

Study of Surface Properties of Ti-6Al-4V with Double-glow Plasma Non-hydrogen Carburizing

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The double-glow plasma non-hydrogen carburizing technology was utilized to harden the surface of titanium alloy Ti-6Al-4V. The effect of double-glow plasma non-hydrogen carburizing on the surface properties of titanium alloy Ti-6Al-4V was investigated. The results indicated that the implanted carbon ion and sputtered carbon atoms reacted with titanium atom to format carburized layer, which consisted of two layers and its depth was not less than $312\mu\text{m}$. The content of titanium carbide gradually decreased with increasing the depth of carburized layer. The micro-hardness of carburized layer was much higher than that of titanium alloy Ti-6Al-4V matrix. The wear resistance of titanium alloy Ti-6Al-4V after plasma non-hydrogen carburizing was significantly improved due to the reduction in friction coefficient and increase in surface hardness.

Keywords: Ti-6Al-4V, double-glow plasma, non-hydrogen carburizing, carburized layer

1. Introduction

Titanium alloys are widely used in industry because of its many excellent properties. Including high corrosion resistance and high specific strength. However titanium alloys used in mechanical engineering easily suffer from adhesion wear due to its low coefficient of heat conduction and poor wear resistance. The wear resistance of titanium alloy can be improved by surface hardening. The conventional methods to harden surface are electroplating carburizing, physical vapor deposition, chemical vapor deposition, laser clad, pile welding and gas nitriding. Plasma carburizing and gas carburizing has been demonstrated to be the most effective technology to harden surface to improve wear resistance. For the conventional carburizing technology, carbon ions are generated from the decomposition of methane (CH_4) or acetylene (C_2H_2). Unfortunately, hydrogen ions are simultaneously generated. The solid solubility of hydrogen in titanium alloy will significantly increase with elevated temperature, which results in its significant decrease in plasticity, toughness, and tensile strength, leading to the catastrophic failure of titanium alloy¹⁻⁴⁾.

In this paper, double-glow plasma carburizing technology had been utilized to harden the surface of titanium alloy Ti-6Al-4V without introducing any hydrogen element during preparation process and the carburized surface also acted as a barrier to retard hydrogen permeation during service. The microstructure, phase, micro-hardness and friction behaviors of carburized layer were investigated.

2. Experimental

The schematic diagram of double-glow plasma non-hydrogen carburizing device⁵⁾ is illustrated in Figure 1. Double-glow discharge takes place between the graphite source cathode and the vacuum chamber anode, and between the work piece cathode and the vacu-

um chamber anode^{6,7)}. The work piece is heated and the graphite cathode is sputtered due to the effect of unequal potential of hollow cathode. The sputtered carbon atoms are partly ionized. The carbon ions are implanted into work piece due to the electric field speeding. The implanted ions and sputtered atoms react with work piece atoms to form the hardened layer.

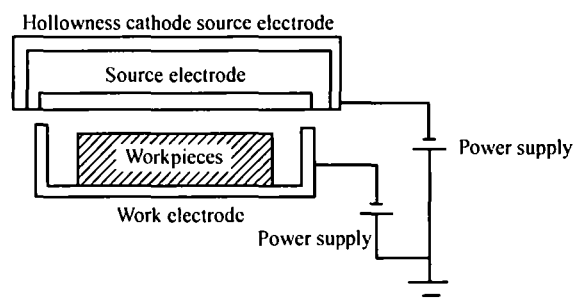


Figure 1. The schematic diagram of double-glow plasma non-hydrogen alloying device

The basic pressure in vacuum chamber was 5×10^{-3} Pa and argon with 99.999% purity was used as discharge gas. The high purity graphite and Ti-6Al-4V alloy were respectively used as source cathode and work piece cathode.

The dimensions of Ti-6Al-4V work piece were $50\text{mm} \times 50\text{mm} \times 2\text{mm}$. The sample was acid leached, polished and ultrasonically cleaned in acetone. Then, after drying, it was carburized.

The microstructure of carburized layer was studied using scanning electron microscopy (SEM, JSM-6460). The phase analysis of carburized layer was identified by X-ray diffraction (XRD, RigakuD/MAX2200). Element distribution of carburized layer was analyzed by glow discharge optical spectrometer (GDA-2). Micro-hardness was determined at room temperature by indentation tester (M-400-H1). Wear resistance of carburized sample and pure Ti-6Al-4V alloy was measured by wear tester (MM-200), and the couple was Al_2O_3 balls with 490N load and oil lubrication.

3. Results and Discussion

3.1 Phase Analysis and Microstructure of Carburized Layer

The surface of the sample is black on which there are no defects, such as cracks and scales, after carburizing. Figure 2 shows the XRD patterns of carburized layer. It can be seen from Figure 2 that the carburized layer consist of TiC, α -Ti, β -Ti and V_8C_7 phases, and there is no aluminum carbide phase. The content of TiC phase increases with increasing carburizing time and elevated carburizing temperature. It can be concluded that the formation of TiC phase is due to the solid state reaction of implanted carbon ions and sputtered carbon atoms with titanium atoms.

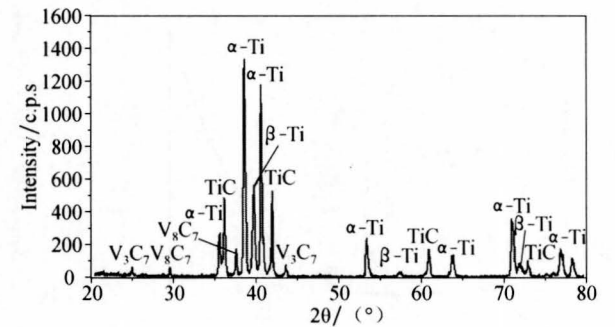


Figure 2. XRD pattern of carburized layer on titanium alloy matrix

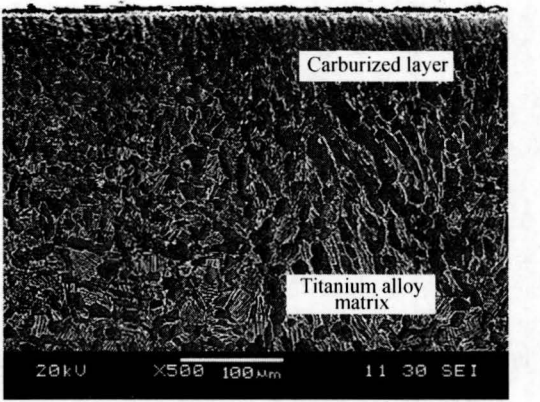
The cross-section image of carburizing sample is shown in Figure 3. As can be seen, the carburized layer consists of two layers. The depth of outer layer is about 2 μ m. There is distinct interface between outer layer and interior layer of carburized layer, while there is no distinct interface between carburized layer and alloy matrix.

Figure 4 shows the element distribution patterns of carburized layer. It can be concluded that the outer layer of carburized layer consists of pure titanium carbide and the content of titanium carbide gradually decreases and the content of α -Ti and β -Ti matrix gradually increase along the interior layer of carburized layer.

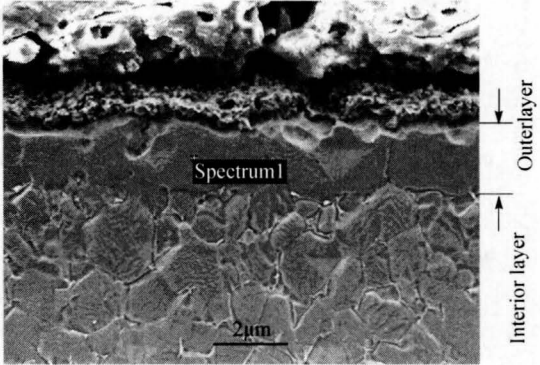
Table 1 shows the element concentration in grain and at grain boundary in Figure 5. It is indicated that the content of carbon element at grain boundary is higher than that in grain. This is because the carbon is an interstitial element, and it diffuses along grain boundary at low temperature.

Table 1. Element concentration in grain and at grain boundary in Figure 5

	Element	Weight%	Atom%
Spectrum1	C K	2.07	7.73
	Al K	2.46	4.07
	Ti K	78.41	73.23
	V K	17.06	14.98
Spectrum2	C K	1.54	5.63
	Al K	5.93	9.65
	Ti K	90.65	83.10
	V K	1.88	1.62



(a) Micrograph of cross section of the carburized layer



(b) The magnifying image of outer layer of carburized layer

Figure 3. SEM image of cross section of the carburized layer

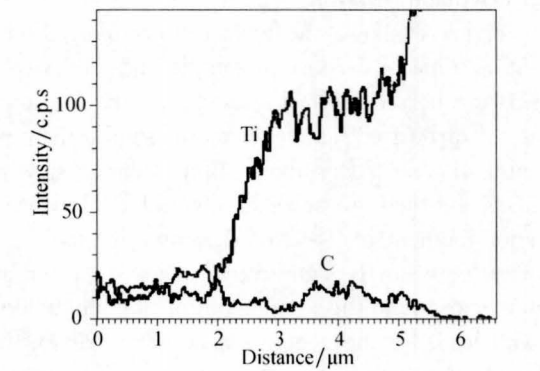


Figure 4. Element distribution of carburized layer on the titanium alloy surface

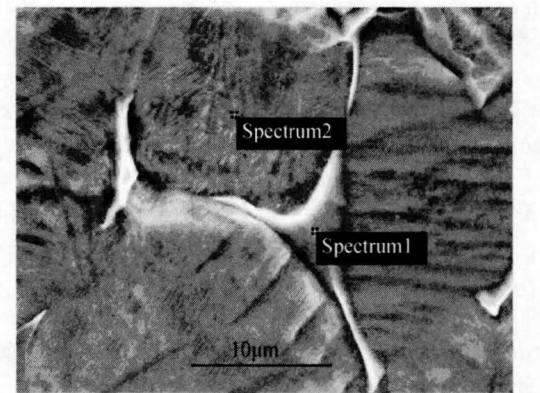


Figure 5. SEM image of interior layer of carburized layer

3.2 Micro-hardness of Carburized Layer

Figure 6 shows the micro-hardness vs. depth from the surface to interior of carburized sample. The micro-hardness decreases gradually from the surface to interior of carburized sample, which is about 850HV and 400HV at a depth of 10 μ m and 310 μ m respectively. The micro-hardness of Ti-6Al-4V alloy matrix without heat treatment is about 400HV and it would decrease after heat treatment. It is indicated from Figure 6 that the depth of interior layer of carburized layer is at least 310 μ m.

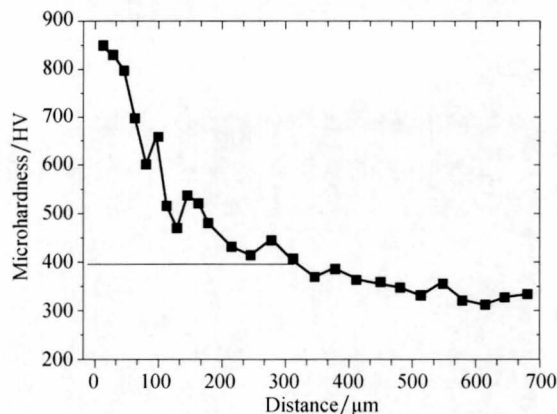


Figure 6. Micro-hardness along carburized sample from surface to interior

3.3 Frictional Behavior

Figure 7 shows the typical curve of friction moment vs. time of carburized sample and Ti-6Al-4V alloy. It can be seen from Figure 7 that the friction moment of carburized sample decreases significantly at beginning of wear. After about 26min wear, it slowly decreases and tends to be relatively stable. However, the friction moment of Ti-6Al-4V sample is stable at beginning of wear. It significantly increases after about 3min wear due to the running out of titanium oxide layer and leads to the generation of great friction heat. The sample adhered by epoxy resin disengages due to great friction heat and results in its failure.

The micrograph of friction surface of Ti-6Al-4V sample and carburized sample is shown in Figure 8. It can be seen from Figure 8 that the friction surface of Ti-6Al-4V sample is rough, indicating the characteristic of adhesion wear. However, the friction surface of carburized sample is smooth and the wear resistance is significantly improved after carburizing.

3.4 Service of Titanium Alloy Gear after Carburizing

The service life of Ti-6Al-4V alloy gear after carburizing, operating at rotation speed higher than 5000n/min, transmission power of 5-15KW and liquid media of chloride, exceeds 5 years, which is much higher than that of Ti-6Al-4V alloy gear without carburized layer. Moreover, running noise of Ti-6Al-4V alloy gear after carburizing has been decreased.

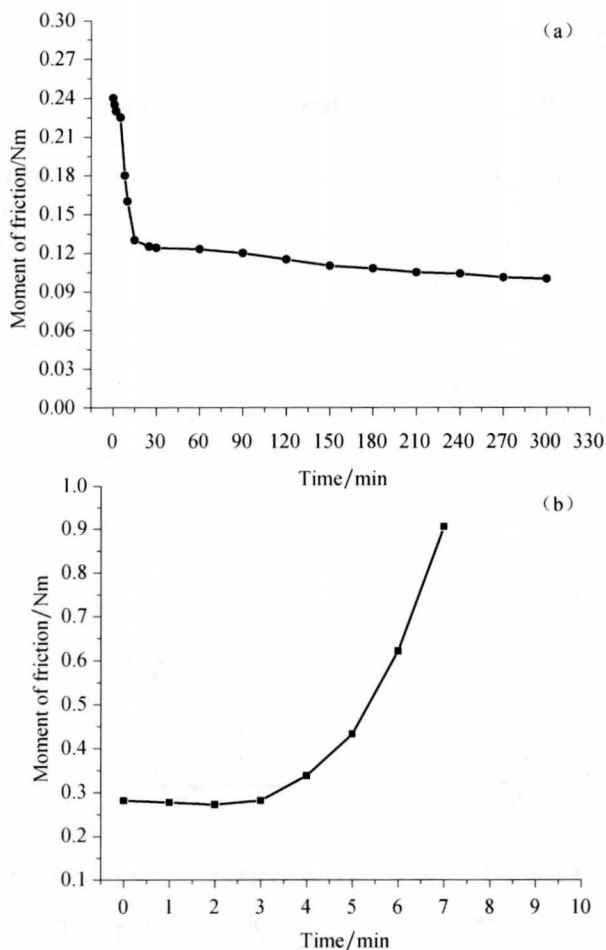


Figure 7. Curve of friction moment vs. time of (a) Carburized sample (b) Ti-6Al-4V alloy

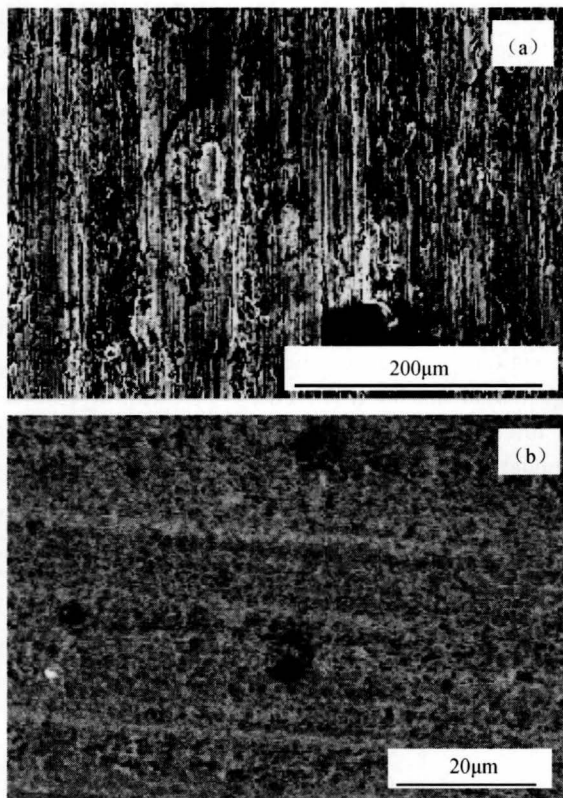


Figure 8. Micrograph of friction surface of (a) Ti-6Al-4V alloy and (b) carburized sample

4. Conclusions

Double-glow plasma non-hydrogen carburizing was implemented to harden the surface of Ti-6Al-4V alloy to improve the wear resistance. The carburized layer consisted of two layers and its depth is not less than $310\mu\text{m}$. The outer layer consisted of pure titanium carbide and the content of titanium carbide in interior layer gradually decreased with increasing its depth. The micro-hardness of Ti-6Al-4V alloy was significantly improved due to the formation of carburized layer. The wear resistance of Ti-6Al-4V alloy with carburized layer was significantly improved due to the decrease in friction coefficient and increase in surface micro-hardness. The Ti-6Al-4V alloy gear hardening by double-

glow plasma non-hydrogen carburizing has been successfully applied in engineering.

REFERENCES

- 1) X. J. Xin. *The Corrosion and Protection & Engineer Application of Titanium*. (An Hui Science & Technology Press: He Fei. 1988) pp. 336-342.
- 2) Z. X. Li, J. H. Du, H. Zhou, et al. , *Rare Metal Mater. Eng.* 2004; 33(11); pp. 1174-1177.
- 3) Z. X. Li, H. Zhou, J. H. Du, et al. , *Rare Metal Mater. Eng.* 2004; 33(12); pp. 1355-1358.
- 4) Z. X. Li, J. H. Du and Z. Xu, *Ti-2003 10th world conference on Titanium*, Germany: Wiley-VCH, 2004, cap. 7, p. 899.
- 5) Z. X. Li, J. H. Du, Z. Xu, et al. , *Vacuum*, 2003; 40(6): 31-35.
- 6) C. M. Li, Z. Xu and X. S. Xie, *J. TaiYuan University of Technology* 2003; 28(1): 1-5.
- 7) Z. Xu, US Patent. No. 4,731,5.