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Laser surface coating of Mo–WC metal matrix composite on Ti6Al4V alloy☆

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Abstract

Laser surface alloying of Mo, WC and Mo–WC powders on the surface of Ti6Al4V alloys using a 2 kW Nd-YAG laser was performed. The dilution effect upon the microstructure, microhardness and wear resistance of the surface metal matrix composite (MMC) coating was investigated. With a constant thickness of pre-placed powder, the dilution levels of the alloyed layers were found to increase with the incident laser power. The fabricated surface MMC layer was metallurgically bonded to the Ti6Al4V substrate. The microhardness of the fabricated surface layer was found to be inversely proportional to the dilution level. The EDAX and XRD spectra results show that new intermetallic compounds and alloy phases were formed in the MMC layer. With the existence of Mo content in the pre-placed powder, the β-phase of Ti in the MMC coating can be retained at the quenching process. With increasing weight percentage content of WC particles in the Mo–WC pre-pasted powder, the microhardness and sliding wear resistance of the laser surface coating were increased by 87% and 150 times, respectively, as compared with the Ti6Al4V alloy. The surface friction of the laser-fabricated MMC coatings was also decreased as compared with the worn Ti6Al4V substrate.

Keywords: Laser surface alloying; MMC; Titanium alloys; Wear resistance; Friction

1. Introduction

Titanium alloys have higher specific strength, stiffness, fatigue resistance and good high-temperature strength than other light metals such as magnesium and aluminum. They also have excellent corrosion resistance to seawater and aqueous chloride solution over a wide range of temperatures and concentrations. These superior properties made titanium alloys widely used for structural applications in the aircraft industry and gas turbine engine industry. For other industrial applications, titanium alloys can be used wherever mass effects must be reduced and high strength is needed.

However, all titanium alloys exhibit poor tribological characteristics, which include abrasion resistance, metal-to-metal wear resistance, and solid particle erosion and cavitations. These poor tribological properties have limited the applications of titanium alloys in many sliding components, tools and parts that are related to wear resistance [1–4]. The main reasons for such limitations are the low surface hardness and high friction coefficient of titanium alloys. In order to enhance the tribological performance of titanium, laser surface coating of a metal matrix composite (MMC) layer on the alloy is one of the advanced surfacing technologies that are being researched. Man et al. [4] investigated the formation mechanism of in situ synthesized TiC/Ti composite layer on the Ti6Al4V by laser cladding Cr_3C_2 and Ti powders. Zhang [5] studied the wear performance of TiC particle-reinforced composite coating on Ti6Al4V alloy. Weisheit and Mordike [6] investigated laser surface alloying of the ternary system Ti–V–C and Ti–Si–Mo for improving the surface wear resistance of the titanium alloys. Folkes and Shibata [7] investigated the microstructures of the laser-clad layer on Ti6Al4V using various weight percentages of different carbide pow-

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Table 1
The weight percentage content of the Mo and WC powders in PVA pre-placed coating

Specimen (in wt.%)						
	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 (%)
Mo	100	80	60	40	20	0
WC	0	20	40	60	80	100

Ø = 3 mm, speed = 25 mm/s, power = 1400 W.

ders. Furthermore, laser surface modification of NiCrBSiC, SiC, TiC + NiCrBSiC and TiN on titanium alloys [8–10] have also been investigated.

Molybdenum (Mo) is an important element that is usually used to produce high-temperature strength alloy. It has a higher melting point than titanium alloys and provides strength at elevated temperature. The thermal expansion coefficient of Mo is only about half that of the steel alloys, and the stiffness is greater than steel. It resists metal erosion better than steels do [11]. Furthermore, Mo is one of the effective elements that can stabilize the β-phase of the Ti [6] after the quenching process. The equilibrium solid phases [12] of the Ti–Mo system are (i) the bcc (β-Ti, Mo) solid solution, in which Ti and Mo are completely miscible above the transformation temperature of pure Ti (882 °C) and (ii) the cph (α-Ti) solid solution with restricted solubility of the Mo. The maximum solubility of Mo in (α-Ti) phase is 0.4% [12,13]. When the alloy contains more than 5–6% of Mo, the bcc phase (β-Ti + ω) can be retained completely during the quenching process.

Metal matrix composite layers consisting of tungsten carbide (WC) normally possess a high resistance for all type of wear [14]. WC has hardness up to 2200 Hv. The melting point of the WC is 2835 °C, which is higher than many other elements, and it shows good strength and is stable under high temperatures. With the characteristics of Mo and WC, it is expected that the formation of Mo–WC MMC composite coating on titanium alloy would improve the wear resistance of the alloy. This paper reports the investigations of laser surface coating of Mo–WC MMC layer on Ti6Al4V alloy and the subsequent friction characteristics and wear-resistant properties.

2. Experimental methods

The nominal chemical composition of the matrix alloy Ti6Al4V (wt.%) is: 6.01% Al, 3.84% V, 0.3% Fe, 0.15% Si, 0.1% C and Ti balance. The Ti6Al4V specimens were cut from a rolled slab into pieces of 30 mm × 15 mm × 5 mm, and then grounded, sandblasted, ultrasonic ally cleaned with acetone and rinsed with methanol. Different weight percentage of Mo and WC powders were mixed together to form powder mixtures according to Table 1. The particle sizes of the Mo and WC powders were about 38 and 64 μm, respectively. All the powder mixtures were then mixed with 4 wt.% polyvinyl alcohol (PVA) and pasted on the specimen's surface. In considering the laser power available and previous investigations [15], the thickness of the pre-placed powder was set at 0.3 mm, because effective melting with good level of dilution can be achieved at this thickness. All the specimens were placed in a furnace at 60 °C for 24 h to vaporize the water moisture in the pre-placed coatings.

A Lumonics 2 kW continuous wave (CW) Nd-YAG laser was used as the laser energy source, and a 200 mm focal length ZnSe lens was used for focusing the laser beam on the specimen. The diameter of laser beam at the specimen surface was set at 3 mm and a scanning speed was kept at 25 mm/s. In

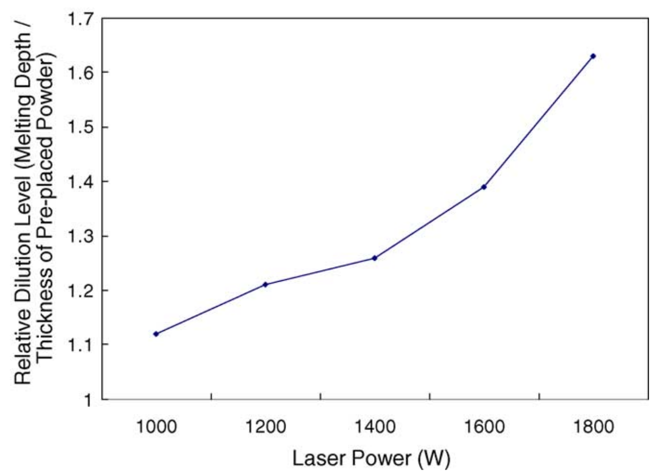

Fig. 1. Dilution level vs. laser power (powder composition as specimen 3, Ø = 3 mm, speed = 25 mm/s).

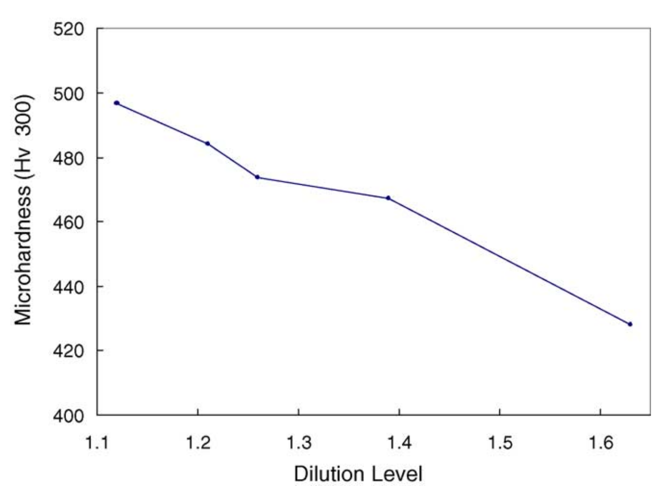

Fig. 2. Microhardness vs. dilution level of laser-fabricated layer (specimen details same as Fig. 1).