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Tribological properties of WC and CeO_2 particles reinforced in-situ synthesized NiAl matrix composite coatings at elevated temperature

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ABSTRACT

WC and CeO_2 particles reinforced in-situ synthesized NiAl matrix (WC/CeO_2/NiAl) composite coatings were prepared on aluminum alloys by laser surface alloying. The microstructure, microhardness and fracture toughness as well as the tribological properties at 25 °C and 400 °C of the composite coatings were investigated. The results show that the WC/CeO_2/NiAl composite coating contains the phases of NiAl, WC, W_2C, γ-(Fe,Ni), CrB, $Cr_{23}C_6$, Al_3Ni_2 and $CeNi_5$. Due to the synergistic strengthening effects of WC and CeO_2 particles, the average grain size of the composite coating is reduced, and the microhardness and fracture toughness are increased. The friction coefficient and wear loss of the composite coatings rise in ascending order with the temperature, which are smaller than those of the WC/NiAl composite coatings, the NiAl coatings and the substrates. As the temperature increases from 25 °C to 400 °C, the wear mechanisms of the composite coatings change from micro-cutting wear into multi-plastic deformation wear and slight oxidative wear.

1. Introduction

NiAl intermetallic compounds, as the high temperature coating materials, possess extensive application prospects in aerospace industry owing to their low density, high melting point, high thermal conductivity and excellent oxidation resistance. For example, the service life of the turbine guide blades coated by NiAl coatings can be obviously prolonged [1–6]. Recently, some researchers have found that NiAl intermetallic compounds also have good tribological properties, which exhibit the great potential to be used in severe wear conditions [7,8]. With the increasing use of aluminum alloys as friction parts in engineering fields, it is necessary to overcome their poor wear resistance for extending their service lives. Therefore, preparing NiAl intermetallic compound coatings with remarkable tribological properties on aluminum alloys may be an effective way for enhancing the antiwear property.

Laser surface alloying is an important surface engineering technology, which utilizes high-energy laser to irradiate and melt the precursor materials and substrate surface, and then form the alloyed coatings with metallurgical bonding interface, proper thickness and superb properties [9–11]. Therefore, the laser surface alloying coatings commonly have higher bonding strength with substrates than the coatings mechanically bonded with substrates. By now, the laser surface alloying NiAl coatings with refined microstructure and good mechanical behavior have been fabricated on steel or Ni-base alloy substrate [12–14], but little attention is paid to the preparation and tribological properties of NiAl coatings on aluminum alloys by laser surface alloying. To meet the needs of severe working conditions, more researches need to be done for further improving the wear resistance of NiAl coatings on aluminum alloys. It is reported that the addition of ceramic particles into NiAl matrix composites is helpful to obtain excellent comprehensive properties [15–18]. Among the ceramic particles, tungsten carbide (WC) is the most popularly used one due to its high hardness and excellent wear resistance [19,20]. Moreover, several works have proved that rare earth cerium oxide (CeO_2), with strong surface chemical activity, can improve the microstructure and properties of NiAl coatings [21–25]. It is clear that either WC or CeO_2 particles enable to strengthen the NiAl coatings, but little is known about the NiAl composite coatings reinforced by both WC and CeO_2 particles.

In this work, WC and CeO_2 particles were simultaneously used to reinforce the in-situ synthesized NiAl matrix (WC/CeO_2/NiAl) composite coatings by laser surface alloying. The microstructure, microhardness and fracture toughness of the composite coatings were studied. A detailed investigation was undertaken to research the tribological behavior and mechanisms of the composite coatings at room temperature of 25 °C and elevated temperature of 400 °C. The aim of this work is to research the synergistic strengthening effects of WC and CeO_2 particles on the microstructure and tribological properties of

Table 1
Chemical composition of alloyed composite materials.

Coating no.	Composition/wt.%		
	Ni-base alloy	WC particle	CeO_2 particle
A1	100	–	–
A2	80	20	–
A3	78	20	2

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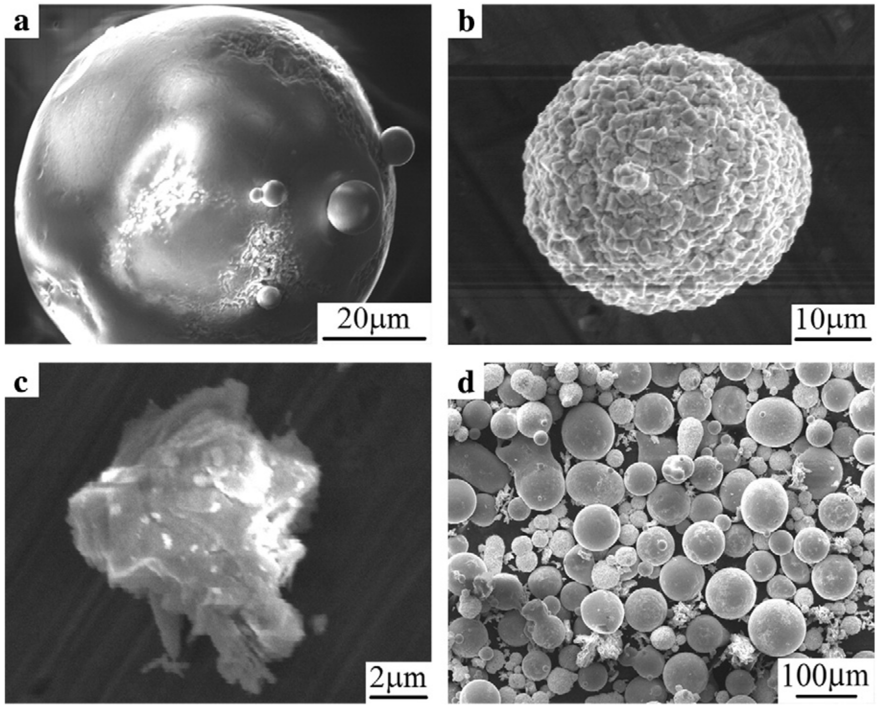

Fig. 1. SEM images of Ni-base alloy powder (a), WC particle (b), CeO_2 particle (c) and composite powder (d).

laser surface alloying NiAl matrix composite coatings on aluminum alloys, which are helpful to extend the applications of laser surface alloying composite coatings in various working environments.

2. Experimental

2.1. Specimen preparation

Laser surface alloying materials consisted of Ni-base alloy powder, WC and CeO_2 particles with the optimized ratios listed in Table 1 by previous experiments. The chemical composition of Ni-base alloy powder with the size distribution of 47–100 μm was 15.5Cr, 3.5B, 4.0Si, 15.0Fe, 3.0W, 0.8C and 58.2Ni in wt.%. Sintered WC particles, with the sizes in the range of 36–44 μm, were composed of 88%WC and 12%Co. Both the Ni-base alloy powder and WC particles were provided by Shanghai Dahao Company, China. Rare earth CeO_2 particles were 99.9% AR with the sizes of 8–12 μm (provided by Jiangxi Jiarun Company, China). Fig. 1 shows the SEM images of the laser surface alloying materials, from which different particles can be distinguished by morphology and particle size. Aluminum alloy 7005, with the chemical composition of 0.35Si, 0.4Fe, 0.1Cu, 0.2–0.7Mn, 1.0–1.8Mg, 0.06–0.20Cr, 4.0–5.0Zn, 0.08–0.20Zr, 0.01–0.06Ti and residue of Al (wt.%), was selected as substrates in the sizes of 50 × 50 × 6 mm.

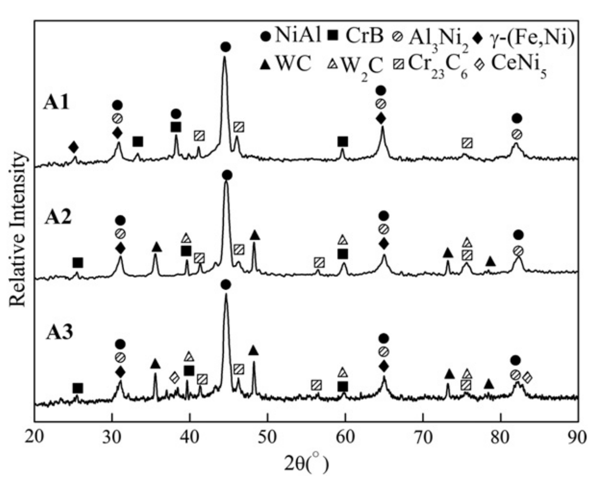

Fig. 2. XRD patterns of coatings A1, A2 and A3.

Prior to laser treatment, the substrates were grit blasted to the level of Sa 2.5 with a surface roughness of Ra = 25 μm to remove gross oxidation film, and then were cleaned by an ultrasonic cleaner filled with acetone to eliminate residual particles and greasy dirt. The composite powders were blended sufficiently using a QM-ISP planetary ball mill at a speed of 200 rpm for 2 h, and then were mixed with absolute ethanol binder to form a preplaced layer onto the substrate surface with an approximate thickness of 1 mm. After drying for 3 h at 25 °C, the specimens were treated by a CS-TEL-10 kW high power continuous CO_2 laser to prepare alloyed coatings. The processing parameters optimized via previous experiments were laser power of 1.5 kW, beam diameter of 4 mm, scanning speed of 6 $mm \cdot s^{-1}$ and overlapped rate of 40%. Argon was used as shielding gas at a flow rate of 18 $L \cdot min^{-1}$.

The laser surface alloying specimens were ground by silicon carbide abrasive paper and polished by diamond abrasive paste to a surface roughness of 0.5 μm, and then were incised into test pieces of 15 × 15 × 6 mm by wire-electrode for wear tests. Some pieces were etched by $FeCl_3$ + hydrochloric acid solution for 30 s to observe the microstructure.

2.2. Microstructure observation

A DMM-330C optical microscope (OM) and an XQUANTA200 scanning electronic microscope (SEM) with energy-dispersive analysis of X-rays (EDAX) were employed to observe microstructure and worn surface morphologies, test elemental composition and measure grain size and crack length. Phase composition was identified by an X'TRA X-ray diffractometer (XRD) with CuKα radiation scanning from 20° to 90° at a step size of $0.02° \cdot s^{-1}$. Microhardness was measured by a DHV-1000