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In situ observation of the magnetic domain in the process of ferroalloy friction

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ABSTRACT

An in situ observation system was developed to monitor the magnetic domain structure in the process of rubbing. By means of this system, the magnetic domain motion beneath the sliding area was observed while a carbon steel 1045/316 L stainless steel pin specimen rubbed on a pure iron block specimen under certain loads. Experiments showed that plastic deformation stimulated changes in magnetic domain beneath the rubbing surface as a result of sliding friction, which means plastic deformation was a crucial activation factor for tribo-magnetization. Then the variations of the magnetic domain structure beneath the rubbing surface with the increasing of rubbing cycles were characterized. From experimental results the relation between plastic deformation in tribological process and the original process in mechanism of the tribo-magnetization phenomenon was discussed.

1. Introduction

Tribo-magnetization phenomenon has been known and used for a long time since the compass was invented. However, there was little research explaining the phenomenon. In recent years, relevant experiment studies including pin-on-block reciprocating friction in the absence of an external magnetic field and pin-on-block rotating friction in air were conducted by Mishina [1–6], Chang [7–10] and so on [11–12]. However, the precise mechanism for the tribo-magnetization phenomenon was not determined and it was discussed by different authors with different discordances. In order to reveal the tribo-magnetization phenomenon, this paper focused on its micro-mechanism – the change of microscopic magnetic characteristic of ferromagnetic material in the rubbing process. In general, there are innumerable micro magnetic regions in a ferromagnetic material which are called magnetic domains. The domains in an unmagnetized sample are randomly oriented [13]. The magnetic field is strongly non-uniform as shown in Fig. 1(a). If all the domains were aligned perfectly, there would be a magnetic field directed from the north pole at one end to the south pole at the other as shown in Fig. 1(b) [13–15]. At present, many articles referred to changes of magnetic domains under different contact stress such as compressive stress, tensile stress and bending angle, which elucidated the relation between magnetic domain and stress [16–22]. But seldom studies were put into its micro-mechanism explaining relation between friction and magnetic domain as a result of complexity of frictional process [23].

In this paper, we found that plastic deformation was a crucial factor to stimulate magnetic domain motion. The final direction of domain wall nearby the sliding area tended to perpendicular to sliding surface in the process of friction. The microscopic variation corresponded to the most previous research on deformation relation magnetic field [24,25]. Based on relation between magnetic domain and magnetization as well as relation between magnetization and friction, this paper pays attention to the changes of magnetic domain beneath sliding area in the process of rubbing. In situ observation method is used to observe the changes of magnetic domain in the case of different degrees of wear. Plastic deformation beneath the sliding area was also presented by optical and scanning electron microscope. The aim of this study is to fundamentally study the tribo-magnetization phenomenon by observing changes of magnetic domain in the process of rubbing.

2. Experiment apparatus and experimental methods

2.1. Experiment apparatus

The schematic of the in situ observation system is shown in Fig. 2, which is made up of a microscope, a full-frame CCD camera and a pin-on-flat frictional device which is driven in the field of view of the microscope. Pin-on-flat frictional device is composed of an electric translation machine, a fixed platform, a pin and a

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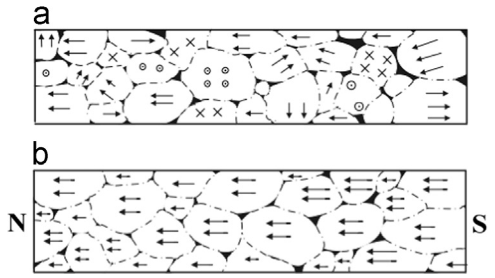

Fig. 1. (a) An unmagnetized sample, and (b) a perfectly magnetic sample.

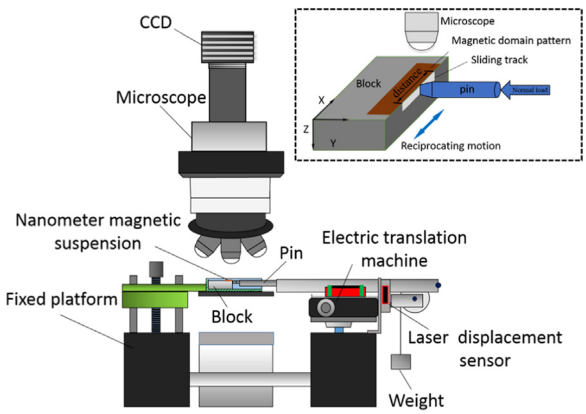

Fig. 2. Schematic of in situ observation system.

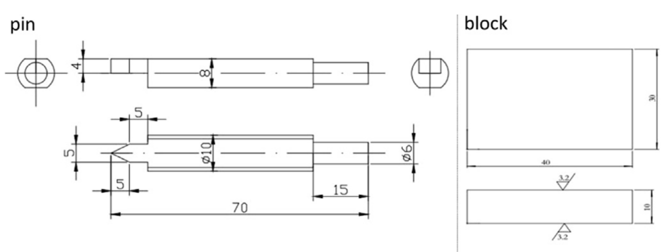

Fig. 3. Schematic representation of the pin and block sample (mm).

block. The pin was set to the pin holder, which is installed in electric translation machine. Electric translation machine is fixed in fixed platform. The block, which was also fixed in fixed platform, is just across from the pin. The block and pin could be adjusted along the *Z* direction to get better micrograph. The pin is driven by electric translation machine to reciprocate along the opposite *X*-axis of the opposite XZ-surface close to the top XY-face of the block. The normal load is applied by a dead weight which was tied by the rope through the pulley loading pin holder. The distance of reciprocating rub is controlled by the laser displacement sensor. A nanometer magnetic suspension is applied evenly to XY-surface close to the opposite XZ-face of the block. The movement of the nanometer magnetic suspension is observed by microscope and recorded in a full-frame CCD.

2.2. Experimental methods

The experiment was conducted at room temperature(20 ± 4 °C) in air with about $20 \pm 5\%$ relative ambient humidity, and the environmental magnetic field was about 0.5 Gs. Magnetic carbon steel 1045 and non-magnetic stainless steel 316 L were chosen as the pin specimens. The block was a rectangular parallelepiped (40 mm × 30 mm × 10 mm), the pin specimen was shown in Fig. 3. The block was demagnetized by heating to below 0.3 A/m, then the surfaces of block were mechanically finished by using emery paper in proper order of #800-SiC, #1000-SiC, #2000-SiC to achieve the surface roughness of less than 3 μm, polished with alumina powders of a grid size of 1.5 μm and degreased by ultrasonic washing in acetone. The nanometer magnetic suspension was uniformly applied to the XY-surface overlap completely opposite *X*-axis. The distance of sliding area was 5 mm at the sliding velocity of 0.21 mm/s. The motion of magnetic domain was recorded once every reciprocating sliding 5 times by CCD camera.

3. Results and discussion

3.1. Changes in magnetic domains before loading and loading

The whole frictional process would be divided into two sections; one was the process of loading. And the other was the process of

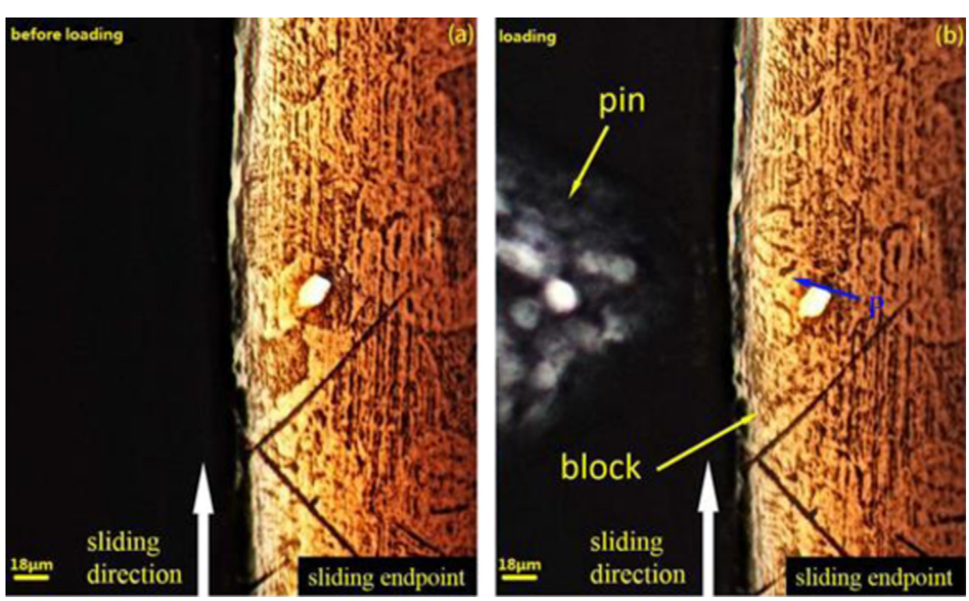

Fig. 4. Changes in magnetic domains before loading and loading, (a) image shows original magnetic domains, and (b) image shows magnetic domains during loading; 1045/Fe, sliding velocity was 0.21 mm/s and load was 0.4 N. The symbol "P" indicates changes of magnetic domain in contact area.