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Effects of temperature, sliding velocity and non-friction time on severe-mild wear transition of iron

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A B S T R A C T

The effects of non-friction time along with temperature and sliding velocity on the distance to achieve severe-mild wear transition are discussed using a twin-ring sliding type wear test rig. It became clear that as the non-friction time increased, while keeping the same velocity, the severe-mild wear transition distance increased. On the other hand, the transition distance from severe to mild wear decreased, as the sliding velocity decreased or as the specimen temperature increased. From these results, it is concluded that the low sliding speed accelerates the severe-mild wear transition by increasing the real friction time at the real area of contact.

1. Introduction

The severe-mild wear transition is most favorable for the durability of materials in sliding contact because the wear rate is reduced by some orders of magnitude [1]. In dry sliding, it results from the oxidation of surface metals associated with the accumulation of wear particles which have been oxidized during severe wear [2]. So the kinetics of oxidation is the primary concern to better understand the mechanisms of the severe-mild wear transition. In thermochemical reactions, both the reaction temperature and the reaction time are main factors in determining the kinetics of oxidation process.

Under tribological contacts, the temperature is increased with the increase of the product of friction coefficient, load and sliding velocity (μPV), because μPV corresponds to the power input to the tribological system. Thus, the role of the increase in sliding velocity is usually regarded as the temperature rise due to the high energy input. In fact, severe wear transforms into mild wear when the sliding velocity is increased [3].

The increase in sliding velocity, however, decreases the oxidation time. The reduced reaction time might inhibit the protective oxide formation resulting in wear increase. This is one of the reasons why the sliding velocity influences the wear characteristics in an unexpectedly complicated manner (twice the occurrence of dramatic rise and fall in the amount of wear) [4].

The reaction time is prolonged by the long non-friction time – the period when specimens are not in rubbing contact but exposed to the air. In normal test rigs, sliding velocity effect inevitably includes non-friction time effect. Therefore, it is necessary to establish the tribo-system which could separate the two variables: sliding velocity and non-friction time. We made some experiments and elucidated that severe wear of metals is increased as the non-friction time is increased [5]. However, we have not yet focused on the effect of non-friction time on severe-mild wear transition in detail.

Another important factor for the severe-mild wear transition is the test configuration. Fig. 1 shows a pin-on-disk type wear test rig (on the left) and the time frame of both specimens (on the right). It is apparent from the time frame that within one cycle, the pin is always in sliding contact with the disk. On the contrary, every point of the disk wear track does not make contact at all times but make contact during only a small period of each rotation cycle. Therefore the difference in the geometry of the specimens, such as pin and disk, leads to the difference in the friction time and non-friction time.

By contrast, in twin-ring sliding tribometer shown in Fig. 2, the two ring specimens are identical in shape. They are rotated at the same speed in the opposite direction, which leads to the sliding contact. In this case, both the rings have the same friction time and non-friction time. Additionally, with the twin-ring sliding apparatus, the temperature rise due to frictional heat is the same for both the rings. It is in contrast with the case of pin-on-disk, where the temperature rise of the pin is larger than that of the disk. To sum up, with the twin-ring sliding tribometer, we can achieve the same temperature and the same non-friction time for both specimens.

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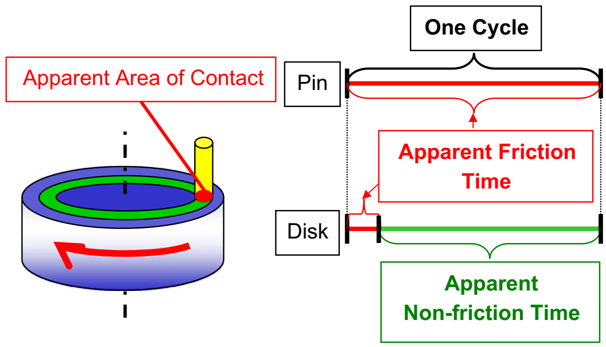

Fig. 1. Pin-on-disk apparatus and its two kinds of time (apparent friction time and apparent non-friction time) in one cycle of rotation.

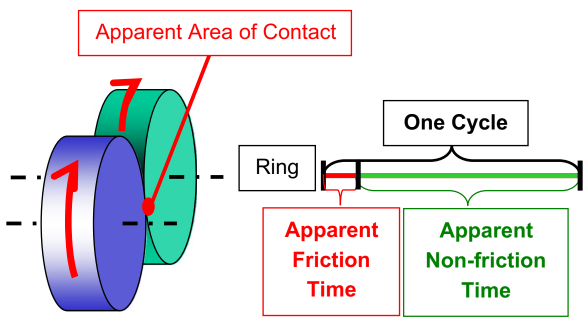

Fig. 2. Twin-ring apparatus and its two kinds of time (apparent friction time and apparent non-friction time) in one cycle of rotation.

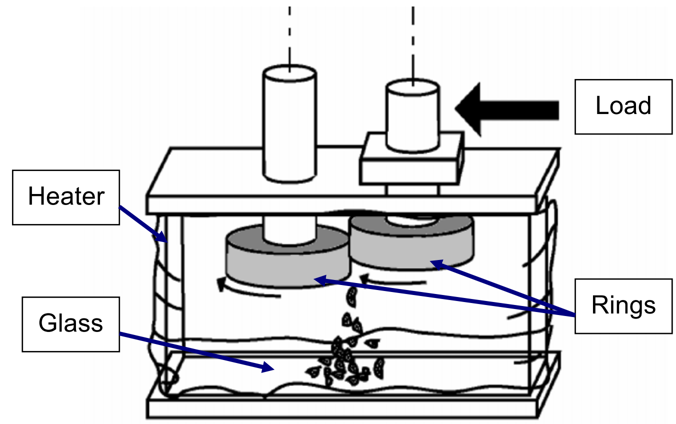

Fig. 3. Schematic of twin-ring apparatus with a glass tray collector within a heat chamber.

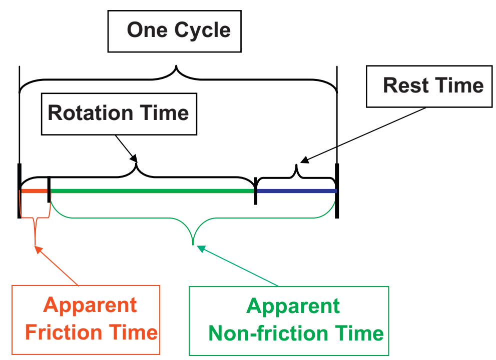

Fig. 4. One cycle in terms of rotation (rotation time or rest time) and of friction (apparent friction time or apparent non-friction time).

In the present study, using the twin-ring tribometer, we will develop new interpretations on the roles of sliding velocity, non-friction time and real friction time in severe-mild wear transition.

2. Experimental procedure

Fig. 3 shows a schematic of the twin-ring apparatus used in this study. The basic assembly is the same as that previously reported except for the orientation of the rings [6]. Two rings of 30 mm in diameter and of 2 mm in thickness were set side by side in the same horizontal plane and loaded by a dead weight. The ring specimens had been cut from the plate of 2 mm in thickness and polished on the periphery using #1000 SiC abrasive paper. The set position of the rings was offset by 1mm parallel to the rotating shafts.

The material tested here was iron (Purity: 99.9%). The ring assembly was enclosed in a heat chamber, where both the specimens and surrounding air were heated up. After every fixed sliding distance, the bottom glass tray was pulled out and the wear particles were carefully collected. Then the weight of wear particles was measured using an electric balance and plotted against the sliding distance in a line graph. Each plot refers to the total weight of the wear particles at each corresponding sliding distance.

The two rings were moving against each other in the opposite direction at the same speed of e.g. 200 mm/s. In this case, the relative sliding velocity was 400 mm/s. The applied load was fixed at 6 N. The temperature of sliding rings could not be measured during the test. So prior to the test, using thermocouples, the temperature of the specimen and of the atmosphere inside the heat chamber were measured and correlated. During the test, the atmospheric temperature was continuously measured to monitor the specimen's temperature.

The relationship among the ring rotation time, the rest time, the friction time and the non-friction time in one cycle is schematically drawn in Fig. 4. The rest time is the period when the motor does not rotate. The sum of the rest time and the rotation time makes one cycle time. Each point on the friction track is in sliding contact only in a short period of time, which is the "apparent friction time". In the remaining period, each point is not in contact. We call it the "apparent non-friction time" or simply the "non-friction time". When the sliding velocity is changed, the non-friction time changes inversely. Therefore the sliding velocity effect intrinsically includes non-friction time effect. It means that we cannot discuss the sliding velocity effect only, if we do not keep the non-friction time constant. In the present study, to separate velocity effect and non-friction time effect, the rotation was stopped for a given period (rest time) after every cycle.

As shown in Fig. 4, one cycle is comprised of the sum of rotation time and rest time. Thus, when we increased the sliding velocity, the rotation time, which is inversely proportional to the sliding velocity, was decreased. In this case, the rest time is extended to keep one cycle time unchanged. On the other hand, to focus on the non-friction time effect, the sliding velocity was fixed.

Additionally, oxide surfaces were prepared by heating two couples of specimens up to 450 °C and 650 °C for 10 h in the furnace. The wear characteristics of these samples were obtained and compared with those of non-heat-treated ones.

3. Results

3.1. *Effect of temperature on wear*

Fig. 5 illustrates an example of the wear-sliding distance curve which was plotted by measuring the weight of the wear particles