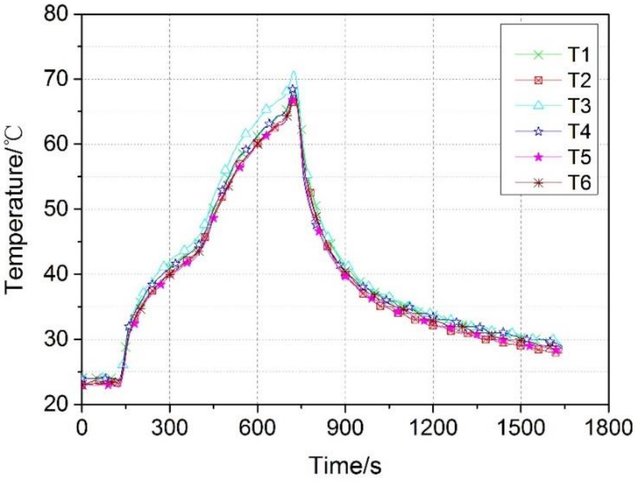


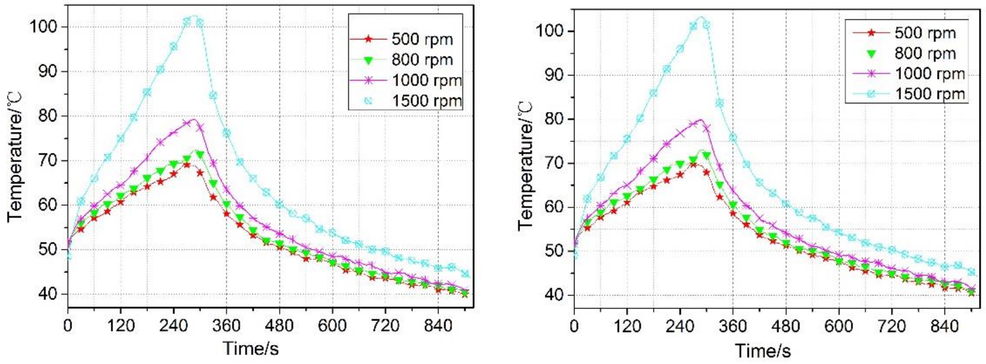
Fig. 3: Temperature change diagram of the friction interface.

Figure 3 shows the variation of the temperature value of each temperature measurement point between the friction pairs with time. It can be seen that in the process of sliding friction, the temperature rise trend of the temperature of each measuring point is roughly the same, but the temperature rise rate of the temperature of each measuring point is slightly different. Since the outer diameter of the friction material is only 40.6 , and the distance between the temperature measuring points is short, the temperature difference between the measuring points is not large. However, it can still be seen that the temperature values are different for different radial depths. The temperature value of the temperature measurement point is the highest, and the temperature rise rate is larger; the second is the higher temperature value; the temperature values of the other four points are roughly the same. This is because point is the radial midpoint near the inner diameter of the friction material, and point is the radial midpoint near the outer diameter of the friction material. The other four measuring points are respectively close to the inner diameter and outer diameter of the friction material, and the lubricating oil conducts convective heat transfer to the edge of the friction material, thereby reducing its temperature value.

4. Analysis of Influencing Factors

4.1. Rotational speed

In order to study the effect of the relative rotational speed difference between the friction pairs on the temperature, the relative sliding and friction rotational speeds were set as 500, 800, 1000 and 1500 r/min, the pressure was 440 N, and the cooling oil flow rate was 30 mL/min.



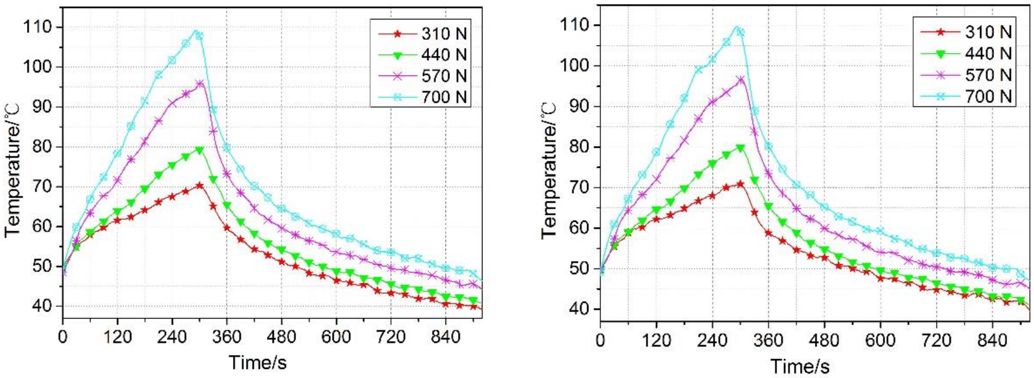
(1) T1 (2) T3

Fig. 4: Temperature change curves under different rotational speed.

Figure 4(a) and Figure 4(b) respectively show the changes of the two temperature values of T1 and T3 under different rotational speed conditions. It can be seen that the temperature value of the friction interface increases with the increase of the rotational speed. When the relative rotational speed is 1500 r/min, the interface temperature can reach a maximum of about 102 °C, and the temperature rise rate is also the largest. When the relative speed is 1000r/min, the maximum temperature reaches 80°C, which is about 22°C lower than when the relative speed is 1500r/min. When the relative speed is 500 and 800 r/min, the maximum temperature can reach about 70 ℃ and 72 ℃ respectively, and the difference is not big.

4.2. Applied load

In order to study the effect of bonding pressure on the temperature distribution, the bonding pressure was set to 310, 440, 570 and 700 N, the relative sliding speed was 1000 r/min, and the cooling oil flow rate was 30 mL/min.



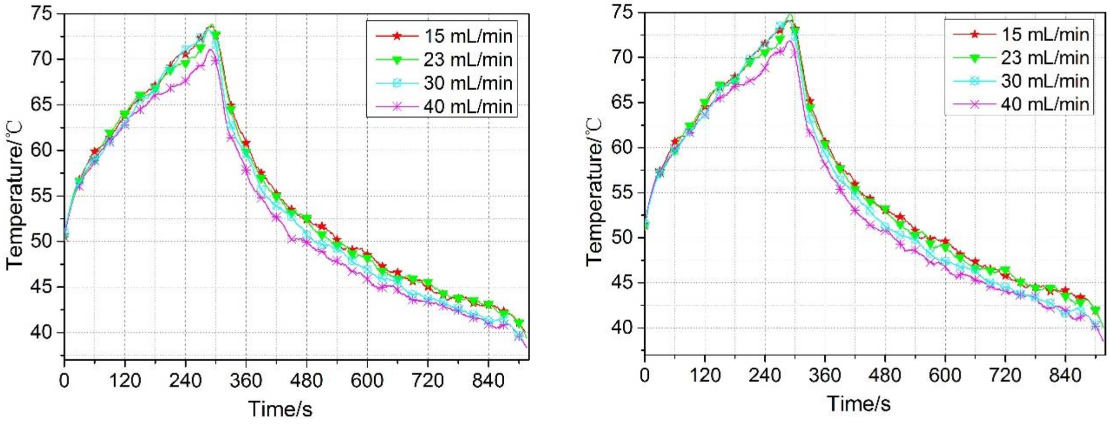
(1) T1 (2) T3

Fig. 5: Temperature change curves under different applied load.

Figure 5 (a) and (b) are the temperature changes of the friction interface and the measuring point under different bonding pressure conditions, respectively. It can be seen that the temperature value of the friction interface increases with the increase of the bonding pressure. When the bonding pressure is 700N, the maximum temperature of the friction interface can reach 110 °C, and the temperature rate is the largest. When the bonding pressure is 570N, the maximum temperature reaches 96°C, which is about 14°C lower than when the bonding pressure is 700N. When the combined pressure is 440 and 310N, the maximum temperature is 80°C and 70°C, respectively.

4.3. Flow rate of lubricant oil

In order to study the influence of the lubricating oil inlet flow on the cooling effect of the friction pair, the lubricating oil inlet flow was set to 15, 23, 30 and 40 mL/min, the relative sliding friction speed was set to 1000 r/min, and the combined pressure was 440 N.



(1) T1 (2) T3

Fig. 6: Temperature change curves under different lubricant oil flow rate.

Figure 6 (a) and (b) are the temperature distributions of friction interface and measuring points under different lubricating oil inlet flow conditions, respectively. It can be seen from Figure 6 that when the friction pair working conditions are constant, the lubricating oil flow rate has a certain influence on the reduction of the friction interface temperature. When the lubricating oil flow rate is 40mL/min, the temperature drop rate of the friction pair interface is the largest. When the change of lubricating oil flow rate is small, the cooling effect of the friction pair changes slightly. For example, when the lubricating oil flow rate is increased from 15 to 23, the temperature change trend of the friction pair is roughly the same.

4. Conclusion

In this paper, disc-disc tests were carried out on a UMT tester to study the temperature distribution law of the friction interface of a wet friction pair. The influence of relative rotational speed, applied load and lubricating oil flow rate on the temperature change of friction interface is analyzed. The main conclusions are as follows:

1) By drilling temperature measuring holes of different depths in the friction material and arranging temperature sensors, the temperature field of the contact surface can be measured.

2) During the sliding friction process, the temperature distribution of the friction interface is not uniform. Different radial depths have different temperature values. Near the radial midpoint of the inner diameter, the temperature value is the highest and the temperature rise rate is the largest. Next is the radial midpoint position near the outer diameter. Temperatures are lowest near the edges of the friction material's inner and outer diameters.

3) The temperature value of the friction interface increases with the increase of relative rotational speed and bonding pressure. When the friction pair working conditions are constant, the lubricating oil flow has a certain influence on the decrease of the friction interface temperature.

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