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Research on the effect of remanence and the earth's magnetic field on tribo-magnetization phenomenon of ferromagnetic materials

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ABSTRACT

In order to research the effect of magnetic field including in remanence and the earth's magnetic field on tribo-magnetization phenomenon, a new apparatus, which could shield the earth's magnetic field, was built to perform reciprocating friction test. Based on changes of surface magnetic field and SEM analyses, the whole friction process of different ferromagnetic materials was characterized. And the effects of wear degree, normal loads, materials and different remanence of blocks on changes in the surface magnetic field were examined. Experimental results show degree of wear, normal load and ambient magnetic field have a positive effect on tribo-magnetization. The increment of surface magnetic field in normal direction, which resulted from the constant earth's magnetic field, was about 0.05GS for pure iron.

1. Introduction

Tribo-magnetization phenomenon has been known for a long time, and been gradually applied to nondestructive testing field such as metal magnetic memory testing technology (MMM), which plays an important role for the early detection of oil pipelines and drilling tools [1–4]. However, the mechanism and origin about the tribo-magnetization phenomenon was discussed by different authors with different viewpoints [5–8]. In our previous article, we found that plastic deformation stimulated magnetic domains beneath the rubbing surface. Then the activating magnetic domains were rearranged under some magnetic field such as the earth's magnetic field and remanence of specimen [8]. However, it was rarely discussed which really decided distribution of magnetic domains [9–12]. In general, basing on the inverse magnetostrictive theory, most people think the earth's magnetic field is a fundamental cause for the magnetization phenomenon. That is, external magnetic field is a crucial factor for magnetomechanical effect [1,12,13,14]. On the contrary, other studies, which are conducted in the absence of an external magnetic field, show that tribo-magnetization is a kind of spontaneous magnetization phenomenon [5,6,15,16]. But these neglect the effect of remanence of ferromagnetic materials on tribo-magnetization. Therefore, the purpose of this study is to investigate the activating effect of the earth's magnetic field and the remanence for tribo-magnetization.

Actually, the influencing factors of tribo-magnetization involve a lot of aspects including in material, load, wear condition, friction speed, friction temperature, external magnetic field and remanence, etc. In this report, surface magnetic field changes of sliding area were traced under different sliding cycles. And through the changes of surface magnetic field on wear scar under different sliding cycles and the analysis of SEM for wear scar and wear debris, it was concluded that tribo-magnetization of 316L/Fe,316L/1045 and 316L/42CrMo was a three-stage process from intense variation to steady stage. The effect of the earth's magnetic field and different remanence of blocks on tribo-magnetization was evaluated on the basis of the steady stage above. We found both the earth's magnetic field and the remanence of block had an impact on generation of surface magnetic field. Relatively, the influence of the earth's magnetic field was constant for pure iron under the same conditions. While the remanence of block made a positive difference for generation of surface magnetic field in the process of rubbing, and the change of magnetic field closed to linearly proportional to the remanence of blocks.

2. Experiment apparatus and experimental methods

2.1. Experiment apparatus

The friction experiment was performed by using a pin-on-block sliding system which could add a magnetic shield. A schematic of the experimental setup is shown in Fig. 1. The apparatus was composed of a magnetic shield, a supereyes which was used to observe wear condition inside magnetic shield, a structure platform, a pin-on-block reciprocating mechanism and a detection mechanism. The parts of the whole experimental apparatus were made of non-magnetic materials to

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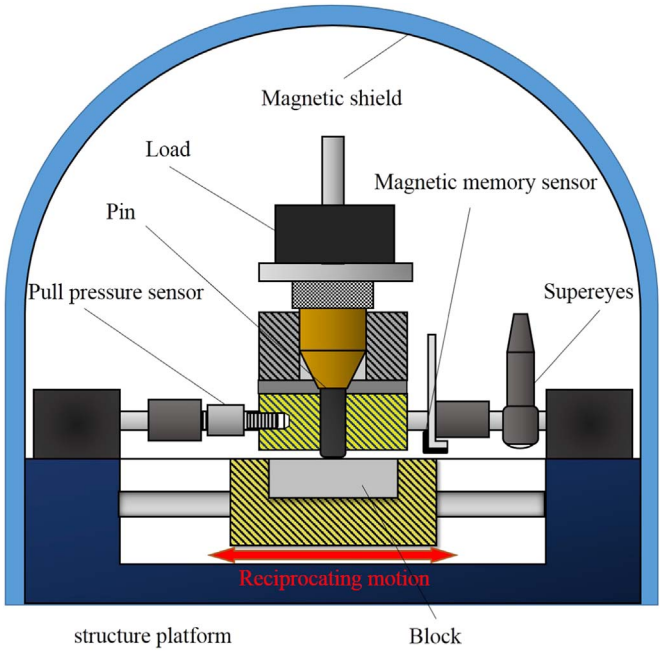

Fig. 1. Schematic of the experimental setup.

eliminate the disturbance for tribo-magnetization process. The pin was installed in beam which was on the structure platform. The normal load was applied to the pin sample by a dead weight. The block was driven by the reciprocating mechanism to reciprocating slide against the pin. Surface magnetic field of the block was measured by a giant magnetoresistance-type magnetic memory sensor while the block was driven by the detection mechanism. The friction force was measured by a pull pressure sensor. Magnetic shield device only had an evident effect on shielding normal magnetic field and could shield about 0.43Gs in normal direction in Fig. 2. So only changes in normal magnetic field was considered in the course of studying the effect of the earth's magnetic field on tribo-magenetization.

2.2. Experiment methods

Sliding was conducted at room temperature (20 ± 5 ℃) in air with about 20 ± 5% relative ambient humidity, without a lubricant. The surrounding magnetic field of tests apparatus was measured by a two-axis probe magnetic memory sensor (sensitivity:12 mV/V/Oe). Normal component of the surrounding magnetic field was 0.62Gs, and tangential component of that was 0.83Gs. The pin was a radius of 8 mm cylindrical specimens, and it was made of non-magnetic stainless steel 316 L to avoid magnetic interference for the tribo-magnetic process of the block. Common soft magnetic material pure iron, hard magnetic material 1045 and a kind of drill tools materials 42CrMo were chosen as the block. The block was a rectangular parallelepiped (50 mm×30 mm×10 mm). The surface roughness of the block before the experiments was below 3.2 μm(Ra=3.2 μm). The block was demagnetized before experiments by alternating current. Then detailed process of the demagnetization was introduced in previous reports [17]. Finally, surface magnetic field of the same material block must be the same in tangential and normal. Then all samples were cleaned with ethanol and acetone before testing. After each test, the worn mass of the specimens was measured by an analytical balance with 1 mg precision. The wear rate (mg/Nm) was given as the ratio of the worn mass (mg) to the normal load (N) and sliding length (m). The sliding friction continued on the same track with 1 Hz reciprocating sliding frequency. The length of sliding track was 25 mm. The experiment performed for each material should be repeated three times.

3. Results and discussion

3.1. The effect of degree of wear on tribo-magenetization

Fig. 3 shows changes in surface magnetic field of different materials block under different sliding cycles. Reciprocating sliding friction was performed at the presence of the constant earth's magnetic field. The frequency of sliding was 1 Hz with a normal load of 2.5 N. According to the regular of changes of magnetic field, surface magnetic field both the normal and the tangential was measured by planning sliding cycles. Within 0 times to 500 times, surface magnetic field was measured every 25 times, from 500 times to 1000 times, surface magnetic field was measured every 50 times, then every 100 times until 2000 times. And calculated the changes in magnetic field both the normal $H(x)$ and the tangential direction $H(y)$. Here, the change in magnetic field was the different between the surface magnetic field before rubbing (H_O) and that after rubbing n times(H_n): $\Delta H_n=H_n - H_O$. Repeatability of experimental results was about 33–66% under ensuring the same experimental parameters and conditions.

The magnetization process of different materials was traced by calculating the absolute average values of ΔH under different sliding cycles as shown in Fig. 3. Meanwhile, the wear process of different materials was examined by scanning electron microscope (SEM). It is shown in Fig. 3 that the changes in tangential magnetic field and the changes in normal magnetic field follow the same trend in spite of difference in the value of amplification. Based on the trend of the

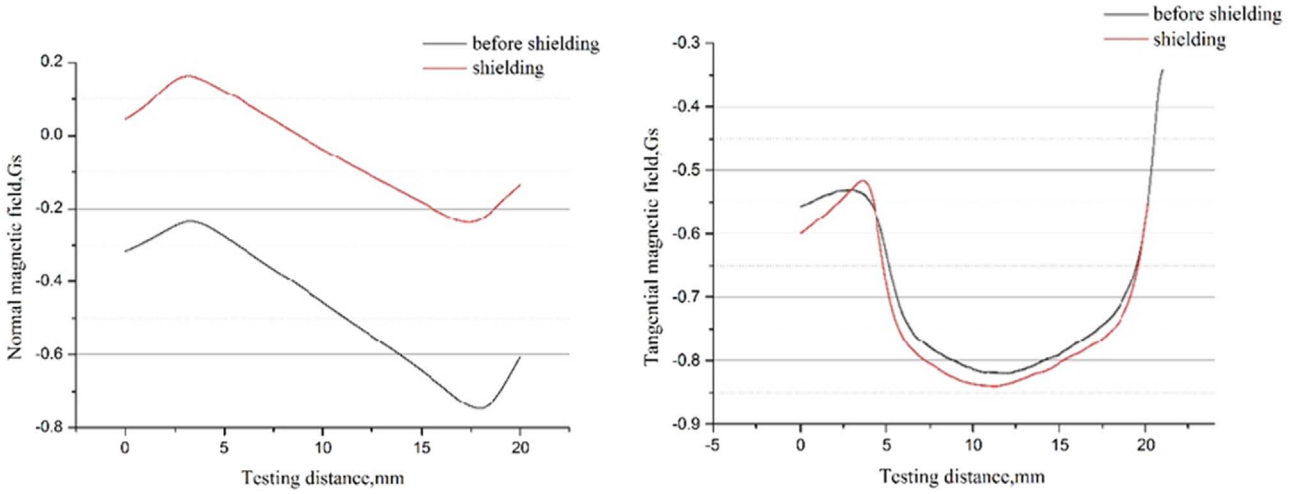

Fig. 2. Effectiveness of magnetic shielding.