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Research on tribo-magnetization phenomenon of ferromagnetic materials under dry reciprocating sliding

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ABSTRACT

In order to reveal tribo-magnetization phenomenon of ferromagnetic materials, a new apparatus which involved reciprocating friction tests of pin-on-block type under the geomagnetic field has been built to perform the tests. Based on the changes of the surface magnetic field of wear scar and the macroscopic and SEM analyses, it is concluded that tribo-magnetization of ferromagnetic materials is a two-stage process and the demarcation point of these two stages is the transition point of the friction forms. Furthermore, the shape and the position of wear scar can be estimated through measuring the surface magnetic field of wear scar.

1. Introduction

Friction and wear is a common phenomenon in our living. The friction process is not only accompanied by heat and electricity [1,2], but also the magnetic field. Tribo-magnetization phenomenon has been realized and used by people with a history of several thousand years, but studies about the mechanism of tribo-magnetization are very limited. A few years ago, a series of tests about pin-on-block rotating friction were made by Chang et al. [3,4] in order to reveal the phenomenon of tribo-magnetization. They proposed that the severe wear was the main reason for the surface tribo-magnetization and the average surface magnetization inversely decreased with increasing sliding speeds and was linearly proportional to high normal loads. However, other mechanisms of tribo-magnetization proposed by Mishina [5–8] indicated that wear elements were magnetized in one direction during friction process and the generation and transfer of wear elements was the main reason for tribo-magnetization. In recent years, however, the phenomenon of tribo-magnetization has not been thoroughly investigated. As a result, the mechanisms of tribo-magnetization mentioned above have not been recognized. At present, the main researches are focused on the effects of the external magnetic field on friction [9–11].

Actually, tribo-magnetization is also a kind of magnetic memory effect on the friction process. Metal magnetic memory testing technology (MMM), a new nondestructive testing technology can detect the stress concentration position by using magnetic memory effect and it has achieved rapid development in recent years. MMM firstly proposed in 1997 by Doubov [12] was used to implement early diagnostic testing to prevent catastrophic accidents. With the wide use of magnetic memory testing technology, numerous experiments are carried out to study magnetic memory effect of the surface of ferromagnetic materials under different stress conditions, such as tension, pressure, bending and torsion [13–15]. The main purpose is to reveal the mechanism of magnetic memory effect. At present, people have begun to study magnetic memory effect in the friction process. Chinese researchers have tested the surface magnetic field of 45 steel on the friction by using MMM [16], and they pointed out MMM method can accurately reflect the size and location of the friction region. Unfortunately, the magnetic memory effect phenomenon in the whole friction process is not elaborated in detail.

This work is devoted to research on tribo-magnetization phenomenon of typical ferromagnetic materials-pure iron under dry sliding condition with geomagnetic field. Both tangential and normal magnetic fields of pure iron samples are measured by a giant magnetoresistance-type magnetic sensor which has a higher sensitivity. In this paper, the changes of magnetic field on wear scar under the different numbers of sliding cycles are presented. To be concluded, tribo-magnetization of pure iron is a two-stage process. Severe wear is the principal source of magnetization of the friction surface and the characteristics of the surface magnetic field on the block specimen can reflect the state of wear scar to some extent.

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2. Experimental methodology

2.1. Experiment apparatus

All tests were carried on a homemade reciprocating friction and wear testing machine. Fig. 1 is schematic diagram of the experiment apparatus that involved reciprocating friction tests of pin-on-block type under the geomagnetic field. The experimental setup was divided into wear region and testing region. A block specimen installed on the moving stage can perform reciprocating motion during wear region. The friction force was measured by a pull pressure sensor and both the sliding distance and the testing distance can be controlled by limit switch. Testing region was arranged in wear region on the left side. The block moved into testing region after friction test. The surface magnetic field could be measured by a giant magnetoresistance-type magnetic memory sensor (sensitivity:18 mV/V/Gauss) which was fixed right above wear scar when the block specimen was moving, and the distance between the sensor and the target surface was kept about 1 mm. Meanwhile a laser displacement sensor was used to detect the depth of wear scar.

2.2. Test specimens

The specimen of block and pin used for experiments were made of pure iron. Test block had the dimension of 200 mm in length, 60 mm in width and 15 mm in thickness and the size of the pin specimen was a cylindrical 6 mm in diameter, as shown in Fig. 2. In order to recognize the effect of the specimens' original magnetic field on tribo-magnetization, alternating current demagnetization method was applied to the specimen. The surface of all specimens was polished by 1000 SiC paper to a surface roughness of less than 0.5 mm and cleaned with ethanol and acetone before testing.

2.3. Experimental procedures

The experiments were performed under dry sliding condition at a room temperature of $20 \pm 4\,^{\circ}$C with an ambient relative humidity of about $20 \pm 5\%$. The wear experiments were carried out with a mean velocity of 53.125 mm/s and a normal load of 25 N and continued on with a stroke of 85 mm until the reciprocating movement was repeated 325 times. The surface magnetic field of wear scar was measured every 25 times and the friction coefficient was detected in real time. The specimens were divided into two groups, one of which do not demagnetize and another demagnetize in order to study the effects of the initial magnetic field for tribo-magnetization.

3. Experimental results

3.1. Demagnetization of specimen

The pure iron blocks should be demagnetized before experiments. There are two kinds of demagnetization methods include of alternating current and thermal demagnetization. The effect of complete demagnetization can be achieved via thermal demagnetization method, but the changes of the organization structure of the block will be caused on the demagnetization process [17]. Therefore, the alternating field demagnetization was applied to the experiments for the above reason. Fig. 3a and b show the results of the tangential and normal magnetic field for the block before and after AC demagnetization respectively. The direction of measuring was from A to B and the measuring distance was about 200 mm. The figures illustrated the distribution of the surface magnetic field. Before demagnetization, the tangential magnetic field ranged from 3 A/m to 36 A/m. It was stable at about 16 A/m after demagnetization. The AC demagnetization removed more than 50% of residual magnetization. The normal magnetic field reduced a little but became smooth in the testing direction after demagnetization.

3.2. The effects of wear debris on the surface magnetic field

During the friction test, a large number of wear debris were generated on the specimen surface. Wear debris had effects on wear process. That is the reason why we stop the reciprocating motion for measuring the surface magnetic field of wear scar per 25 times without clearing wear debris. But it is important to find out the influence of wear debris for measuring. Fig. 4a shows the tangential magnetic field of the pure iron surface before and after clearing wear debris with sliding cycles of 325 under a mean velocity of 53.125 mm/s and a normal load of 25 N. It is obvious that the influence of wear debris is very mild for the tangential

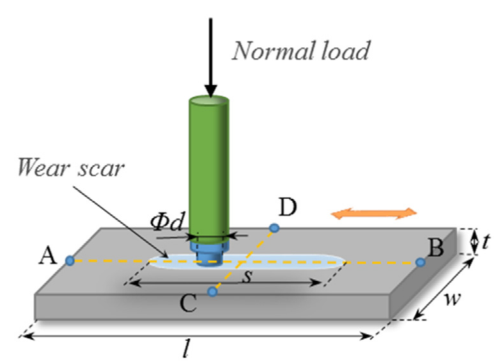

Fig. 2. The size of specimen.

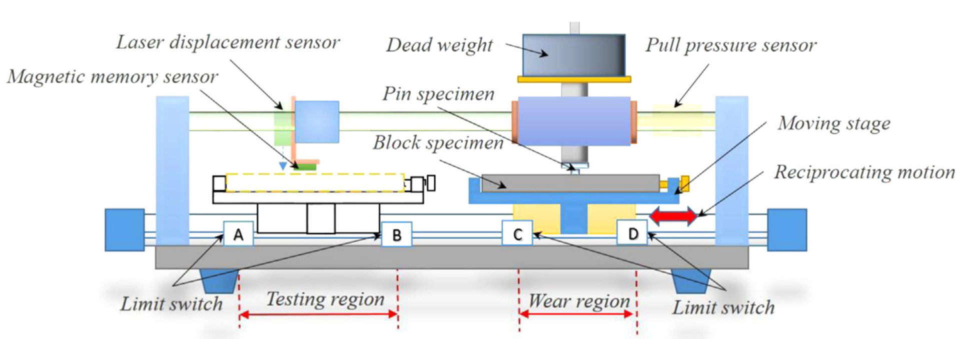

Fig. 1. Schematic diagram of the experiment apparatus.