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Effect of microstructure of low-carbon steels on frictional and wear behaviour

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ABSTRACT

The friction and wear properties of low-carbon steel and conventional carbon steel were investigated through sliding tests, hardness measurements, and microstructure observations. An understanding of these properties is essential to facilitate the application of low-carbon weld steel doped with minor and trace elements to tribological products.The results of the sliding tests showed that the initial wear of the minor and trace element-doped low-carbon steel was higher than that of conventional carbon steel. The results of the hardness measurements showed that conventional steel hardened faster than the minor and trace element-doped steel. The microstructure observations showed that the grain size of conventional steel decreased after the sliding test was performed. Hence, it was suggested that the change in the grain size of conventional steel promoted hardening.

1. Introduction

Welding can help increase productivity, and since there are various types of welding processes, it can be used in many mechanical systems such as structure frames, pressure vessels, hydraulic actuators and so on. However, the main problem with welding is the occurrence of weld defects. There are several types of weld defects. A weld crack can be caused by the generation of a martensitic structure during cooling [1]. A martensitic structure can be formed by carbon in steel, and hence, to prevent this phenomenon from occurring, the carbon content in the steel should be decreased [2]. However, when the carbon content is decreased, the hardness of the steel decreases [3]. Harder materials have lower wear rates and friction coefficients. Thus, sliding materials require high hardness values [4].

Therefore, considerable effort has been into improving the mechanical properties of low-carbon steel. Minor and trace element doping is an effective method for improving the mechanical properties of low-carbon steel. Minor and trace elements are chemical elements that are not found in abundance on Earth, such as Nb, V, and Mo. Doping with minor and trace elements improves the hardness of steel by refining the crystal grain size [5–8]. The relationship between the grain size and hardness is expressed by the Hall–Petch relation:

$$\sigma_y = \sigma_0 + \frac{k}{\sqrt{d}} \tag{1}$$

where σ_y is the yield stress, σ_0 is a materials constant for the starting stress for dislocation movement in a monocrystal, d is the grain size, and k is a constant specific to each material [9]. Fig. 1 shows images of the microstructures of low-carbon steels with carbon contents in the range 0.08–0.12 wt%. Fig. 1(a) shows an image of regular carbon steel, which has large crystal grains. Fig. 1(b) shows an image of minor and trace element-doped steel, which has a smaller crystal grain size. The doping of steel with minor and trace elements is effective for reducing costs and reinforcing the steel. Therefore, its use has been increasing in many fields. However, the effect of the change in the microstructure on the tribological properties is not quite clear, for example, when the grain size decreases and the pearlite structure disappears.

In this study, sliding tests were performed to investigate the tribological properties of minor and trace element-doped carbon steel. In addition, to investigate the difference between the sliding test results for minor and trace element-doped steel and those of regular carbon steel, hardness measurements and microstructure observations were carried out.

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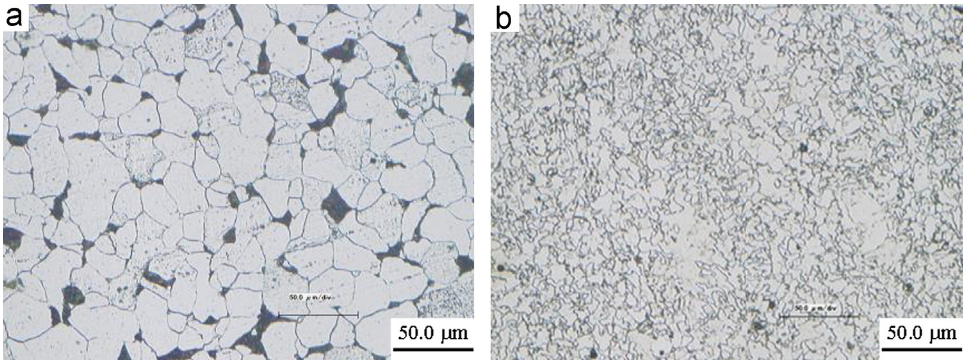

Fig. 1. Microstructure images of low-carbon steels with carbon contents of 0.08–0.12 wt%: (a) regular low carbon steel, (b) trace and minor element-doped steel.

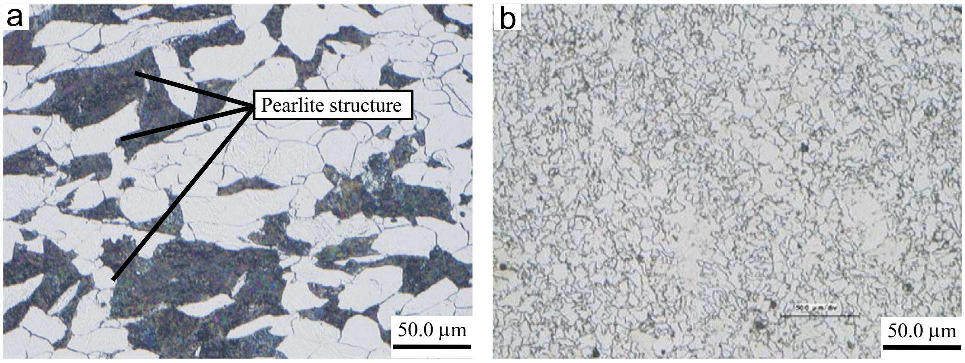

Fig. 2. Microstructure images of test specimens (a) 0.2 wt%C steel, (b) 0.08 wt%C+MTE steel.

2. Experimental details

2.1. Test specimens

Two types of carbon steels were used as the test specimens. One was ordinary carbon steel with a carbon content of 0.2 wt% (0.2 wt%C steel), and the other was a minor and trace element-doped steel with a carbon content of 0.08 wt% (0.08 wt%C+MTE steel). To ensure that hardness does not have an influence on the results, the hardness values of the steels were adjusted such that both specimens had the same hardness value (~237 Hv). Fig. 2 shows images of the microstructures of the specimens observed, using an optical microscope. A pearlite structure was observed on the 0.2 wt%C steel specimen, but no such structure was observed on the 0.08 wt%C+MTE steel specimen. The steel specimens had disk shapes, with a diameter of 24 mm, thickness of 7 mm, and roughness of Ra 0.03 μm. A cylinder, which is made of AISI 52100 with a diameter of 6 mm and length of 8 mm, was used as the counter specimen against the steel disk, the hardness value of the cylinder was approximately 60 HRC.

2.2. Sliding test

The friction coefficient was measured using a cylinder-on-disk sliding tester (SRV, Optimol, GE). The friction coefficient measurements were carried out under normal loads of 20 and 50 N. The test parameters were as follows: a stroke of 1 mm, frequency of 50 Hz, disk temperature of 50 °C, test time of 60 min, and lubricant volume of 30 μl. The lubricant used was a Group III mineral oil. Before and after the friction coefficient measurement, the cylinder and disk specimens were cleaned in a mixed solution of petroleum, benzene, and acetone in an ultrasonic bath for 10 min. The sliding tests were performed three times under each test condition.

The cross-sectional profile of the wear track was measured using a surface profiler (SURFCOM 1500SD3-12, ACCRETECH, JPN). The wear property was evaluated based on the wear depth and wear area, which were obtained from the profile, as shown in Fig. 3.

The wear width of the cylinder was measured using a laser microscope.

2.3. Hardness measurement

The hardness of the wear track surface on the disk specimen was measured in macroscale using a Vickers hardness meter (AUTOVICK4, AKASHI, JPN). The flat surface of the wear track was chosen as the measurement location, and the applied load was100 g, in accordance with ISO 6507-1. The measurement was repeated ten times for each specimen.

2.4. Microstructure observation

The sectional structures under the wear track were observed using a microscope after the specimens were etched with 0.5 wt% nitric acid alcohol. A schematic illustrating the microstructure observation is shown in Fig. 4. The observation area of the 0.2 wt% C steel was 225 × 300 μm, and that of the 0.08 wt%C+MTE steel was 71.5 × 95 μm. The grain sizes were manually measured using the microstructure images, in accordance with ISO 643.

3. Results and discussion

3.1. Sliding test results

Fig. 5 shows the frictional coefficient behaviour under the normal load of 20 N. The behaviour of the 0.08 wt%C+MTE steel was similar to that of the 0.2 wt%C steel. The friction coefficient of each specimen stabilised after approximately 1500 s of sliding. This suggested that the difference in the microstructures did not affect the friction behaviour. Fig. 6 shows the relationship between