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Effect of thermal oxidation on the wear behavior for CP-Ti

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ABSTRACT

Commercially pure titanium (CP-Ti) TA2 samples were thermally oxidized at various temperatures and duration. The wear behaviors and the surface hardness of the samples before and after thermal oxidation were investigated. The worn surface morphology was observed by means of SEM examinations. The results showed that thermal oxidation could significantly increase the surface hardness and enhance the wear resistance of TA2. It was found that 700°C and 240 min were the optimum parameter of thermal oxidation.

KEYWORDS

CP-Ti;
Thermal oxidation;
Wear resistance;
SEM.

INTRODUCTION

Titanium is the fourth most abundant structure metal in the word, and titanium and titanium alloys have been widely used in aerospace, marine, chemical and biomedical industries due to their high strength-to-weight ratio, excellent corrosion resistance and biocompatibility[1-3]. However, titanium alloys are characterized by poor tribological properties, including high and unstable friction coefficients, severe adhesive wear and fretting wear, these properties restrict their use in wear-related applications, where contacting motion of counterparts is maintained. This paper aims to modify its wear resistance by thermal oxidation and evaluated the dry sliding wear performance in comparison with the as-received materials.

EXPERIMENTAL

Commercially pure titanium TA2 in the form of forged and annealed bar of 90-mm-diameter was chosen as the experimental material, the samples with a 31.7mm outer diameter, a 16mm inner diameter, 10mm in thickness, and they were prepared by cutting from the as-received TA2 bar, followed by grinding using 150-grit, 400-grit Al_2O_3 paper and manual grinding using 1~5# metallographic papers, then polished and ultrasonically cleaned in de-ionized water and acetone, dried using a stream of cold compressed air. Thermal oxidation of the Ti samples was carried out at 500° C~750°C in a conventional muffle furnace under air atmosphere for 30min~960min, followed by cooling in the furnace[4-8].

The configuration of pin-on-wheel was used to evaluate the wear behavior of untreated and oxidized samples. Untreated samples were tested in as polished condition. The tests were carried out on a Wear Test Machine Type MMW-1A under ambient condition (20±2°C and 50%RH), During the test, a 4.8 mm di-

ameter 1045 steel pin rotated at a speed of 30rpm on the surface of the samples wheel for the testing time of 180 min. The test load was15N. The friction coefficient was continuously recorded on the test, and the weight of the samples were measured before and after wear tested by a balance accurate to 0.1mg for calculating the weight loss. And the characteristic features of the worn surfaces were revealed after the entire wear test by a JSM6360LA type scanning electron microscope (SEM).

RESULTS AND DISCUSSION

Surface hardness

The surface hardness profile of the TA2 samples thermally oxidized at 650°C for various time was shown in Figure 1. It can be seen that the hardness of the initial sample was 160HV. The surface hardness of the thermal oxidation decreases with the increase of loads. There was an oxide film formed on the sample surface with a certain thickness. When the oxide film was thin, and the load force was great enough, the indenter of the hardness tester will penetrate the oxide film to get the substrate. From Figure 1, it can be clearly seen that with the extension of thermally oxide time, the surface hardness of the samples treated at the same temperature increased gradually. The surface hardness of the sample thermally oxidized at 650°C for 600min was 661$HV_{0.025}$.

Wear behavior

Figure 2 was the friction coefficient curves of the samples as-received and thermally oxidized at various temperatures for 210min. It could be seen that the friction coefficient of as-received sample was high and unstable, which fluctuated greatly during the sliding cycles, it was about 0.5. On the other hand, the friction coefficient of the samples oxidized at all temperatures was reduced and became much smoother, among which, the sample oxidized at 700°C was the most stable one, and it was 0.4.

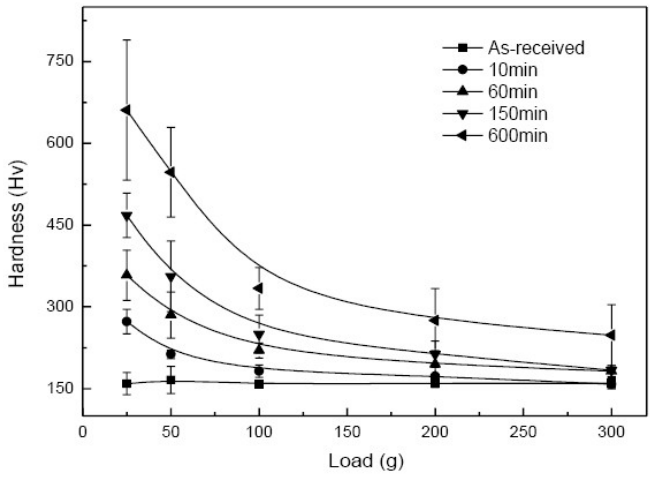

Figure 1 : The surface hardness-load profile of the as-received and the specimens treated at 650°C for various time

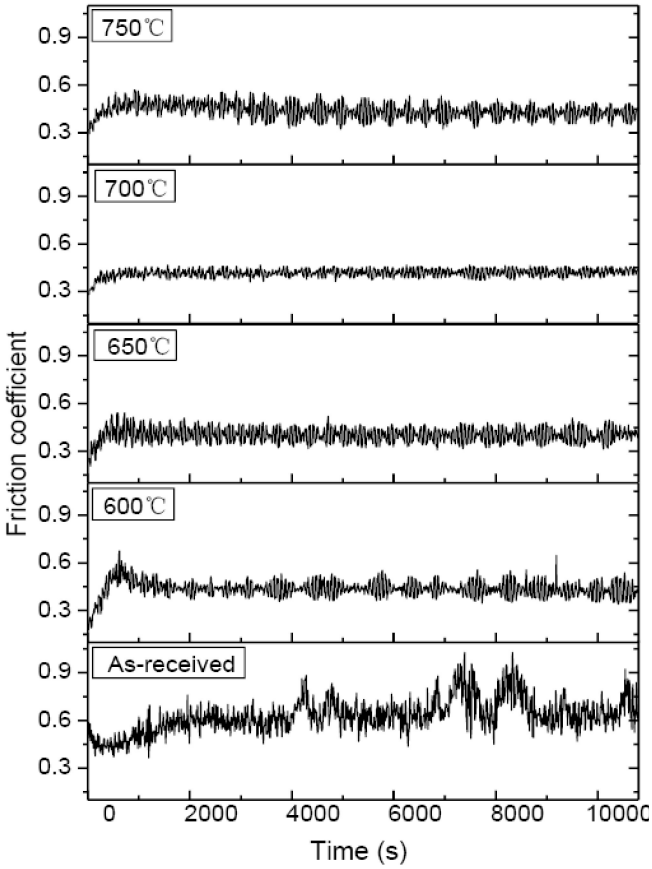

Figure 2 : Friction coefficient curves of the samples as-received and thermally oxidized at various temperatures for 210min

Figure 3 was the weight loss of the samples as-received and thermally oxidized at various temperatures for 210min after wear test. The weight loss of the as-received sample was 12.74 mg. whereas, the weight loss of the samples oxidized at all temperatures decreased obviously. It could be seen that the weight loss of the samples oxidized at 700°C decreased least, and it was 0.02 mg. From Figure 2 and Figure 3, it could get that 700°C was the optimum temperature for thermal oxidation.

Figure 4 was the friction coefficient curves of the

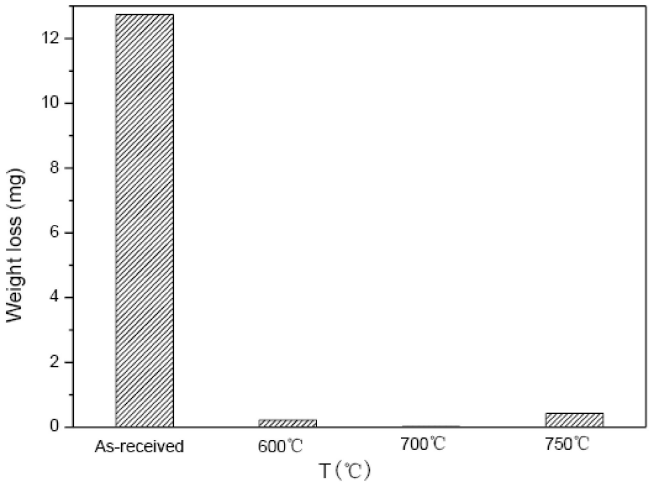

Figure 3 : The weight loss of the samples as-received and thermally oxidized at various temperatures for 210min after wear test

samples of as-received and thermally oxidized at 700°C for different time. The friction coefficient of the samples oxidized at 700°C for different time was reduced and became much smoother, the samples oxidized for 480min were the most stable, and it was about 0.3.

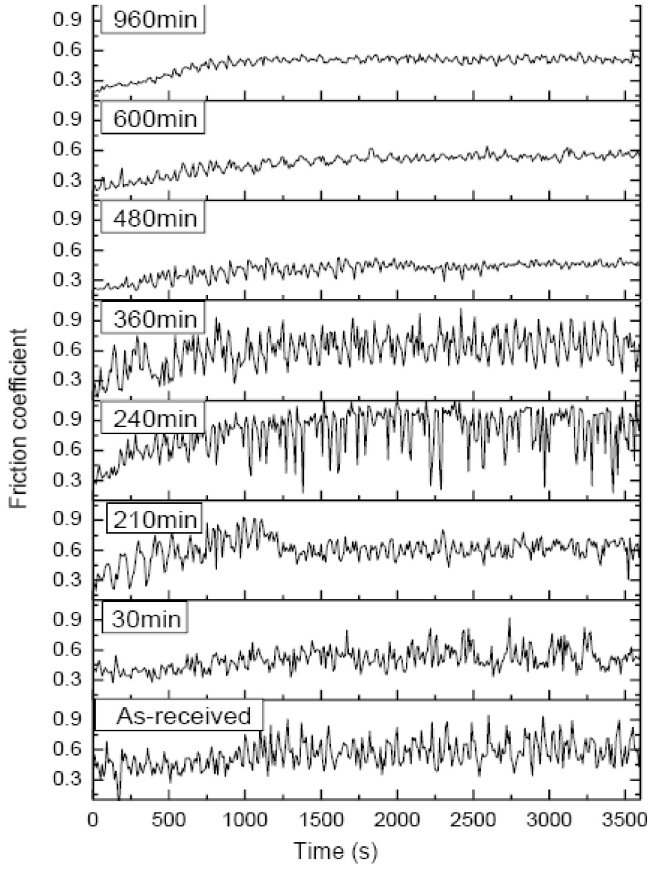

Figure 4 : Friction coefficient curves of the samples as-received and thermally oxidized at 700°C for different time

Figure 5 was the weight loss of the samples corresponding to Figure 4 after undergoing wear test by 60min. As seen in Figure 5, the un-treated sample lost the most weight, about 12.74mg, and the weight loss of thermally oxidized samples was significantly reduced. The sample thermally oxidized by 240min lost the least weight, about 0.02mg. From the perspective of the wear resistance, 240min was the optimum time for thermal oxidation.

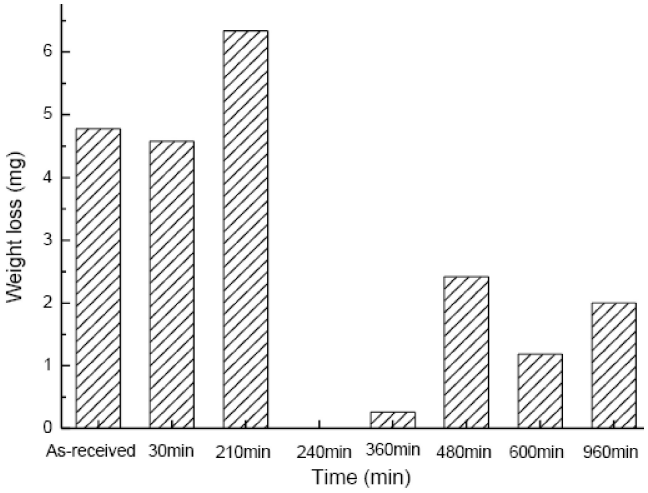

Figure 5 : The weight loss of the samples at 700°C for different duration

Worn surface morphology

Figure 6 was the worn surface morphology of the un-treated TA2 sample under different magnification. It can be seen that pure titanium shows obviously adhesion wear features. The worn surface showed some deep furrows and scratches, simultaneously, the trace of adhesion was found. Therefore, un-treated TA2 can not work under rubbing condition.

Generally, there was a thin oxide film existing on the surface of the titanium, but because the oxide film which formed in air was thin and brittle, under the condition of testing, this oxidation would not obviously improve the wear resistance of TA2. When contacted with other metal, under middle or high load, the oxide film was easily scaled; resulting in the titanium contact with other metal directly, producing plastic deformation and leading the samples lose its efficacy.

Figure 7 was SEM images of the worn surface morphology of TA2 samples thermally oxidized at 700 ! for 960min after wear test. It showed that, under the same experiment condition, the surface of the thermal

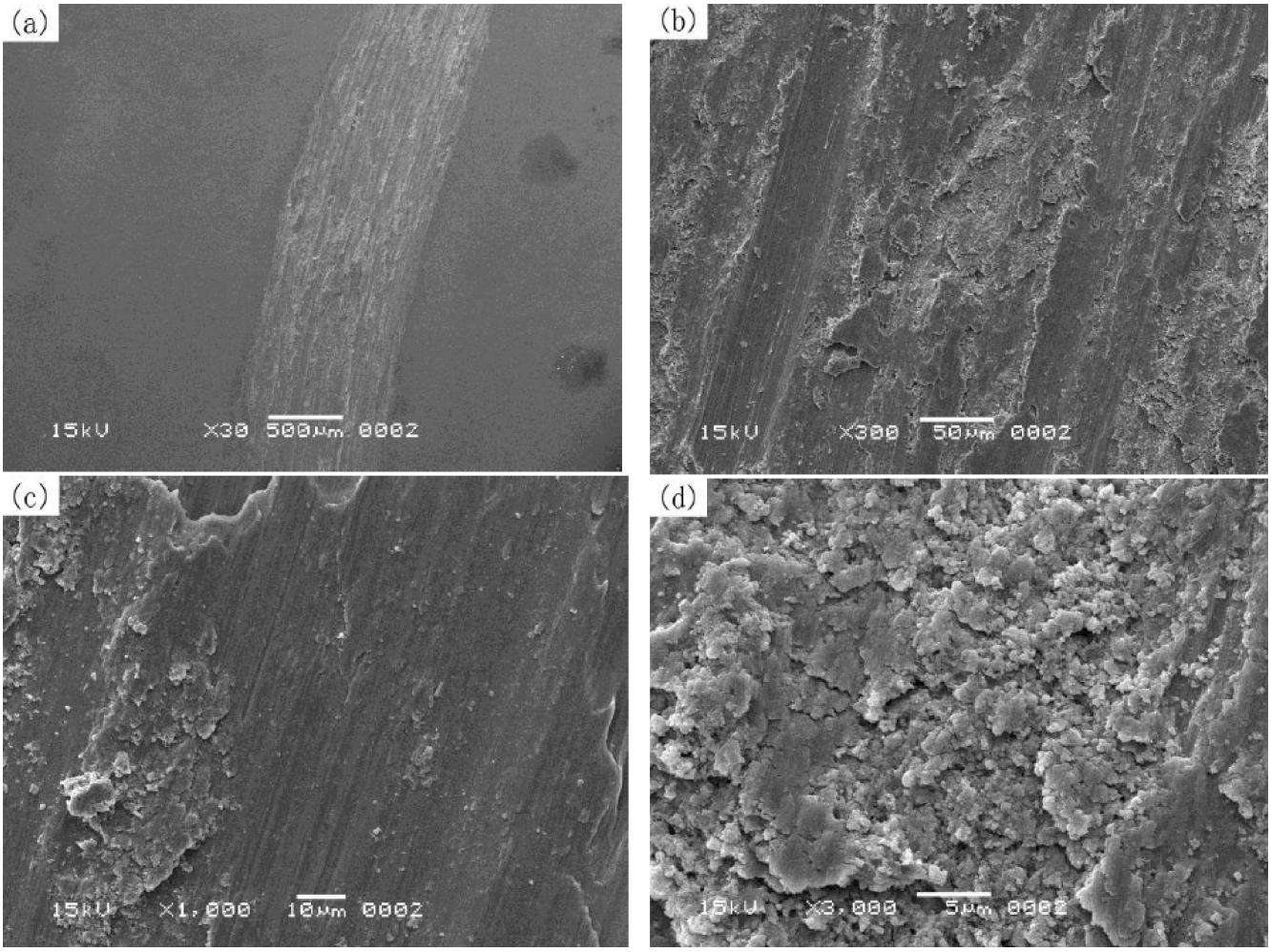

Figure 6 : SEM image of worn surface of the as-received samples under different magnification (a)x30 (b) x300 (c) x1000 (d) x3000

oxidized sample just existed narrow polishing scratch, without deep furrow, the phenomenon of adhesion was observed in (a), (b). According to the friction coefficient and weight loss, thermal oxidation would improve

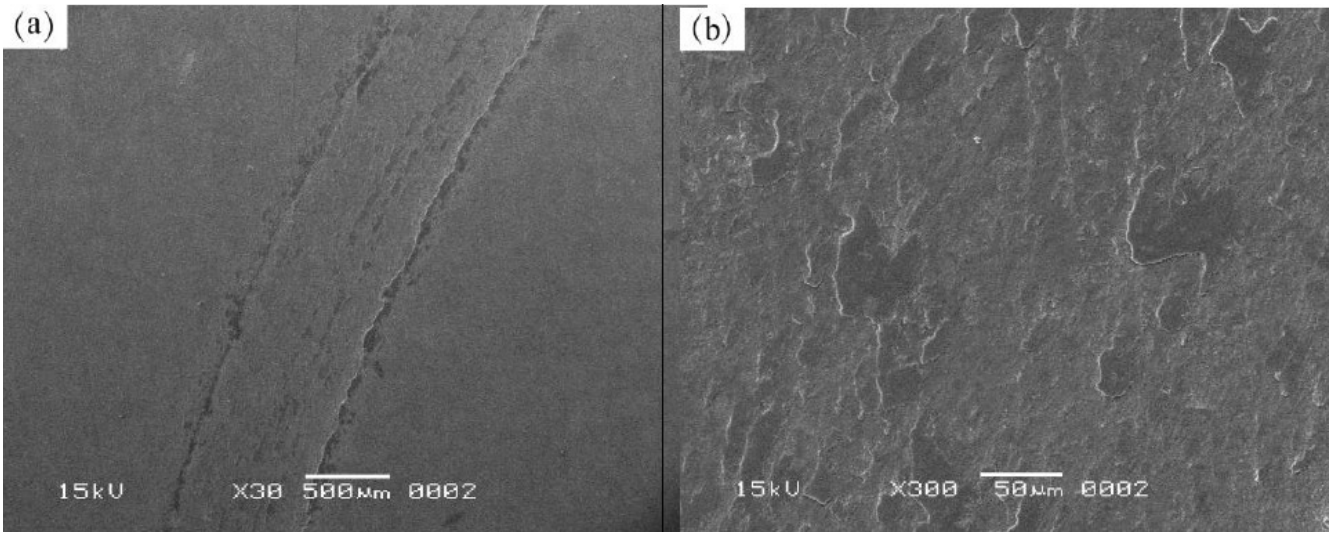

Figure 7 : SEM images of surface morphology of TA2 samples oxidized at 700°C for 960min after wear test (a)x30 (b) x300

the wear resistance of TA2. The reason may be as follows: A compact oxide film was formed after thermal oxidation, leading to the improvement of hardness. Hardness was the most important element of the metal material wear resistance. High hardness would reduce the deformation of the metal surface under load, and deduce the chance of the crack caused by deformation, and then improve the wear resistance. The phenomenon of adhesion was because the surface of TA2 was composed of TiO_2 which was harder than that of the 1045 steel pin, and the abrasive dust of 1045 steel pin adhered on the sample's surface.

CONCLUSIONS

1) The surface microhardness of the samples increased significantly after thermal oxidation.
2) The wear resistance of the samples increased significantly after thermal oxidation and the friction coefficient of the treated samples decreased corresponding.
3) From the perspective of the wear resistance, 700°C and 240min were the optimum parameters of thermal oxidation. Under these parameters, the weight loss was lowest and the wear trace was shallowest.

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