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Relations of counterface materials with stability of tribo-oxide layer and wear behavior of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy

L. Wang, X.X. Li, Y. Zhou, Q.Y. Zhang, K.M. Chen, S.Q. Wang*

School of Materials Science and Engineering, Jiangsu University, 212013 Zhenjiang, China

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ABSTRACT

Dry sliding wear tests of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy (TC11 alloy) sliding against AISI 52100 and AISI M2 steels were performed under the load of 50–250 N at 25–600 °C. For two kinds of counterface materials, the titanium alloy presented totally different wear behaviours as the function of temperature. The appreciable variations of the titanium alloy sliding against different counterface materials were attributed the fact that a hard counterface caused unstable existence of tribo-layers by its microcutting action, thus resulting in the increase of wear rate. It is suggested that the hard counterface must be avoided as the counterface for the titanium alloy/steel sliding system.

1. Introduction

The wear behavior of a sliding system depends on the properties of the specimen and counterface materials, their interaction with the environment and the sliding conditions [1]. The wear behavior and mechanism of the sliding materials would vary as a function of the above factors. The researches on the wear behavior and mechanism of steels, cast irons, magnesium alloys, aluminium alloys have been widely carried out so far [2–6]. Titanium alloys are well known to be of low density, high specific strength and good corrosion resistance, etc., and are extensively used in many industrial fields [7]. However, the researches concerning the wear behavior and mechanism of titanium alloys were rather limited [8–15]. More importantly, most researchers pointed out that titanium alloys possessed low sliding wear resistance [8–13]. This undoubtedly limits their applications, especially in areas involving wear and friction. In order to improve the wear resistance of titanium alloys, many surface treatment methods were investigated and applied to enlarge their application areas, such as thermal oxidation, plasma nitride, laser surface alloying, microarc oxidation, and so on [16–18]. However, in our previous investigation, Ti–6Al–4V and Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloys were found to possess high elevated-temperature wear resistance [19–22]. If the high wear resistance popularly appears in titanium alloys, an important breakthrough in engineering applications will be expected. However, their wear regularities and affecting factors are not well known for the research community. Especially, the effect of counterface materials on the wear behavior of titanium alloys was sparsely reported.

In the present investigation, the sliding wear of Ti–6.5Al–3.5Mo–1.5Zr–0.3Si alloy (code-named TC11) against AISI 52100 and AISI M2 steels was studied. The phase, morphology and composition of worn surfaces and subsurfaces were examined by using X-ray diffractometer, scanning electron microscope, energy dispersion spectrometer. The effects of the different counterface materials on wear behavior and mechanism of TC11 alloy were focused on to be explored.

2. Experimental details

2.1. Material preparation

A commercial TC11 alloy was taken from a hot extruded rod of 70 mm in diameter as pins which were in the form of cylinder with a diameter of 6 mm and a height of 12 mm. Commercial AISI 52100 and AISI M2 steels were chosen as the discs (counterface) with the dimension of 70 mm diameter and 10 mm thickness. The chemical compositions of TC11 alloy, AISI 52100 and AISI M2 steels are listed in Tables 1 and 2, respectively.

TC11 alloy was solid dissolved at 955 °C for 2 h and water quenched, subsequently aged at 540 °C for 4 h and cooled in air (36 HRC). AISI 52100 steel was austenitized at 850 °C and oil quenched, then tempered at 400 °C for 2 h to achieve an average hardness of 51 HRC. AISI M2 steel was austenitized at 1180 °C and oil quenched, then tempered three times at 540 °C for 2 h to achieve an average hardness of 63 HRC. The microstructure of

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* Corresponding author. Tel.:+86 511 88797618.
E-mail address: shuqi_wang@ujs.edu.cn (S.Q. Wang).

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TC11 alloy presented equiaxed α particles in an aged β matrix, as shown in Fig. 1.

2.2. Wear test

Dry sliding wear tests were carried out on an MG-2000 type pin-on-disc high temperature wear tester. The dry wear test rig used in this study was described in detail elsewhere [19]. All wear tests were performed in air, and the test parameters are shown in Table 3. Before each test, the end surfaces of the pins and the discs were prepared by grinding against a 600-grit silicon carbide paper and by a grinding machine to attain R_a values of about 0.38 and 0.30 μm, respectively. Before and after each wear test, the pin and disc were cleaned with acetone and then dried. The mass loss of the pin specimens was measured by using an electronic balance with an accuracy of 0.01 mg. Then the mass loss was converted into volume loss using a density of 4.5 g/cm^3. The wear rate was calculated from the volume loss divided by sliding distance. Each data point represents the average value of three test results.

The morphology, composition and phase of the worn surface and subsurface were examined by a JSM-7001F type scanning electron microscope (SEM), an Inca Energy 350 type energy dispersion spectrometer (EDS), and a D/Max-2500/pc type X-ray diffractometer (XRD) with Cu $K\alpha$ radiation, respectively. The microhardness distribution from the worn surface to the matrix was measured by an HVS-1000 type digital microhardness tester with a load of 0.49 N and a hold time of 15 s. The hardness of the materials after heat treatment was determined by an HR-150A type Rockwell apparatus.

3. Results and analysis

3.1. Wear rate

The wear rates of TC11 alloy sliding against AISI 52100 and AISI M2 steels as a function of the temperature and load are shown in Figs. 2 and 3, respectively. At 25–300 °C, irrespective of counterface materials, the wear rate increased with an increase of load, and the wear rates at 200 and 300 °C were higher than those at 25 °C. The wear rates at 300 °C were slightly lower than those at 200 °C for AISI 52100 steel as counterface. As the temperature reached 400 °C, the wear rate of TC11 alloy started to decrease for the two counterface materials. It is worthy of noting that the wear rate at 400 °C varied slightly under 50–200 N, but increased abruptly as the load surpassed 200 N. For AISI 52100 steel as counterface, at 500–600 °C, the wear rates were further reduced to reach extremely low values. In these cases, the effect of the load on the wear rate seemed to be negligible.

When TC11 alloy slid against AISI M2 steel, the wear rate at 300 °C was markedly higher than that at 200 °C under 150 N or above. At 400 and 500 °C under 50–200 N, the wear rate marginally varied with an increase of load and the former wear rate was slightly higher than the latter one. Interestingly, the wear rates both rapidly increased under 250 N at 400 and 500 °C. These cases were similar to that of sliding against AISI 52100 steel under 250 N at 400 °C. At 600 °C, the wear rate was substantially reduced to reach the lowest value with a slight fluctuation.

No matter what the counterface material was, the wear rates of TC11 alloy in its respective system reached the lowest values at 600 °C. Furthermore, as for AISI 52100 steel as counterface, the wear rate approached zero at 500–600 °C. These meant that TC11 alloy possessed excellent high-temperature wear resistance, which was similar to our previous research results of Ti–6Al–4 alloy [19,20]. Hence, excellent high-temperature wear resistance of titanium alloys

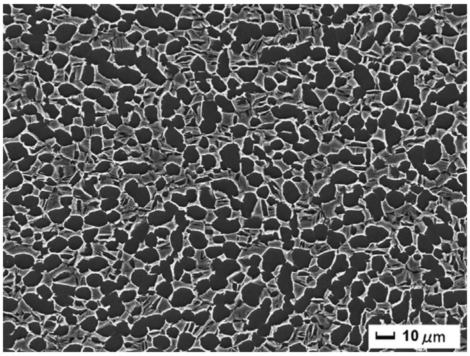

Fig. 1. Microstructure of the TC11 alloy.

Table 3
Wear test parameters.

Normal load (N)	Temperature (°C)	Sliding velocity (m/s)	Sliding distance (m)
50, 100, 150, 200, 250	25, 200, 300, 400, 500, 600	1	1200

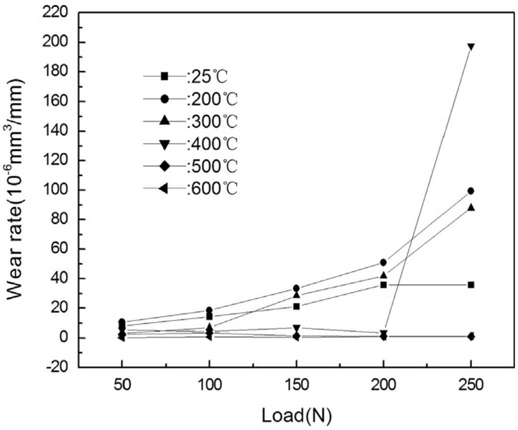

Fig. 2. Wear rate of the TC11 alloy sliding against AISI 52100 steel as a function of the temperature and load.

Table 1
Chemical compositions of pin material (wt%).

Al	Mo	Zr	Si	C	O	N	H	Ti
5.84	3.54	1.57	0.32	0.024	0.02	0.012	0.01	Bal.

Table 2
Chemical compositions of counterface materials (wt%).

Disk/Element	C	Mn	Si	P	S	W	Mo	V	Cr
AISI 52100	0.95–1.05	0.28–0.40	0.15–0.35	0.020	0.027	–	–	–	1.30–1.65
AISI M2	0.95–1.05	0.15–0.40	0.20–0.45	0.021	0.020	5.50–6.75	4.50–5.50	1.75–2.20	3.80–4.40