Surface & Coatings Technology 239 (2014) 102–107

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Laser cladding in-situ NbC particle reinforced Fe-based composite coatings with rare earth oxide addition

Qingtang Li *, Yongping Lei *, Hanguang Fu

School of Materials Science Engineering, Beijing University of Technology, Beijing 100124, P. R. China

ARTICLE INFO

Article history:
Received 31 March 2013
Accepted in revised form 12 November 2013
Available online 21 November 2013

Keywords:
Laser cladding
Composite coating
In situ
Niobium carbide
Rare earth oxide

ABSTRACT

Over the past decade, researchers have demonstrated much interest in laser cladded metal matrix composite coatings for its good wear resistance, corrosion resistance and high temperature properties. The effects of RE on the microstructure and properties of laser coatings have also got more and more attention. In this paper, in situ Fe-NbC composite coatings with different CeO_2 addition were produced on die steel by laser cladding. The formation mechanism of NbC particles was analyzed. The effects of RE on microstructure and micro-hardness of coatings were investigated. It was revealed that larger NbC particles with hard edges formed around Nb particles, and smaller flocculent NbC particles formed by the chemical reaction of Nb and solid graphite in the molten pool. CeO_2 plays important roles in reducing micro-porosities, refining grains, and improving the precipitation of NbC. Therefore, the average micro-hardness and its smoothness from the top to the bottom of the coating were improved after adding CeO_2.

1. Introduction

In the process of automobile structure production, die steel suffers serious damage, such as wear, squeeze and fatigue rupture, etc. It is very necessary to improve the mechanical properties of die steel surface to lengthen the service life and save the production cost. Laser cladding metal matrix composite (MMC) coating, which is widely used in surface modification of steel materials, possesses excellent characteristics, such as good adhesion, fine microstructure, small heat-affected zone, high hardness and outstanding wear resistance [1,2]. For these advantages, it is feasible to repair die steel using laser cladding MMC coating. At present, the reinforcing phases in the composite coating are mainly TiC, WC, ZrC, etc. For examples, Yang et al. [3] prepared the Ni-based coating reinforced with in-situ TiC particles by laser cladding. The coating was uniform, continuous and free from cracks. The microstructure was mainly composed of Ni dendrites, a small amount of CrB, TiB_2, $M_{23}C_6$ and evenly distributed TiC particles. The maximum micro-hardness of the coating was about 1100 $HV_{0.2}$, which was 4.5 times larger than that of the steel substrate. Guo et al. [4] investigated the effects of WC content on the microstructure and tribological properties of NiCrBSi/WC laser coatings. It has been found that the micro-hardness and wear resistance of the Ni-based alloy coatings increased after adding the WC particles, due to the reinforcement of hard WC phase. Wu et al. [5] fabricated Fe-based composite coatings reinforced by in situ synthesized particles by laser melting a precursor mixture of Fe based alloy powders including Ti, Zr and graphite. The microstructure of the coating was typically hypo-eutectic, which consisted of martensite, residual austenite, ledeburite and dispersed in situ carbide particles. The experimental results showed that the volume fraction of particles in the coating containing both Zr and Ti, which was favorable to form multiple carbides particles, was higher compared with those containing either of them.

As a common hard alloy additive, NbC possesses high hardness (>2400 kg/mm^2) and high melting point (2537 K)[6]. For these advantages, NbC has been added in MMC laser coatings as reinforcement particles. For example, colaço and vilar[7] investigated the microstructure and wear resistance of the Fe–Cr–C/NbC laser coating. The results showed that the wear resistance of coatings present a non-monotonous variation showing a maximum for a volume fraction of reinforcement particles between 20% and 30%.

Rare earth (RE) elements possess excellent physical and chemical characteristics due to their particular atomic structure and outstanding chemical appetence. They have been applied successfully in many fields, such as metallurgy, electronics and chemical engineering [8]. One of their important applications is to modify the surface properties of engineering components. In recent years, RE elements are gradually introduced to the area of laser surface treatments. Wang [9] investigated the effects of CeO_2 nanoparticles on microstructure and properties of laser cladded NiCoCrAlY coatings. The results showed that the microstructure of cladding layer was refined, and the solid solubility of Cr in the Ni matrix increased. These changes of microstructure after adding nano-CeO_2p improved the micro-hardness and the thermal shock resistance. Liu et al. [10] investigated the effects of La_2O_3 on the microstructure and the wear properties of $Ni/Cr_7C_3/TiC$ composite laser coatings. The results revealed that the La_2O_3 particles can refine and purify the microstructure of coatings, relatively decrease the volume fraction of

* Corresponding authors at: Number 100, Pingle Garden, Chaoyang District, Beijing 100124, P. R. China. Tel.: +86 10 67391759; fax: +86 10 67396093.
E-mail addresses: liqingtang123@126.com (Q. Li), yplei@bjut.edu.cn (Y. Lei).

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http://dx.doi.org/10.1016/j.surfcoat.2013.11.026

Table 1
Compositions of the substrate (wt.%).

C	Si	Mn	S	P	Cr	Ni	Cu	V	Mo
1.45	≤0.40	≤0.40	≤0.03	≤0.03	11.00–12.50	≤0.25	≤0.30	0.15–0.30	0.40–0.60

primary blocky Cr_7C_3 to Cr_7C_3/Ni eutectics, reduce the dilution of cladding material from base alloy and increase the micro-hardness of the coatings.

The focus of the current work is to understand the formation mechanism of NbC and the effects of CeO_2 on the microstructure and mechanical properties of Fe-based laser coatings on the basis of previous research results.

2. Experimental details

2.1. Materials

A high carbon steel plate with the dimension of 100 × 50 × 12 mm, which is widely used as automobile die steel, was used as the substrate, whose nominal composition is listed in Table 1. The surface of the substrates was polished and rinsed with acetone prior to cladding. A mixture of FeCrBSi alloy powder (140–325mesh), graphite (300mesh) and niobium-iron alloy powder (300mesh) was used in this study. CeO_2 powder was added into the mixture with different mass fractions. The compositions of the alloy mixture and the cladding powders are listed in Tables 2 and 3, respectively.

2.2. Laser process

An IPG fiber laser system with a maximum power of 6 kW was used to produce a single clad track. The laser beam spot was fixed to a 5 × 5 mm square spot. The laser head was integrated with an ABB robot. DPSF-2 powder feeding system and a coaxial nozzle were used to feed the cladding powders into the molten pool by argon gas. Meanwhile, high-purity argon shielding gas was supplied through the same coaxial nozzle to protect the molten pool. The detailed processing parameters are listed in Table 4.

2.3. Characterization

The specimen with the dimension of 10 × 10 × 10 mm was sectioned along the clad track. A metallographic cross-section of the coating was mounted and etched with a solution of HNO_3 and alcohol for the examination. The phase identification of coatings was carried out on a Shimadzu XRD-7000 x-ray diffractometer with CuKα radiation operating at 40 kV. The microstructure characterization of coatings was performed with a OLYMPUS BX51 optical microscope and S-3400 scanning electron microscope equipped with a energy-dispersive spectroscopy (EDS). The micro-hardness was measured with a load of 200 g using a HX-200 micro hardness tester.

Table 2
Compositions of the alloy mixture(wt.%).

Nb	Cr	B	Si	C	Fe
10	15	1.62	1.5	3.5	bal

Table 3
Compositions of the cladding powders (wt.%).

	Fe-based alloy	CeO_2
No. 1	100	0
No. 2	98	2
No. 3	96	4

Table 4
Laser processing parameters.

Power/kW	Scanning velocity/mm/s	Beam size/mm	Powder feeding rate/g min^{-1}	Carrier gas flow/L min^{-1}	Shielding gas flow/L min^{-1}
1.8	4	5 × 5	10	10	10

3. Results

3.1. Phase structure of coatings

The XRD spectrums for three samples are shown in Fig. 1. It is found that α-Fe, Fe_3C, γ-Fe and NbC exist in all coatings, which means that the NbC particles can be in-situ formed. No CeO_2, cerium compound or new generated phase is observed after adding CeO_2. This phenomenon might be caused by the small addition of CeO_2. Fig. 2 reveals that the diffraction

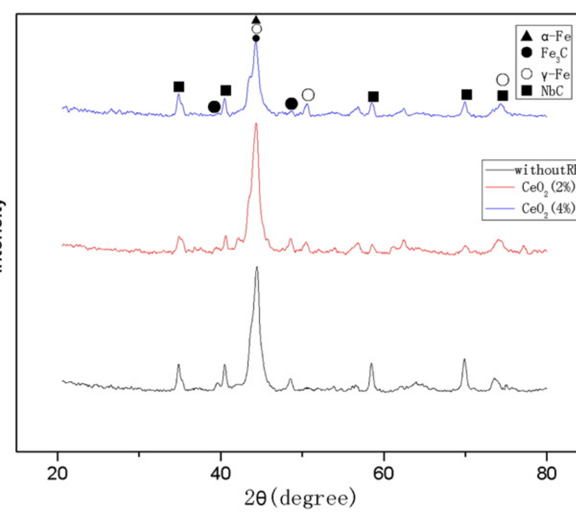

Fig. 1. XRD results of laser coatings.

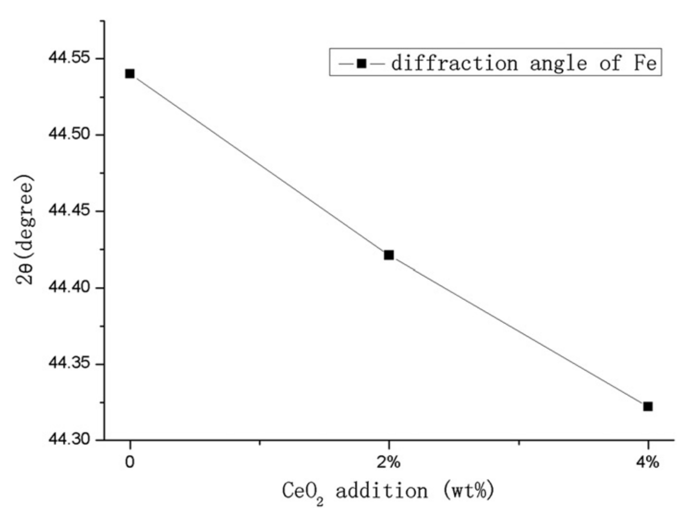

Fig. 2. Effect of CeO_2 on the diffraction angle of Fe.