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Short communication

Friction and wear of nanostructured metals created by large strain extrusion machining

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Abstract

Tribological behavior of nanocrystalline oxygen-free high conductivity (OFHC) copper and commercially pure titanium produced by large strain extrusion machining (LSEM) is compared with the coarse grained counterparts. Friction and wear of these materials have been determined using a pin-on-disk tribometer, sliding against AISI 52100 steel pins. Although friction coefficients are very similar, microstructure refinement reduces wear factors for these conditions. Wear mechanisms are discussed from optical microscopy and SEM observation of wear tracks, wear debris morphology and transfer tribolayers.

Keywords: Wear; Friction; Nanocrystalline structure; Copper; Titanium

1. Introduction

Ultra-fine grained (UFG) and nanostructured materials are often harder, stronger and more wear-resistant than their coarse grained counterparts [1].

Developments in the fabrication of UFG materials have focused on the use of large strain or severe plastic deformation (SPD). There has been a recent development at Purdue University of a low-cost manufacturing process, using principles of shear deformation by machining, for the production of nanostructured metals and alloys. It is the focus of this paper to investigate into the wear characteristics of the materials processed by this new method. The chips produced during common machining of a variety of pure metals, steels, and other alloys, are shown to be nanostructured with grain (crystal) sizes between 100 and 800 nm. The hardness of the chips is found to be significantly greater than that of the bulk material [1–4]. A potentially exciting opportunity resides in the creation of material systems which could show enhanced wear performance.

In the present study, the machining method is used in the preparation of nanostructured oxygen-free high conductivity (OFHC) copper and pure titanium chips of high hardness [1–4]. We report here the influence of the microstructure refinement on the wear resistance of these materials.

The authors have previously reported [5] a wear reduction of a polymer–matrix composite reinforced with nanostructured Al 6061 particles with respect to the conventional microstructured reinforcement.

The wear performance of the materials, sliding against AISI 52100 steel pins, are studied using a pin-on-disk tribometer. The predominant wear mechanisms in each case are discussed.

2. Experimental

Oxygen-free high conductivity (OFHC) copper and commercially pure titanium were deformed by LSEM [6] to obtain a nanostructured microstructure. For the copper samples, three different shear strains (γ) were imposed by appropriately changing the opening between the constraining edge and the cutting

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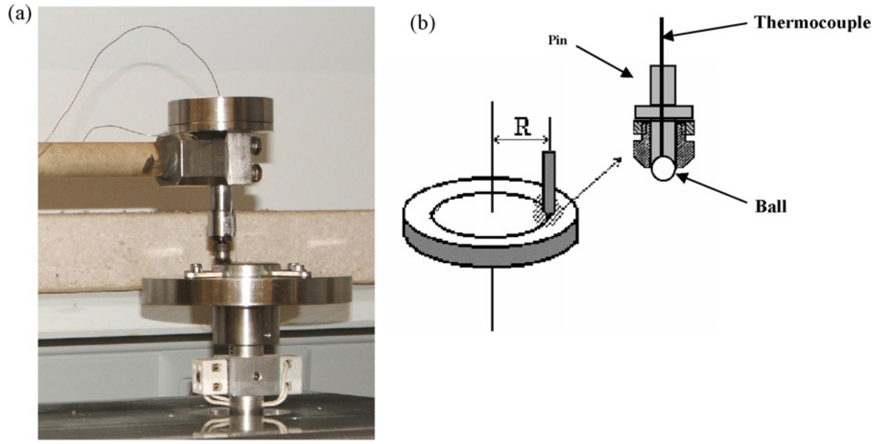

Fig. 1. (a) Pin-on-disk test machine and (b) scheme showing the thermocouple embedded in the steel pin.

Table 1
Materials designation, grain size and hardness values

Designation	Hardness HV (kg/mm^2)	Microstructure	Grain size
Cu-micro	97	Equiaxed grains	~150 μm [6]
Cu-nano $\gamma = 7.4$	158	Equiaxed grains	~250 nm [6]
Cu-nano $\gamma = 4.3$	157	Mix of elongated and equiaxed grains	~300 nm [6]
Cu-nano $\gamma = 2.2$	148	Elongated grains	~300 nm[a] [6]
Ti-micro	144	Equiaxed grains	~60 μm [9]
Ti-nano	230	Elongated grains	~200 nm[a] [9]

[a] In the narrow direction.

edge of the especially designed extrusion and machining tool [6]. The chosen values of γ were 2.2, 4.3 and 7.4. By varying the level of strain imposed in the material a progressive refinement of microstructure is observed [6]. For titanium, a single shear strain of 3 was imposed using the same method [6]. Machining speeds were kept low to avoid any temperature effects on the processed materials.

Specimens were tested in a pin-on-disk (Fig. 1) test machine (Microtest, Spain), where an AISI 52100 steel ball (0.8 mm spherical radius, hardness 848 HV) rigidly held is used as the pin specimen, according to ASTM G99-05 standard. Tribological tests were carried out in air under a load of 3 N for copper and 1 N for titanium. The following experimental parameters were kept constant for all tests: sliding velocity = 0.01 m/s; radius = 2 mm; sliding distance = 30 m. Friction coefficients were continuously recorded with sliding distance. The "contact" temperature was recorded during the tests by means of a thermocouple embedded (Fig. 1) in the steel pin at a distance of 1.6 mm from the pin–disk interphase. Volume loss was determined using two different methods: from wear track width values according to ASTM G99-05 [7] and from the change of cross-sectional area measured with a profilometer ALPA-SM [8]. Mean friction coefficients and wear factors were obtained after three tests under the same conditions. Optical micrographs of wear track were obtained using a Leica DMRX optical microscope. SEM images and EDS analysis were obtained using a Hitachi S3500N scanning microscope.

3. Results and discussion

As can be seen from Table 1, grain-refinement due to large strain extrusion machining produces nanostructured materials with hardness values at least 1.5 times as high as that of the conventional micro-structured material.

3.1. Copper

3.1.1. Friction

Friction behavior is the same for all samples. Fig. 2 shows the typical friction variation with sliding distance in this case

Table 2
Friction coefficients (standard deviations in parenthesis)

Material	Cu-micro	Cu-nano			Ti-micro	Ti-nano
		$\gamma = 7.4$	$\gamma = 4.3$	$\gamma = 2.2$		
Friction coefficient	0.7 (0.26)	0.7 (0.15)	0.79 (0.03)	0.69 (0.04)	0.42 (0.09)	0.47 (0.07)