Tribology International 43 (2010) 925–928

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Friction-induced ultra-fine and nanocrystalline structures on metal surfaces in dry sliding

Hirotaka Kato [a,*], Masato Sasase [b], Nobuaki Suiya [c]

[a] Department of Mechanical Engineering, Fukui National College of Technology, Sabae, Fukui, 916-8507, Japan
[b] The Wakasa-wan Energy Research Center, Tsuruga, Fukui, 914-0192, Japan
[c] NESI, Inc., Tsuruga, Fukui, 919-1279, Japan

ARTICLE INFO

Available online 21 December 2009

Keywords:
Sliding surface
Metal
Nanocrystalline
Transfer layer

ABSTRACT

Sliding friction tests of pin-on-disc type were carried out for carbon steel, pure iron and pure copper, and the microstructure and hardness near the sliding surfaces were investigated in detail. It was found that patchy transfer layers with ultra-fine (<200 nm) structures were produced on the disc surfaces. Nanocrystalline grains of 30–50 nm were identified for carbon steel, and submicron sized grains of 100–150 nm were observed in pure copper. The thicknesses of the ultra-fine structures were in the range of 10–50 μm, depending on the specimen material, sliding speed and applied load. The hardness near the sliding surface of pure iron was increased compared with the matrix. It was suggested that the hardening was due to the very fine structure formed by severe plastic deformation, but not due to phase transformation caused by thermal effects.

1. Introduction

Nanocrystalline materials have attracted considerable scientific interests because these materials are expected to possess superior mechanical properties, i.e. high hardness and toughness. It has been reported that nanocrystalline structure was formed at the steel surface by high speed drilling, in which mechanical and thermal effects were introduced [1]. Moreover, friction-induced ultra-fine (<200 nm) structures have been reported to be produced near the sliding metal surfaces [2–5]. The ultra-fine structure formation is considered to be due to the very large plastic shear strain caused by sliding friction.

In the present work, sliding friction tests of pin-on-disc type were carried out, and the microstructure and hardness near the sliding surfaces were investigated. The influence of specimen material, sliding speed and applied load on ultra-fine structure formation and hardness were also studied.

2. Experimental

A common pin-on-disc method as shown in Fig. 1 was employed in sliding friction tests. A pin, 5 mm in diameter (the diameter of the contact area was 2 mm) and 16 mm in length, was loaded on a rotating disc, which had a diameter of 60 mm and a thickness of 5 mm. The materials used for the pin and disc specimens were 0.45 mass% carbon steel, pure iron and pure copper. A pin and a disc of the same materials were rubbed against each other in a normal laboratory air. The sliding speed was varied in the range of 0.1–5 m/s, and the applied load was varied in the range from 4.9 to 49.1 N. The microstructures of the specimens after rubbing were examined by optical microscopy, SEM and TEM, and Vickers hardness was measured near the surfaces of the specimens at a test load of 0.098 N.

3. Results and discussion

Fig. 2 shows the rubbed surfaces of pin and disc specimens of carbon steel observed by a CCD microscope. Adhesive wear scars

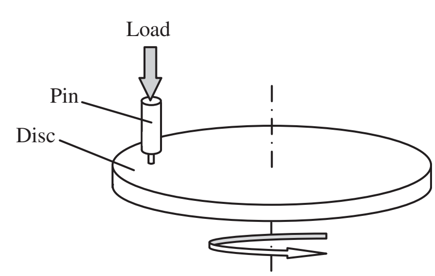

Fig. 1. Schematic diagram of pin-on-disc friction method employed in this study.

* Corresponding author. Tel.: +81 778 62 1111; fax: +81 778 62 2597.
E-mail address: hkato@fukui-nct.ac.jp (H. Kato).

0301-679X/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2009.12.040

were observed on the pin and disc surfaces, and at high sliding speeds of 1.0 and 5.0 m/s, patchy transfer metals were formed on the disc surfaces.

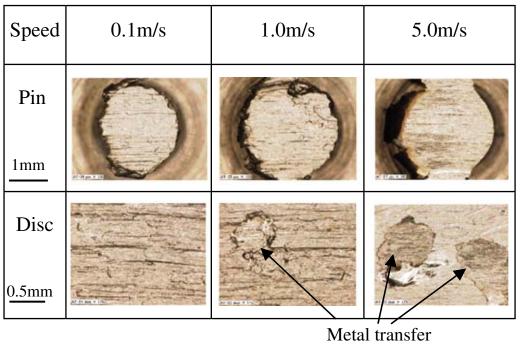

Fig. 2. Microscope observations of rubbed surfaces of pin and disc specimens (specimen material: carbon steel, load: 19.6 N).

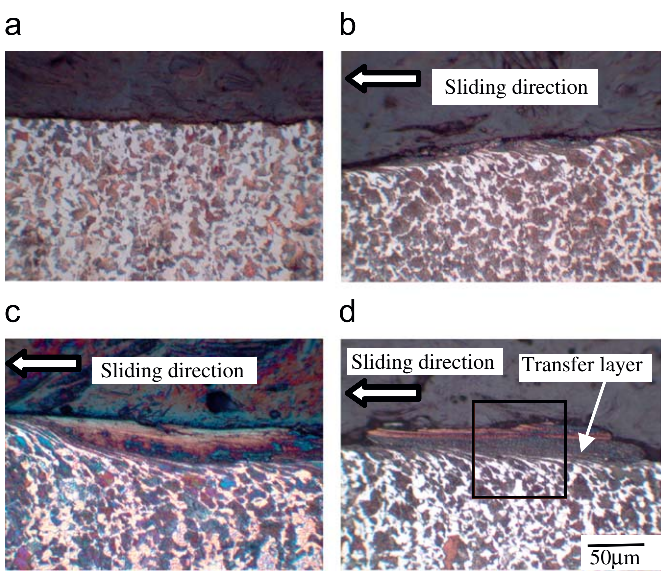

Fig. 3. Optical microstructures of longitudinal cross-sections of carbon steel disc specimens. (Specimen material: carbon steel, load: 19.6 N.): (a) No friction, (b) 0.1 m/s, (c) 1.0 m/s and (d) 5.0 m/s.

Fig. 3 is a set of optical micrographs of longitudinal cross-sections of the carbon steel disc specimens. The applied load was constant at 19.6 N. It is seen that featureless layers, which had completely different microstructure from that of matrix, were formed at the sliding surfaces, and that beneath these layers, ferrite and pearlite grains were inclined to the sliding direction. At a sliding speed of 5 m/s (Fig. 3(d)), the featureless layer, which was about 50 μm in thickness and 350 μm in length, was considered to be a metal transfer layer, although it was not clear that at 0.1 m/s (Fig. 3(b)) and 1.0 m/s (Fig. 3(c)) whether the featureless layers were produced by metal transfer or not.

Fig. 4(a) is a SEM image of the marked square area of Fig. 3(d). It was impossible to observe any grain boundary in the transfer layer, which was also featureless under SEM examination. The boundary between the transfer layer and plastic flow region was not clear. TEM observation (Fig. 4(b)) revealed that the transfer layer consisted of ultra-fine grains with an average grain size of

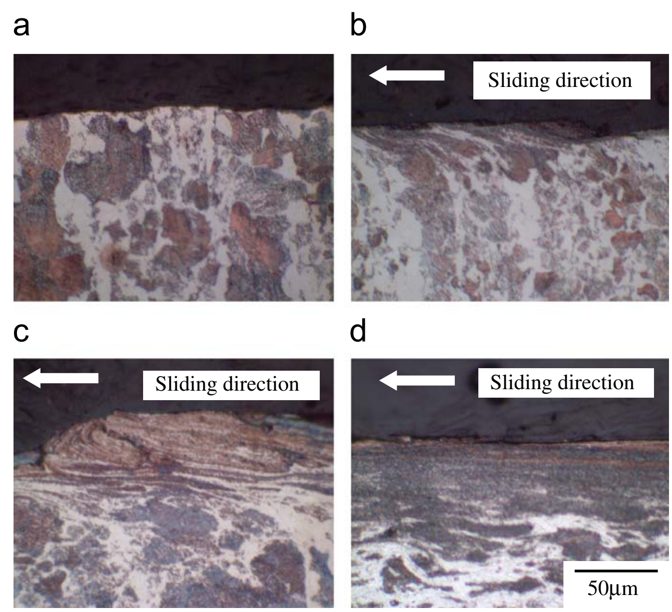

Fig. 5. Optical microstructures of longitudinal cross-sections of carbon steel pin specimens. (Specimen material: carbon steel, load: 19.6 N.): (a) No friction, (b) 0.1 m/s, (c) 1.0 m/s and (d) 5.0 m/s.

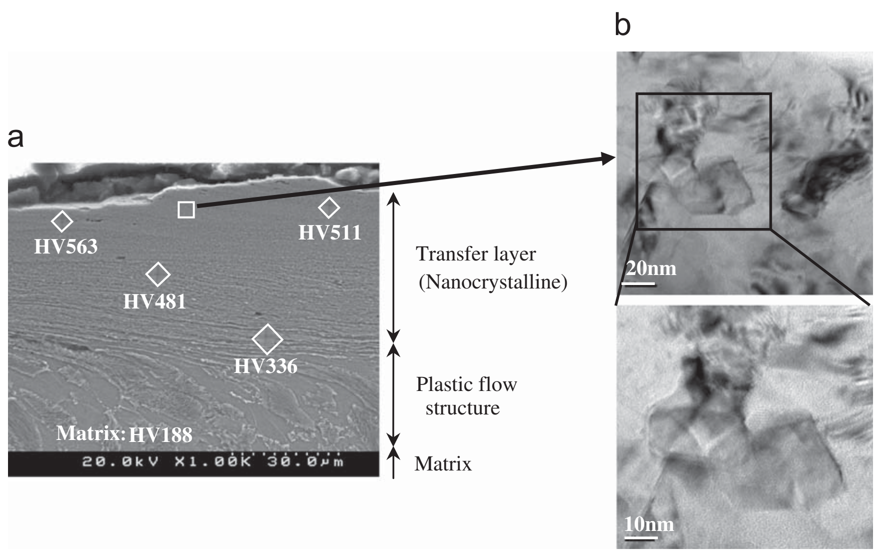

Fig. 4. SEM and TEM Microstructures of carbon steel disc specimen. (Specimen material: carbon steel, Sliding speed: 5 m/s, load: 19.6 N.) (a) SEM image of the marked square area of Fig. 3(d) and Vickers hardness results. (b) TEM observation at the marked square area of the transfer layer in Fig. 4(a).