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Effect of powders refinement on the tribological behavior of Ni-based composite coatings by laser cladding

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ABSTRACT

$NiCr+Cr_3C_2+Ag+BaF_2/CaF_2$ composite coatings were produced on stainless steel (1Cr18Ni9Ti) substrates by laser cladding. Corresponding powders were prepared by high-energy ball milling technique. The friction and wear behavior at room temperature was investigated through sliding against the Si_3N_4 ball. The morphologies of the wear debris, worn surfaces of both samples and the Si_3N_4 ball were analyzed by scanning electron microscopy and three dimensional non-contact surface mapping. Results showed that milling time had a great effect on the size, morphology, uniformity of the powders as well as the microstructure and properties of laser cladding coatings. The wear mechanism of the coatings is dominated by abrasive wear, plastic deformation and slight adhesive wear. The consecutive evolution trend of friction coefficient, wear rate as well as microhardness of the serials of coatings produced with powders of different sizes was presented.

1. Introduction

As one of the most promising materials, Ni-based composite coatings are well known for their various properties such as high bonding strength, excellent corrosion and wear resistance [1]. PS212 and PS304 developed by NASA are typical examples, which are popular in turbomachinery applications. These composite coatings are originally prepared by plasma spray. Coatings produced by this method usually consist of porous microstructure and low cohesive strength, thus the true contact area only occupies a little portion of the nominal one [2]. This causes a reduction in the hardness and bonding strength of the coatings [3]. Fortunately, these disadvantages can be overcome by an advanced surface modification technology-laser cladding, which uses a high power laser beam to form a coating metallurgically bonded to the substrate [4]. In addition, Wang et al. [5] pointed out that besides metal matrix, friction/wear behavior of the composite coatings is also determined by the type, volume content, size and distribution of lubricants. Thus feeding some lubricants with appropriate content and sizes into Ni-based powders to improve the self-lubricating properties of the composite coatings arouses great interest. For example, Ding et al. [6] have done some researches on the distribution of lubricants and variation of sizes during different ball-milling time, and concluded that tensile strength and crack-growth resistance increased with the refinement of self-lubricating phases in PM304 as compared with PS304. Numerous other investigations have also been made on the friction and wear behavior of Ni-based composite coatings composed of different lubricants by laser cladding, like Ni_3Al–h-BN–Ag composite coating, Ni-based WS_2 self-lubricating composite coating, h-BN/Ni coating and MoS_2/Ni-based solid self-lubrication coating [7–10]. However, few researches are absorbed in the continuous varying process with the refinement of powders, especially the evolution of friction and wear behaviors of different coatings. Since most tribological components not only have to offer excellent friction and wear properties at high temperature, but also have to operate at a relatively low temperature range during the start and shut-up cycles [11], the research on the tribological properties at lower temperature is of great importance. Thus this work aims at probing into the continuously evolutive friction and wear mechanism of Ni-based laser cladding coatings under room temperature with powders pre-milled for different time via high-energy ball milling technique.

2. Experimental details

As-received stainless steel (1Cr18Ni9Ti) blocks (25 mm in diameter, 20 mm in thickness) were used as substrates. Prior to coating preparation, the substrates were sand blasted. Pre-heated and post-annealed treatments were both practiced at 500 °C to decrease the residual stress during laser cladding treatment. The mixed powders of NiCr (27 wt.%, grit size 45–105 μm), Cr_3C_2 coated with NiCr (43 wt.%, grit size 45–105 μm), Ag (15 wt.%), BaF_2/CaF_2 (15 wt.%)

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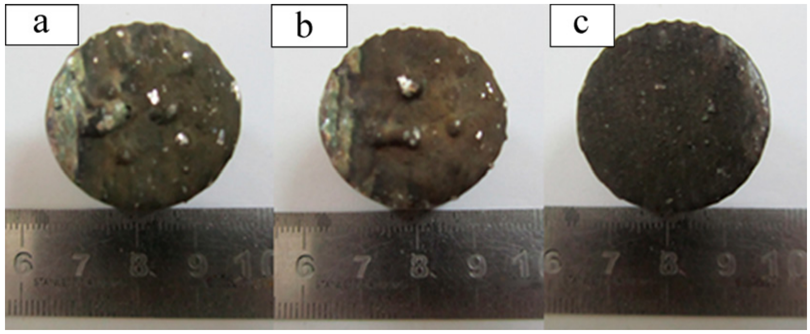

Fig. 1. Optical surface morphologies of the composite coatings prepared under scan speed, (a) 500 mm/min, (b) 1000 mm/min, (c) 1500 mm/min, at a laser power of 1.5 kW.

were employed as coating materials, and were pre-placed onto the substrates at a thickness of approximately 1.2 mm without a binder. The powders were first ball-milled in the air atmosphere using a high-energy vario-planetary ball mill (Fritsch Pulverisette P-4) with tungsten carbide vials and balls. The ratio of ball to powders was 4:1 in weight and the rotation speed of vial was 1200 rpm. The composite powders with different ball-milling time were scattered in ethanol and then the particle sizes were tested by Zetasizer Nano 3600 laser dynamic light scattering instrument. A 10 kW transverse-flow continuous-wave CO_2 laser connected to a computer for numerical controlling was used as the energy source for laser cladding. The laser processing parameters were selected as laser power of 1.0–2.0 kW, beam traverse speed of 500–1500 mm/min, beam diameter of 2 mm, and overlapped tracks of 50%. Laser processing was conducted in argon shielding gas at a pressure of 0.1 MPa. After laser treatment, the coatings with optimized processing parameters were selected and ground with nos. 320, 800, 1500, 2000 SiC abrasive papers and mechanically polished for further tests. The phase composition of powders and coatings was investigated by a D/Max-2400 X-ray diffractometer (XRD, 40 kV, 100 mA, Cu-Kα radiation; scanning within $2\theta = 20–90^\circ$). The microstructure of both powders and coatings as well as the distribution of components were identified by scan electron microscope (SEM, JEOL JSM-5600LV) equipped with energy-dispersive spectrometer (EDS, KEVEX) and field emission scanning electron microscope (HITACHIS4800). The samples for SEM observation were prepared through mechanical polishing and the following etching in aqua regia. The hardness profile along the cross-section was tested by an MH-5 Vickers microhardness tester at a load of 0.49 N and dwell time of 5 s. A THT01-03951 (CSM, Switzerland) ball-on-disk tribometer was used to evaluate the dry sliding friction and wear behavior. The disc was the specimen, while the counterpart ball was made of Si_3N_4 ceramic (hardness of 1700 HV, diameter of 6 mm). The sliding tests were carried out with a normal load of 10 N, a constant sliding speed of 0.21 m/s, and a sliding distance of 300 m. The friction coefficient was recorded by the computer connected to the tester. The wear volume, wear surface of the specimens as well as the wear scar of the Si_3N_4 ball were determined by a MicroXAM 3D non-contact surface mapping profiler (ADE Corporation, Massachusetts, USA). Each test was repeated for three times. The elemental composition of the worn surfaces and the wear debris were investigated by energy-dispersive spectrometer.

3. Results and discussion

3.1. Effect of laser power and scan speed on the surface appearance of the coatings

Figs. 1 and 2 show the surface morphologies of the composite coatings fabricated with powders pre-milled for 12 h at different laser processing parameters. Before polishing, rippling waves can be seen on the coatings' surface. The coating surface tends to be overburned with laser power decreasing from 1500 mm/min to 500 mm/min at a laser power of 1.5 kW. Similar trend is reached with laser power increasing from 1.5 kW to 2 kW at a scan speed of 1500 mm/min, and the surface is rougher with laser power lower than 1.5 kW. The rough surface with low laser power can be attributed to that the matrix is not melted enough, or the convective flow and surface tension gradient in the molten laser pool is strong [12]. These results indicate that the laser energy density shows great influence on the surface morphology of the composite coatings. The optimized laser processing parameters are selected as laser power of 1.5 kW, scan speed of 1500 mm/min.

3.2. Evolution of size and distribution of the composite powders

Fig. 3 shows the morphologies of the composite powders after different ball-milling time. It can be seen that the powders are prone to be refined first and then congregate into composite agglomerate with the prolonging of milling time. This can be

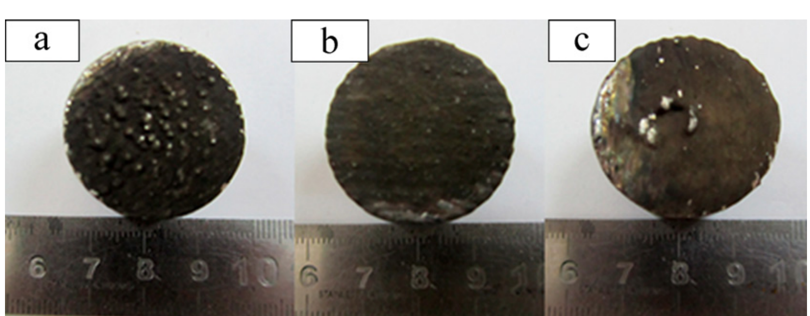

Fig. 2. Optical surface morphologies of the composite coatings prepared under laser power, (a) 1.0 kW, (b) 1.5 kW, (c) 2.0 kW, at a scan speed of 1500 mm/min.