Surface & Coatings Technology 304 (2016) 283–292

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Wear resistance of diode laser-clad Ni/WC composite coatings at different temperatures

Zhikun Weng [a], Aihua Wang [a,*], Xuhao Wu [b], Yuying Wang [a], Zhixiang Yang [a]

[a] State Key Laboratory of Material Processing and Die and Mould Technology, School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan, 430074, PR China

[b] Ruian Demonstration Center for Laser Application, Ruian 325207, PR China

ARTICLE INFO

Article history:
Received 21 February 2016
Revised 27 June 2016
Accepted in revised form 29 June 2016
Available online 01 July 2016

Keywords:
Laser cladding
Ni/WC composite coatings
Wear resistance
High temperature
Oxidation film

ABSTRACT

Ni/WC composite coatings with different weight percentage (0–60%) of WC particle were produced on a stainless steel by diode laser-cladding technology with the aim to improve wear resistance of the stainless steel in the present study. The effects of laser power, WC particle content and rare earth element (La) on the quality of the coatings were investigated. The influences of WC content on microstructure and hardness were investigated. The friction and wear behavior of the laser-clad coatings at room temperature and elevated temperatures of 600 °C and 700 °C were evaluated using a ring-on-block tribometer. Results revealed that the laser-clad composite coatings with WC content ranging from 20 wt.% to 60 wt.% were free of cracks and pores by controlling laser power level and adding 0.4 wt.% La. An increase in WC content increases wear resistance significantly at three test temperatures except for the Ni-20% WC coating. The phase structure of the oxidation films formed during the wear test process played important role on the wear behavior of the laser-clad coatings.

1. Introduction

Nickel-based alloys are widely used in the severe environment suffering from high temperature, wear, corrosion, impact and fatigue for its high wear resistance and corrosion resistance. However, single nickel-based alloys are hard to meet the requirements of the work piece under severe conditions. Composite coatings consisting of metallic matrix and reinforcement possess comprehensive properties, which have been widely employed to improve the lifetime of components such as roller, wearing plates, piston rods and turbines. The wear resistance of the Ni-based alloy coatings can be increased by the addition of hard ceramic particles such as WC, TiC and VC [1,2]. Tungsten carbide (WC) has been extensively used as a reinforcement in Ni-based alloys for its good wettability with Ni, high hardness (2500 ~ 2700 HV) and high wear resistance. Laser cladding has been an effective approach to build a metal matrix composite coating. However, good quality of metal-ceramic composite coating without any defects such as pores and cracks is hard to achieve for the different properties between metal matrix and reinforcement, and the heat damage of WC particle during laser cladding [3]. Other authors have studied that the pores formed in the coatings are mainly resulted from dissolution of WC particles [4] and gas trapping due to large fluid viscosity induced by WC particles in the melt pool [5]. Pores in the coating are increased with the increase in laser power and high laser power can reduce the WC content in the coating [6]. Furthermore, many methods have been put forward to eliminate the cracks in the composite coating during laser cladding, such as preheating the substrate [7], functionally graded coating [8], adding the rare earth or nano-particles [9] and the laser induction hybrid rapid cladding [3]. Some alloy elements such as Cr have an obvious effect to cracking sensitivity [10].

Recently, various investigators have put to developing different methods to improve the quality of the Ni/WC composite coating. Farahmand et al. reported laser cladding of Ni-60%WC composites using a diode laser with induction heating and the addition of nano-WC and La_2O_3, the composite coatings without any defects possess good mechanical properties in this study [9]. Tobar et al. investigated laser cladding of NiCrBSi–WC composite coatings on stainless steel using a 2.2 kW industrial CO_2 laser and results showed that dense and pore free layers could be obtained as far as the WC content was maintained below 50 wt.% [11]. Zhou et al. achieved the NiCrBSi + 35 wt.%WC composite coatings free of cracks and pores produced by laser induction hybrid rapid cladding [12].

There are plenty of scientific investigations containing information about wear resistance of laser-clad Ni/WC composite coatings. However, most of the investigations were concentrated on the friction and wear behavior of the coatings at room temperature. Huang et al. investigated the abrasive wear performance of laser-clad WC/Ni layers produced on H13 tool steel substrates with a pulsed Nd:YAG laser, the abrasive wear performance of the layers was 5–10 times higher than that of the substrate [13]. Fretting and wear behaviors of Ni/nano-WC

* Corresponding author at: School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan, 430074, PR China.
E-mail address: ahwang@mail.hust.edu.cn (A. Wang).

http://dx.doi.org/10.1016/j.surfcoat.2016.06.081
0257-8972/

composite coatings in dry and wet conditions were studied by Benea, results showed that the Ni/nano-WC coatings have higher nanohardness and wear resistance in dry and wet conditions as compared with pure Ni coatings [14]. Guo et al. investigated the wear resistance of NiCrBSi and NiCrBSi/WC–Ni composite coatings at 500 °C, they found that the NiCrBSi/WC–Ni composite coating showed better high temperature wear resistance than NiCrBSi coating and the composite coating only experienced mild abrasive and fatigue wear when sliding against the ceramic counterpart [15]. Xu et al. have found that the wear resistance of Ni/WC composite coating is strongly dependent on the content of WC and microstructure of the coating and a defined amount of WC in the coating can possess a best wear resistance [16]. The excellent wear resistance of the WC/Ni composite coating is the combined result of the touch Ni-based matrix, the distribution of the WC particles and the good bonding between the WC particles and the matrix [17]. So far, few publications are currently available about the wear behavior of the laser-clad Ni/WC composite coatings with different content of WC, in particular, at different test temperatures.

Therefore, the aim of this article was to investigate the influences of laser power, WC content and the addition of element La on the macroquality, microstructure and hardness of the laser-clad composite coatings. Furthermore, the effect of temperature on the wear behavior of the composite coatings was investigated.

2. Materials and experimental procedure

In this experiment, an austenitic stainless steel AISI 304 with the dimension of 200 mm × 150 mm × 12 mm was used as the substrate. The clad material used in this study was a mixture of a Ni-based self-fluxing powder (see Table 1) and a crushed WC powder. The size of the powder particles was in the range of 80 μm–100 μm for the Ni-based alloy and 45 μm–100 μm for the WC powder.

Four different mixed powders with the WC contents of 0, 20, 40 and 60 wt.% were performed in the experiments. The substrate surfaces were polished with sand paper and cleaned with acetone before the experiments.

Laser cladding was carried out using a 3 kW high-power diode laser (DILAS SD3000/S) with 980 ± 10 nm wavelength. An off-axial auto-feeding powder equipment was used as the powder feeder and the lateral nozzle was kept at an angle of 45° to the horizontal. Both the laser and the nozzle were fixed to a 6-axis KUKA robot system. Finally, argon gas was used as shielding and powder carrying gas. Laser processing parameters used in the experiments included the following: laser power (P) was in the range of 1.3–1.9 kW at a scanning speed (V_s) of 11 mm/s, the laser spot diameter was kept constant at 5 mm. Using these parameters power densities and interaction time between 66.2 and 96.8 W/mm^2 and 0.45 s, respectively, were achieved. The powder delivery velocity (V_p) was set at 25–26.5 g/min. A 50% overlap ratio was used for multi-track laser cladding. Prior to cladding, the substrate was preheated to 300 °C to reduce thermal stress and then to avoid cracking of the laser-clad coatings.

After laser cladding, a liquid dye penetrant testing was used to detect the crack presence in the clad area. The transverse cross sections of each laser-clad coating were prepared for the microstructure analysis. The cross-sectional samples were polished and etched by 75% HCL and 25% HNO_3 to reveal the microstructure of the coating. Microstructure characterization was analyzed using an optical microscopy (XJL-03) and environmental scanning electron microscope (ESEM Quanta 200 with EDX microanalysis system equipped with light elements). The phase structures of the laser-clad coatings were analyzed by X-ray diffraction using Cu-K_α radiation at 40 kV and 30 mA (XRD-7000S).

Microhardness of the coatings was measured using a Vickers-1000 tester, with 12 s dwelling time and under load of 200 g. The average hardness of the coatings was measured using a Rockwell hardness tester. Friction and wear behavior of the laser-clad coatings were evaluated using an MM-U10G ring-on-block wear tester at room temperature, 600 °C and 700 °C. Fig. 1 shows the scheme of MM-U10G wear tester. The sliding was performed at laser-clad coating block (with dimension of 30 mm × 30 mm × 12 mm) sliding against the Ni-60% WC laser-clad composite coating ring. The sliding tests were carried out under applied loads of 200 N, rotated at 50 rpm and 180 min application time in air. The friction coefficient was continuously recorded by the computer connected to the tester. Prior to sliding test, the specimens were all ground and polished by a grinder and then washed in acetone. The wear mass loss of the samples was determined by an electronic analytical balance with an accuracy of 0.1 mg. The worn surfaces were analyzed using SEM and color 3D violet laser scanning microscope (VK-×1000). Oxide phases formed after high temperature wear test were conducted by Raman spectroscopy using a LabRAM HR800 Raman spectrometer with a laser wavelength of 532 nm. The spectra were measured in the range 100–1600 cm^{-1} with a laser power of 50 mW.

Table 1
Composition (in wt.%) of the Ni-based alloy powder.

Elements	C	Cr	Fe	Ni	Mo	Si	Co
Ni	0.3	4.0	6.6	bal.	0.1	3.2	0.1

3. Results

3.1. Effect of power density and WC content on the quality of the laser-clad coatings

The cross-sectional micrographs of the laser-clad Ni-60%WC coatings produced at laser power density ranging from 66.2 W/mm^2 to 96.8 W/mm^2 are shown in Fig. 2. With the increase of laser power density to a higher value, the porosity of the composite coatings increases clearly. The pores in the clad coatings tend to concentrate at the overlapped zone where less WC particles are distributed, and the amount of WC particles decreases significantly when the power density increases from 66.2 W/mm^2 to 96.8 W/mm^2. Sound laser-clad coatings without any cracks and obvious pores could be produced at power density 66.2 W/mm^2 and preheating temperature 300 °C, as shown in Fig. 2(a) and Fig. 3.

Fig. 4 shows the cross-sectional micrographs of the laser-clad coatings with different WC content (0, 20, 40 and 60 wt.%). It can be seen that no cracks are observed through the laser-clad coatings, the crushed WC particles are distributed homogenously with the appropriate laser power and scanning velocity. Most of the WC particles remain in their

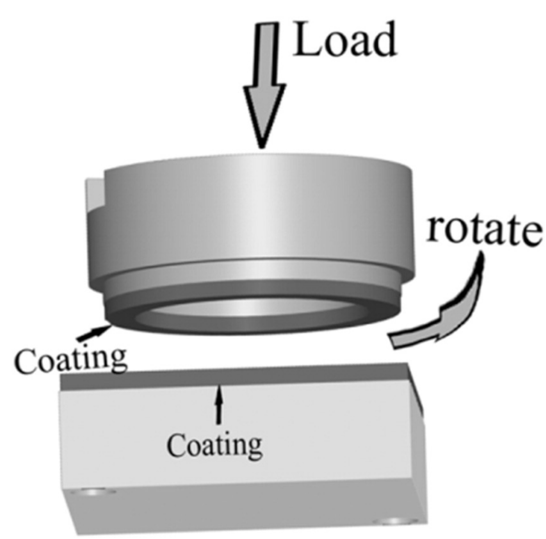

Fig. 1. Schematic illustration of the wear test.