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Study on the microstructures and properties of the boride layers laser fabricated on Ti–6Al–4V alloy

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ABSTRACT

Coatings containing stick borides were produced by laser surface alloying of Ti–6Al–4V with powder mixtures of boron and titanium. The test results indicated that the coatings have high microhardness, excellent wear resistance and are more resistant to oxidation than the original sample. The size and the morphology of the borides vary with laser scanning speed, which have an effect on the properties of the coatings.

1. Introduction

Titanium and its alloys, due to their intrinsic properties such as high specific strength, good oxidation and corrosion resistance, are extensively used in the aeronautical, marine and chemical industries. Nevertheless, owing to the poor tribological resistance and being prone to galling, the applications of titanium alloys under severe wear conditions are highly restricted. In addition, titanium alloys present limited high temperature oxidation resistance because of their high affinity towards oxygen at elevated temperature in air.

Surface treatments can effectively improve the properties of titanium alloys. Of all the surface treatment techniques, laser treatments are widely used in surface modification of many kinds of metals. Laser treatments have several advantages over commonly used heat treatment techniques, including precise control over the width and depth of processing, the ability to selectively process specific areas of a component, and the ability to process complex parts.

The researches of laser alloying of titanium alloys to improve their wear and oxidation resistance have been performed. García et al. (2002) fabricated coatings containing TiN, Ti_2AlN and Ti_2N compounds on the surface of pure titanium by laser alloying with aluminum powder in a nitrogen atmosphere. The results of laser alloying pure titanium with powder mixtures of silicon and aluminum showed that the laser treated samples were much more resistant to oxidation than the untreated titanium (Majumdar et al., 2000). Jiang et al. (2000) applied laser nitriding to Ti–6Al–4V and the test results showed that the wear resistance of the treated samples was significantly enhanced. The results laser alloying of powder mixtures of Mo and WC on the surface of Ti–6Al–4V alloy indicated that the sliding wear resistance of the coatings was 5 times as high as that of the original Ti–6Al–4V alloy (Pang et al., 2005).

Nevertheless, the investigations of laser boronizing of titanium alloys have been seldom reported. As known to us, titanium borides have very high hardness, excellent wear

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Table 1 – The laser scanning speed

Sample	Scanning speed ($mm\,s^{-1}$)
1	3
2	5
3	9

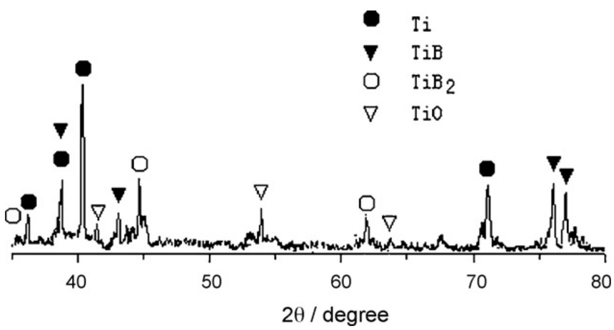

Fig. 1 – XRD spectrum of the sample 2.

resistance, and high stability at elevated temperature. So, the aim of the present work is to produce composite coatings containing titanium borides on the surface of titanium alloy Ti–6Al–4V by a laser alloying technique and to investigate the wear and oxidation resistance of the coatings.

2. Experimental procedures

Ti–6Al–4V alloy samples of 10 mm × 10 mm × 40 mm in size were polished with SiC grit paper prior to the coating operation. Fine powder mixtures of boron and titanium, particle size of about 10 μm, weight ratio of 1:8, blended with sodium silicate solution were coated on the surface of the samples to a thickness of about 0.5 mm and then dried. A 1.5 kW continuous wave CO_2 laser, with an output power of 1200 W and beam diameter of 2 mm was employed to melt the surface of the samples and the tracks were 50% overlapped. During the laser surface melting process, the powders were dissolved into the melted pool, leading to alloying the surface of the samples with boron. To protect the melt 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. The laser scanning speeds are indicated in Table 1.

The compounds formed in the coatings were identified using D/max-RC X-ray diffractometer with Cu Kα radiation operated at a voltage of 40 kV, a current of 40 mA, and a scanning rate of 4°/min. For observation, the polished samples were chemically etched in a mixed solution of HF, HNO_3 and H_2O in volume ratio of 2:1:47 to reveal the microstructure of the coatings. The microstructure was characterized using JXA-8800R EPMA and H-800 TEM. The hardness change of the boride layer every 30 μm from surface to matrix was measured using Shimadzu Vickers hardness tester with a load of 100 g. Sliding wear test was performed using MM200 wear test machine with a load of 4 kg. A sintered carbide abrasive wheel (rotation speed: 400 rpm) with a diameter of 40 mm was selected as the wear couple. Prior to sliding wear test, the laser treated and the as-received samples were annealed at 500 °C for 1 h. The weight loss due to the sliding wear test was evaluated every 5 min using a type of FA2104 electronic balance with an accuracy of 0.1 mg. For oxidation test, all the surfaces of the samples were laser treated. The cyclic oxidation tests were conducted at 800 °C and a total exposure time was 72 h in static air. One cycle consisted of holding at 800 °C for 12 h, and heating and cooling taking up about 30 min, respectively. During oxidation test, the samples (laser treated and untreated) were placed in ceramic trays. After each cycle, each sample together with the spalled oxidation scales were weighed on the electronic balance mentioned above.

3. Results and discussions

3.1. *Microstructural analysis*

X-ray diffraction (see Fig. 1) shows the formation of major TiB and minor TiB_2, but only TiB can be identified by TEM micrograph and selected area electron diffraction pattern, as shown in Fig. 2. This means that the molten liquid produced by instantaneous laser processing is not homogeneous, and hence the TiB_2 phase was not detected in Fig. 2. The microstructures of the coatings (see Fig. 3) indicate that the stick titanium borides change from coarse but sparse to fine but dense as the scanning speed increased from 3 to 9 mm/s.

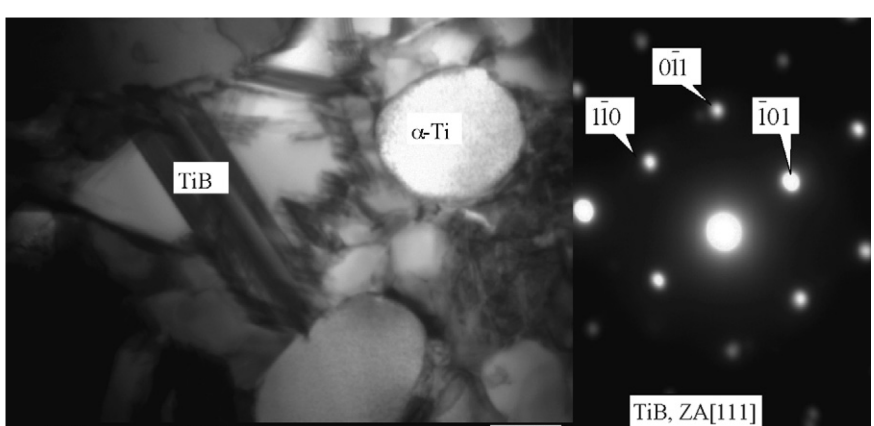

Fig. 2 – TEM micrograph and the SAED pattern of the sample 2.