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Microstructure and properties of TiB_2–TiB reinforced titanium matrix composite coating by laser cladding

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ABSTRACT

TiB_2 particle and TiB short fiber reinforced titanium matrix composite coatings were prepared utilizing in situ synthesized technique by laser cladding on the surface of Ti6Al4V alloy. Through the experiment, it was found that the surface of the single-track coatings appeared in the depression, but it can be improved by laser track overlapping. With the increase of laser power density, the amount of TiB short fiber was increased, and the distribution of TiB_2 and TiB became more uniform from the top to bottom. The micro-hardness of TiB_2/TiB coating showed a gradient decreasing trend, and the average micro-hardness of the coatings was two-fold higher than that of the substrate. Due to the strengthening effect of TiB_2 particle and TiB short fiber, the wear volume loss of the center of the coating was approximately 30% less than that of the Ti–6Al–4V substrate, and the wear mechanism of the coating was mild fatigue particle detachment.

1. Introduction

Titanium alloys have been widely used as various auxiliary components in aeroengine owing to their low density, high specific strength and excellent corrosion resistance, such as a cup-shaped parts and a double hinge. However, safety and reliability of titanium alloy are greatly affected due to its low fatigue strength, high friction coefficient and severe adhesive wear [1–3]. It has been reported [4–6] that the fatigue life of titanium alloy is reduced by about 60% due to the fretting action, and the major fretting failure modes are fatigue delamination and adhesive wear.

TiB short fiber reinforced titanium matrix composite material has been extensively studied during the last few decades. TiB short fiber has the following advantages. The diameter of TiB short fiber is very small, so that internal crystal contains few defects and atomic arrangement is very ordered, so the strength of TiB is very close to the theoretical value of the perfect crystal [7,8]. The chemical reaction between TiB and Ti does not occur, and fixed orientation relationship can be obtained, which is beneficial to the improving of mechanical property and fatigue performance [8,9]. In addition, the density and thermal expansion coefficient between TiB and Ti are very close, so the residual stress of the composite coating can be reduced [10,11]. Li et al. [12,13] showed that the failure mode of TiB short fiber reinforced titanium matrix composite coating at room temperature was load bearing and fracture, which indicated interfacial bonding strength between TiB and Ti matrix is very high. Kim et al. [14] found that TiB short fiber reinforced titanium matrix composites fabricated by the investment casting process appeared in the low fatigue delamination in the fretting wear, but composite materials appeared in the serious adhesive wear.

TiB_2 being harder next to diamond and cubic boron nitride is found to be a good choice as reinforcement due to good properties, such as high hardness (25 GPa), high elastic modulus (565 GPa), low friction coefficient and excellent chemical stability [15,16]. However, TiB_2 is ceramic brittle phase. Sharma et al. [17] found that M-TiB_2 composites fabricated by spark plasma sintering technique appeared in the low adhesive wear in the fretting wear, but M-TiB_2 composites appeared in the serious fatigue delamination.

Recently, laser cladding is developed as a new preparation technique, because it is capable of producing a wide range of composite coatings with many unique required properties, such as good metallurgical bonding between coating and substrate and dense microstructure [18,19]. In this study, TiB_2 particle and TiB short fiber reinforced titanium matrix composite coatings are prepared by laser cladding of TiB_2 powder on the surface of titanium alloy. The macroscopic feature, microstructure and micro-hardness of the single track coating and overlapping zone are studied, respectively, and fretting wear behavior of the coating and the titanium alloy substrate is also analyzed.

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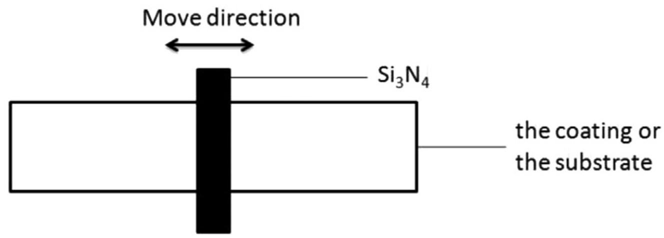

Fig. 1. Structural diagram of wear tester.

2. Experimental

2.1. Material prepartion

Cylindrical samples of Ti–6Al–4V alloy with dimensions of Ø30 mm × 15 mm were used as the substrate. The end face of the substrate was ground with emery paper to eliminate the oxide scale, and rinsed with alcohol before laser cladding. Pure TiB_2 (particle size 5 μm) powder was used as the clad material. TiB_2 powder was preplaced on the surface of substrates using 2123 phenolic resin, to form a layer of 0.3 mm thickness. Before laser cladding, precoated layer was dried at 140 °C for 10 h. Laser cladding was performed on a 6 kW YLS-6000 fiber laser system with a coaxial argon shielding device, and the wavelength of the laser was 1025–1080 nm. Process parameters of laser cladding were selected: laser power *P* was 1.5–3.5 kW, scanning velocity *V* was 4–12 mm/s and spot size *D* is 5 mm × 5 mm (square spot), shielding gas flow of argon is 15 l/min.

2.2. Microstructure characterization

After laser cladding treatment, single track specimens were sectioned in the transverse direction (dimension, 10 mm × 5 mm × 5 mm). Transverse sections were ground with emery paper, mechanically polished and then etched using an etchant of HNO_3:HF:H_2O = 3 ml:2 ml:95 ml. The phase identification of the coating was carried out on a Shimadzu XRD-7000 X-ray diffraction with Cu Kα radiation at 40 kV and 300 mA. The microstructure of the single track coating and overlapping zone was examined using S-3400 scanning electron microscope equipped (SEM). In order to further identify the phase constituent of the coating, electron probe microprobe analyzer (EPMA, JXA-8100) was used to analyze the composition.

2.3. Fretting wear test

The micro-hardness ($HV_{0.3}$) along the depth direction on the cross-cut surface was measured by a HXD-1000 B microhardness tester with a load of 300 g and dwell time of 10 s. Before micro-hardness testing, the standard sample was used for calibration, and each value of the micro-hardness was the average value of three measurements.

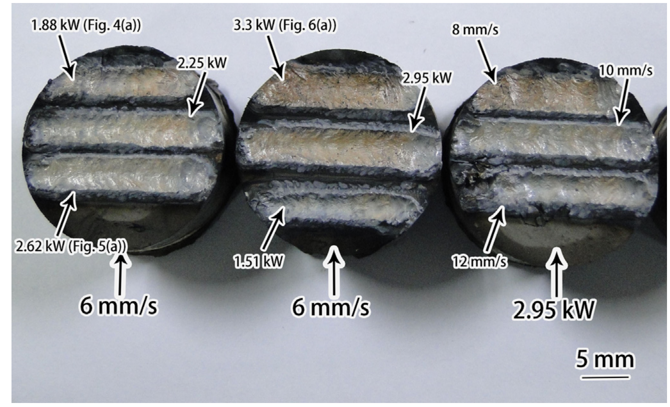

Fig. 2. Macroscopic morphology of single track coatings under different laser energies.

The fretting wear property was evaluated using a FTM 200 fretting wear tester, and the contact style of fretting wear was line-contact (cylinder/plane). The structural diagram of the tester was shown in Fig. 1, and the detailed material and measuring parameters were listed in Tables 1 and 2. In the following results analysis, the wear evaluation of Fig. 1 is to test the microstructure of Figs. 4(c)–6(c), and the wear volume is summarized in Fig. 12. The wear loss of the coating and the substrate was measured by Mahr-M1 profilometer. The wear volume was calculated by the equation below:

$$V = S \times A$$

where *V* is wear volume (mm^3); *S* is wear scar cross-sectional area (mm^2); *A* is displacement value (mm). Meanwhile, the wear scar morphology was observed by SEM. The crack propagation of the strengthening phase was observed by the Vickers indentation method, and the fault of TiB fiber was also observed by a JEM-2100 transmission electron microscopy (TEM).

3. Results and discussion

3.1. Macroscopic morphology of the coating

Fig. 2 shows the macroscopic morphology of the coatings under different laser energies. It can be found that the surface of all coatings is free from pores and cracks under various laser energies, but the smoothed surface of the coatings cannot be observed. The yellow of the surface of the coatings gradually becomes apparent and surface depression can be improved with increasing laser energy input. The reason is that TiB_2 has a high melting point and

Table 1
Parameters of Si_3N_4 material.

Cylindrical diameter (mm)	Cylindrical length (mm)	Cylindrical roughness (μm)	Elastic modulus (Kgf/cm^2)	Rupture tenacity MPa $m^{3/2}$	Hardness (HV)
6	10	< 0.8	300–320	4.5	1500–1800

Table 2
Measuring parameters of fretting wear test.

Temperature (°C)	Load (N)	Frequency (Hz)	Amplitude (μm)	Time (min)	Sample dimension (mm)
23–30	100	20	100	30	12 × 20 × 10