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MECHANICAL BEHAVIOR AND TRIBOLOGICAL PROPERTIES OF ELECTROCHEMICAL BORIDE TITANIUM ALLOY Ti-6Al-4V

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Abstract: Some mechanical properties and tribological properties of borided Ti-6Al-4V titanium alloy were investigated with different testing methods; tensile tests, and bending tests along with hardness measurements. In this work, boriding process based on the electrochemical boriding applied on titanium alloy at 950 °C for 30 min, this method has an electromagnetic frequency in the range of 100–500 kHz during electrolysis has been proposed and realized on Ti-6Al-4V alloy. The surface methodology was used to analyse the effects of boride. The formation of the new microstructure was examined by optical-light microscopy, scanning electron microscope inspections along with thin film X-ray diffraction analyses, and elemental dispersion spectrometry analyses, which confirmed the borided layer formations. XRD patterns confirmed the formation of titanium borides (TiB and TiB_2). The micro-hardness of the boride layer was measured using Vickers microhardness tester. Some mechanical characterization were investigated on the borided substrates such as the surface hardness of borided titanium alloy, microhardness measurements were achieved to study the consequence of the microstructure on hardness. Vickers microhardness values were around 1400 HV to 1800 HV, its exhibited excellent adhesion to the substrate as long as the boride layer, which was much higher than 260 HV hardness of Ti-6Al-4V titanium alloy.
Keywords: titanium alloy Ti-6Al-4V, electrochemical boride, mechanical behavior, tribological properties

INTRODUCTION

Titanium is lustrous transition metal with low density and high strength; it is resistant to corrosion, seawater, and chlorine. Titanium is widely distributed in the earth's crust and lithosphere and it found in almost all living things water bodies rocks and soils the metal is extracted from its principal mineral ores by the crawl and hunter processes [1–3]. The most common compound titanium dioxide is a popular vote a catalyst and it used in manufacture of white pigments other compounds include titanium tetrachloride a component of smokescreens, catalysts, and titanium tri-chloride, which is used as a catalyst in the production of polypropylene titanium, can be alloyed with iron, aluminium, vanadium, and molybdenum. Among other elements to produce strong lightweight alloys for aerospace, jet engines, missiles, and spacecraft military, industrial processes, chemicals, petrochemicals, desalination plants, medical prosthesis, orthopaedic implants dental, endodontic instruments, files dental implants, and many other applications. Titanium is as strong as some steels but less dense there are two allotropic forms and five naturally occurring isotopes of this element.

However, the hardness of titanium alloy is relative low and revealed a weak wear resistance. With a view to enhanced some properties of titanium alloy, the processes of surface hardening and diffusion of chemical elements on the surface of materials have been established, among those methods is boriding. Boriding or boronizing is a thermochemical hardening treatment, which boron can form compounds with materials, such as steels, cast iron, and titanium alloy. Boriding processes involves solid; pack or past, liquid; with or without electrolysis, gas, and plasma boriding. Among these methods, melted salt does not require special equipment to achieve the treatment.

In the literatures, some researchers reported that titanium can be treated by boriding to enhance some properties [4, 5], but these reports are very little. The aim of this work is develop the properties of titanium and study the effect of boriding on mechanical and tribological properties on titanium alloy Ti-6Al-4V. The effects of wear under dry sliding conditions on the sample were investigated.

EXPERIMENTAL

— Materials

Titanium alloy Ti-6Al-4V used as the base material in this work. The chemical composition of Inconel 600 alloy was as follows: 5.65 Al, 3.67 V, 0.30 Fe, 0.05 C, 0.05 O, 0.04 N, 0.01 H and balance Ti (wt %).

Before the boriding process, the samples should be pre-treated. The samples with the size of 50×20×5 mm were polished by grinding with emery paper using the 2000 mesh emery paper, cleaned with acetone in ultrasonic cleaner, and then washed in deionized water.

— Boriding process

The boriding was performed on titanium alloy Ti-6Al-4V after cutting. Each sample was put in an Al_2O_3 crucible and covered by the boriding componds of 20 wt% B_4C (as boron source), 60 wt% of sodium tetraborate $Na_2B_4O_7$ (as a transport medium), 10 wt% Al (as a reducing agent), and 10 wt% NaCl (as an activator) [6].

Boriding was carried out by immersing the samples in the bath at 950°C for 30 min and constant current of 200 mA/mm^2 [7]. After the treatment, the samples were taken out from the solution and water cooled, and then it was boiled and washed in water for about 1 h.

— Experimental method

Microstructural and morphological characteristics of borided titanium alloy Ti-6Al-4V were analysed and examined by a TESCAN Scanning Electron Microscope (SEM), with an Energy Dispersive X-Ray Spectro- scope (EDS). The presence of the titanium boride formed on the surface of sample and the phase composition of the samples were confirmed by X-Ray diffractometer (XRD) with 2h varying 0° to 90°, using Cu Ka radiation worked at the optimum voltage of 32 kV, anodic current of 20 mA, and the wavelength k = 1.54060 Å.

Microhardness measurements were carried out throughout the boride layers via SHIMATZOU Vickers microhardness. The results of microhardness of boride layers formed on the surface of titanium alloy Ti-6Al-4V was obtained after three times measurements.

The wear resistance of borided titanium alloy Ti-6Al-4V was estimated using the four-ball method. Furthermore, the wear mechanisms occured in the boride layers were examined during the four-ball test method. After boriding wear test at room temperature was achieved along a circular track of 10 mm diameter against ZrO_2 of a radius of 3/32 inch counterpart at 50 rpm under a constant normal load of 4.9 N in the atmosphere of the relative humidity of about 30% at room temperature using the pin-on-disk-type abrasion testing equipment.

The wear width obtained with a metallographic microscope to test the width of wear scar. The wear depth and wear width tested four times to get the average value. The other tribological configurations that utilize a pin-on-disk tribometer. A Mitutoyo Surft- est SJ-30 roughness meter was used to analyse the surface rough- ness, the CNs deposit thickness, and the wear profiles performed by the tribological test. The wear of both borided and non-borided titanium alloy Ti-6Al-4V was evaluated in dry and lubricant conditions under different applied loads.

The friction and wear tests of the coatings were carried out using ball-on-disk method with a CSM Tribometer. The tests were performed dry sliding a tungsten carbide (CW) ball (5 mm diameter) at a temperature of 25 °C with a relative humidity 66%, during a total sliding distance of 600 m with a sliding speed of 0.2 m/s and the covered radial distance was 5 mm under a normal load of 1 N.

RESULTS AND DISCUSSION

— Structure analysis

The surface morphology of the sample was observed by SEM. Fig. 1 appearances the SEM micrographs of boride layer of titanium alloy Ti-6Al-4V. It is apparent from the micrograph that a dual boride layer consisting of monolithic TiB_2 and needle-like TiB whiskers form beneath the surface, but present a high roughness at higher magnifications, with a degree of porosity due to the presence of amorphous grains.

No discontinuity and lack of adhesion are observed between boride layer and substrate, which means that TiB whiskers anchor boride layer formed on the substrate.

According to the results of the line analysis, the thickness of the boride layer was 25 µm, which consists of 3 µm thick continuous and smooth monolithic TiB_2 and remaining TiB layers 22 µm.

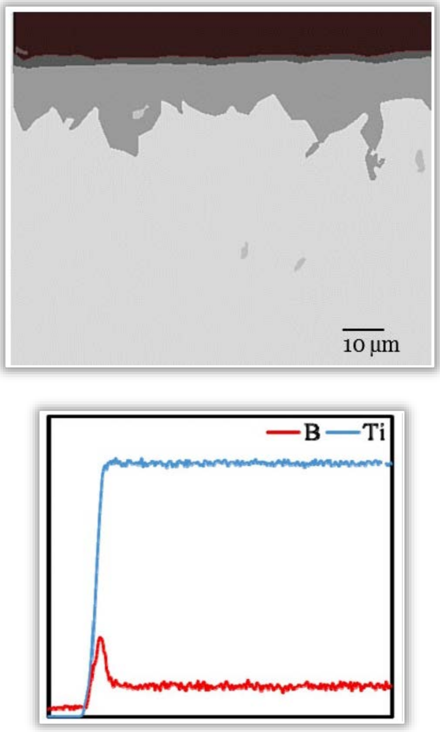

Figure 1. SEM images of the cross section of boride layer of titanium alloy Ti-6Al-4V and EDS analysis

XRD patterns of the sample analyzed is shown in Fig. 2, Fig. 2 revealed the X-ray diffraction patterns of the surface of titanium alloy Ti-6Al-4V at 950 °C. As shown in Fig. 2 as the first peak is shallow and relatively low, the degree of graphitization is low, from the X-ray diffraction measurement, it was confirmed that TiO2, TiB, and TiB_2 were formed. The main chemical composition of TiB_2 is obtained from the EDS, showing mostly B and Ti. Since neither TiB_2 peaks are present in the XRD, nor B is obtained in the EDS.

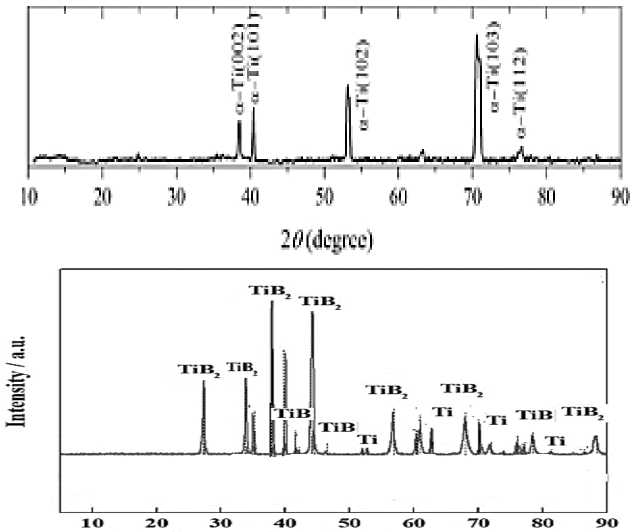

Figure 2. X-ray diffraction patterns; (a) Untreated titanium alloy Ti-6Al-4V (b) boride layer of titanium alloy Ti-6Al-4V

— Mechanical property

The surface hardness of boride samples was investigated. The hardness of titanium alloy Ti-6Al-4V was about 260 HV. However, the microhardness of boride samples was about

1458 HV, it was much higher than that of the untreated specimen. The surface hardness of the hardened layers was improved significantly.

Young's modulus of boride samples reached the maximum value was about 352 GPa. Thus, the Young's modulus of boride samples was much higher than that of the untreated specimen; which was about 111 GPa.

Table 1. Some mechanical and tribological values of untreated and boride sample

Characterization	untreated	boride sample
Microhardness (HV)	260	1456
Young's modulus (GPa)	111	352
Wear width (μm)	1240.28	57.82
Wear depth (μm)	640.04	25.84

It should be noted that corrosion occurred in the surface of the ball in addition to the surface of the hard layer. The wear depth and the wear width of boride sample decreased significantly compared to untreated. It can be concluded that the reason for these differences is the transition from mechanical to abrasive wear.

Table 1 regrouped some mechanical and tribological values of untreated and boride sample such as: microhardness, Young's modulus, wear width and depth. It is noted that the higher the hardness, the lower the wear depth of the hardened layer. Therefore, the wear of boride layers is improved.

CONCLUSIONS

Mechanical and tribological properties of Ti-6Al-4V titanium alloyafter boriding were estimated including the *H*, *E*, and wear. The main conclusions are as follows:

- Boriding process based on the electrochemical boriding was achieved at 950 °C for 30 min.
- The surface methodology was used to analyze the effects of boride.
- XRD patterns confirmed the formation of titanium borides (TiB and TiB_2).
- Vickers Microhardness values were around 1400 HV to 1800 HV.

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