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Study on the microstructure and wear resistance of the composite coatings fabricated on Ti–6Al–4V under different processing conditions

Y.S. Tian [a], C.Z. Chen [a,*], L.B. Chen [a], L.X. Chen [b]

[a] School of Materials Science and Engineering, Shandong University, Jinan Shandong 250061, PR China
[b] Shandong Electronic Devices Co. Ltd., Jinan Shandong 250061, PR China

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Abstract

Composite coatings mainly containing titanium carbides and borides were produced by laser surface alloying of Ti–6Al–4V with graphite and boron mixed powders. The test results show that the coatings have higher hardness (1600–1700 $HV_{0.1}$) and are more resistant to wear than the as-received sample. Laser scanning speed and the content of alloying elements (weight ratio of graphite to boron) have an effect on both the microstructure and the wear resistance of the coatings. TEM results show that strip titanium carbides and borides grow alternately and thus restrain the formation of coarse needle-like TiB and dendritic TiC crystals produced by laser alloying of titanium alloys with boron and graphite separately.

Keywords: Laser surface alloying; Wear resistance; Titanium carbides and borides

1. Introduction

Titanium alloys offer many attractive properties such as high specific strength, good oxidation and corrosion resistance, which lead to an ever increasing interest in using them in such areas as aeronautical, marine and chemical industries, etc. Nevertheless, during sliding contact with most metals and alloys, titanium alloys are susceptible to galling and seizing due to their low hardness and poor tribological properties [1–3]. So, the applications of titanium alloys under severe wear conditions are highly restricted. Since wear of material is a gradual degradation phenomenon initiated from the contacting surface and is governed by the materials properties at the contacting surface, one of the most efficient approaches to enhance the tribological properties and hence to expand the industrial application for titanium alloys as tribological machinery components is to fabricate a hard and wear resistant coating on the surface of titanium components. Owing to good coherence and directionality, laser beams are widely used in surface modification of many kinds of metals. Therefore, the disadvantages of titanium alloys can be overcome by laser surface treatment on the special surfaces of the workpieces where they suffer in operation.

Many researches of laser alloying of titanium alloys with different kinds of alloy elements for improving their wear resistance have been carried out. García et al. [4] fabricated alloyed layer containing of TiN, Ti_2AlN and Ti_2N compounds on the surface of pure Ti by laser alloying with aluminum powder in a nitrogen atmosphere. Majumdar et al. [5] found in their investigation of laser alloying of pure Ti with Si and Al mixed powders that the laser treated samples is much more resistant to oxidation than the untreated. Jiang et al. [6] performed laser nitriding Ti–6Al–4V and the test results show that the wear resistance of the treated samples is obviously enhanced. Chen and Wang [7,8] carried out laser alloying of TiAl alloy with carbon and found that the wear resistance of the coatings containing dendritic TiC is significantly improved. Composite coatings containing titanium borides fabricated on titanium alloys also exhibit excellent wear resistance [9]. Nevertheless, the coarse needle-like titanium borides and well-developed dendritic titanium carbides (see Fig. 1) produced by laser surface alloying can reduce the toughness of the coatings [10]. From our previous experiments we found that laser surface alloying of titanium alloys with graphite and silicon mixed powders can obviously reduce the size of dendritic compounds [11]. So, the aim of present study is to fabricate

* Corresponding author. Tel.: +86 531 839 5991; fax: +86 531 836 5388.
E-mail address: felix@sdu.edu.cn (C.Z. Chen).

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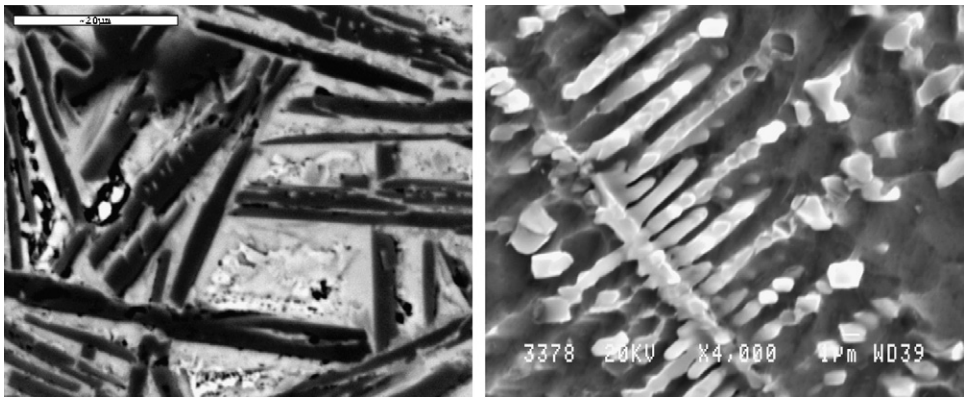

Fig. 1. Authors' previous works: (a) coarse needle-like titanium borides fabricated by laser surface alloying of Ti–6Al–4V with boron; (b) dendritic TiC produced by laser surface alloying of pure Ti with graphite.

composite coatings on titanium alloy Ti–6Al–4V by laser surface alloying process and investigate the effect of different laser scanning speed and weight ratio of graphite to boron on the microstructure and wear resistance of the coatings. In addition, using graphite and boron as alloying elements is for the purposes of both strengthening the coatings and restraining the formation of well-developed dendritic titanium carbides and coarse needle-like titanium borides.

2. Experimental procedure

Ti–6Al–4V alloy samples of 10 mm × 10 mm × 20 mm in size were polished with SiC grit paper prior to the coating operation. Fine graphite and boron mixed powders of size about 10 μm, blended with dilute sodium silicate solution were coated on the surface of samples to a thickness of about 0.5 mm and then dried. A 1.5 kW continuous wave CO_2 laser, with a beam diameter of 4 mm, power output of 1200 W, was employed to melt the surface of samples and the tracks were 40% overlapped. During the laser surface melting process, the powders were dissolved into the melted pool, leading to alloying the surface of the samples with carbon and boron. To protect the melted pool from oxidation during processing, argon gas shield at a pressure of 0.3 MPa was fed through a nozzle, which was coaxial with the laser beam. In addition, there was a side argon gas flow through another nozzle at an angle of 30° to the melted pool. The laser scanning speed and the weight ratio of graphite to boron are presented in Table 1.

The hardness and microstructure of the samples were evaluated using Vickers hardness tester and electron microprobe analysis (EMPA) and transmission electron microscopy (TEM) respectively. Compounds formed in the coatings were identified using D/max-RC X-ray diffraction (XRD) with Cu Kα radiation operated at a voltage of 40 kV, a current of 40 mA, and a scanning rate of 4°/min. For EMPA observation, the metallographic samples were prepared using standard mechanical polishing procedures and then etched in a solution of HF, HNO_3 and H_2O in volume ratio of 2:1:47 to reveal the microstructure of the coatings.

Table 1
Laser scanning speed and weight ratio of graphite to boron

Sample	Scanning speed (mm s^{-1})	Graphite	Boron
1	4.5	1	2
2	2.0	1	2
3	4.5	1	1
4	2.0	1	1
5	4.5	2	1
6	2.0	2	1

Sliding wear tests were performed using MM200 wear test machine with a load of 5 kg. A sintered carbide abrasive wheel (rotation speed: 400 rpm) with a diameter of 40 mm was selected as the wear couple. The weight loss was evaluated using an electronic balance with an accuracy of 0.1 mg.

3. Results and discussions

3.1. Microstructure analysis

The surface morphology and the cross-section micrograph of the sample 5 are shown in Fig. 2. It is seen that the alloyed layer, thickness of about 0.8 mm, surface roughness of about 0.2 mm, is free from cracks but has a few pores. Comparing Fig. 3(a) with (b), (c) with (d) and (e) with (f), respectively, it is seen that the compound morphology changes obviously with different scanning speed. It means that laser-processing parameters affect the size of the compounds and which can be explained as following.

A longer irradiation time due to slower laser scanning speed results in the melt pool absorbing more heat energy. The melt thus takes a longer time for solidification to start and the temperature of the base material becomes higher which results in lower temperature gradient and cooling rate. Therefore, the element carbon and boron have more time to diffuse because of relatively slow solidification rate of the melt after the laser beam removed. So, the compounds in the coatings get well developed [see Fig. 3(b), (d) and (f)]. On the other hand, with the scanning speed increasing, the irradiation time is relatively shorter and less heat energy is absorbed by the melt pool. Thus, the solidification rate of the melt is relatively faster after the laser beam removed, which results in the formation of fine microstructure [see Fig. 3(a), (c) and (e)]. In addition, the