Optics and Laser Technology 105 (2018) 58–65

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Phase evolution and wear resistance of in situ synthesized V_8C_7 particles reinforced Fe-based coating by laser cladding

C. Wang [a], S. Zhang [a,*], C.H. Zhang [a], C.L. Wu [a], J.B. Zhang [b], Adil O. Abdullah [c]

[a] School of Materials Science and Engineering, Shenyang University of Technology, Shenyang 110870, Liaoning, PR China
[b] Shenyang Dalu Laser Technology CO., LTD, Shenyang 110136, Liaoning, PR China
[c] School of Stomatology, China Medical University, Shenyang 110002, Liaoning, PR China

ARTICLE INFO

Article history:
Received 22 October 2017
Received in revised form 8 January 2018
Accepted 12 February 2018

Keywords:
Laser cladding
In situ synthesis
Fe-based coating
V_8C_7
Wear resistance

ABSTRACT

In situ synthesized V_8C_7 reinforced Fe-based composite coating was successfully prepared on 35CrMo steel by laser cladding, aiming at improving the wear resistance. Constituent phases, microstructure, microhardness and wear resistance of the coating were investigated using XRD, SEM, microhardness tester and friction-wear tester. The results showed that the obtained coating was uniform and dense with no pores or cracks appearing, in addition to satisfied metallurgical bonding to the substrate. The coating was mainly composed of α-Fe, V_8C_7, Cr_7C_3, Fe_3C and Mo_2C phase. Fine V_8C_7 reinforced particles were in situ synthesized during the melting process. The shape of V_8C_7 particles changed from sphere to irregular blocks as a distance from the interface, which was due to the crash and binding of V_8C_7 particles with each other. The microhardness of coating was 775 $HV_{0.3}$, which was about 4 times greater than the substrate. The wear resistance of the coating was significantly improved as indicated by the higher relative wear resistance.

1. Introduction

35 CrMo is widely used in machinery manufacturing, automotive and petrochemical industry because of its excellent impact toughness, fatigue strength and in a series of the heavy loaded environments, such as impactive and flexural-torsional working environments. However, due to the low hardness about 200 HV, 35 CrMo has relatively low wear resistance, and its applications are limited to some extend, particularly, in environments where the friction and wear at the surface of materials is present. In general, most of the outstanding properties, such as wear and corrosion resistances are surface properties rather than bulk properties. Therefore, surface modification technology provided a solution to the problem which could yield a reasonable combination of surface and bulk properties, while consuming only a small amount of expensive elements to improve the alloy properties [1,2]. Among various surface modification engineerings, laser cladding technique is one of the attractive tools because of its unique features such as low dilute rate, small heat affected zone, and good metallurgical bonding between the coating and the substrate [3,4]. For instance, the diamond tools with different matrices (Ni-, Co-, Fe- and Ti-based) produced by laser cladding were investigated by Rommel et al. [5,6]. They studied the interfacial reactions of diamond and molten metal in detail and the fact that the distribution of the diamond was related to the matrix material was revealed. During the laser cladding, alloy powder could be heated to melt and then rapidly solidified, which contributes to the formation of non-equilibrium phases and homogeneity in microstructures and more [7,8]. Previous studies showed that Ni- and Co-based coatings have been widely investigated. Janicki et al. [9] have successfully deposited Inconel 625-based composite coatings reinforced by porous Cr_3C_2 on AISI 304 plate by laser cladding to improve the erosion resistance. They found that the Cr_7C_3 phase was in situ synthesized and the reinforcing particles (chromium carbides) were uniformly distributed throughout the matrix and porous structure of the chromium carbides had been completely infiltrated by the liquid alloy matrix in the molten pool. The composite coating exhibited notably higher erosion resistance than metallic coatings (even 3 times) at both 30° and 90° impact angles because the reinforced particles acted as the skeleton which possessed the ability to absorb the kinetic energy of the impacting erodent particles than non-porous (solid) ones. In addition, an excellent mechanical interlocking with the matrix could be provided by the complex shape of the carbide skeleton, leading to an improved erosion resistance of the coating. Guo et al. [10] have successfully prepared Co-based composite coating on the single wheel or rail material by laser cladding to improve the surface

* Corresponding author.
E-mail address: songzhang_sy@163.com (S. Zhang).

https://doi.org/10.1016/j.optlastec.2018.02.019
0030-3992/

properties. However the hardness of the coating was only 438 $HV_{0.5}$, just about 1.5 times that of the substrate (283 $HV_{0.5}$). In general, the application of the Ni- and Co-based alloy powder is limited due to their expensive cost and lower hardness. Therefore, laser-clad Fe-based alloy becomes an attractive way because of the low cost and a changeable surface mechanical properties by adjusting the volume fraction of various component phases (ferrite, austenite, and martensite). Nevertheless, Fe-based alloy still suffers from severe friction and wear due to the relatively low hardness. For example, Wen et al. [11] produced Fe-based coating by laser hot wire cladding to repairing martensite precipitation hardening stainless steel. However, the hardness of the Fe-based coating was only ~300 HV. Hence, particulate-reinforced Fe-based alloy composite can be adopted to overcome this problem. Ceramic particles are a promising candidate for wear-resistant components because of its high hardness, high stiffness and optimum chemical and mechanical stability [12–14]. Particle reinforced Fe-based coating was prepared successfully by laser cladding by El-Labban et al. [15] and Zhang et al. [16], respectively. However, the reinforced phase particles were added into the coating directly, which leaded to the interface between reinforced phase particles and matrix was unstable and easy to be contaminated due to the poor wettability between them [17–19]. As a consequence, conventional methods in the fabrication of vanadium carbide reinforced Fe-based composite possess certain degree of difficulty. These difficulties, however, can be avoided if the Fe-based composite can be synthesized in situ. In situ synthesis utilizes a chemical reaction among the elements to form reinforced phases, such as vanadium and titanium carbide particles, which can contribute to achieving a clean interface with good bonding strength [20], with the fine ceramic particles which uniformly dispersed in the matrix. Recently, the composite coating reinforced by V_8C_7 with many favorable properties, such as high hardness, high melting temperature (2810 °C [21]), low heat conductivity and accepted wettability and a small contact angle with the iron matrix [22,23] has been investigated widely. Wang et al. [24] prepared successfully the V_8C_7/Fe-based composite by the cast-penetrated-heat treatment process on the surface of iron base composite material. This particular study revealed that the maximum hardness of V_8C_7 composite was 2333 $HV_{0.05}$ and the wear resistance of the composite was about 13 times compared with that of grey cast iron. The microstructure, wear and oxidation resistance of the in situ synthesized $Nb_2(C, N)$ and V_8C_7 particulates reinforced Fe-based composite coating by laser cladding was investigated by Li et al. [25]. They reported that the microstructure of the composite coating consist of α-Fe, γ-Fe phase, $Nb_2(C, N)$ and V_8C_7. The wear and oxidation resistance of the composite coating were about 8 times compared with that of substrate (42 CrMo). Therefore, in situ synthesized V_8C_7 reinforced Fe-based composite coating provides an effective approach to strengthen the wear resistance.

In the present study, the in situ synthesized V_8C_7 reinforced Fe-based composite coating was successfully fabricated on the 35 CrMo steel by laser cladding, aiming at improving the wear resistance. The detailed investigation has been undertaken to study the microstructure evolution, constituent phases and mechanical properties of the coating. The mechanism of V_8C_7 formation in the melt pool was also focused based on thermodynamics. The results of the present study on rules of phase formation, microhardness and wear resistance would provide essentials for further research and applications of Fe-based composite coating.

2. Materials and methods

35 CrMo steel substrate with a dimension of Φ110 mm × 10 mm was used and the chemical compositions (wt.%) were illustrated in Table 1. The substrate was ground clean with 600 grade SiC paper to remove the oxide layer and then cleaned with acetone solution. The powder used for laser cladding was obtained by mixing 70% powder I with 30% powder II with the particle size of 100–270 meshes. The chemical composition of powder I, powder II and mixed powder were illustrated in Table 2. In order to obtain homogeneous distribution, the powders mixtures were blended by ball milling at 300 rpm in a planetary ball mill for 1 h. Then the blended powders were mixed with 4 wt.% polyvinyl alcohol (PVA) and then pasted onto the 35 CrMo steel. The thickness of the paste was controlled to 1.2 mm. The specimens were dried in an oven for 12 h at 80 °C.

Table 1
Chemical composition of 35 CrMo steel (wt.%).

C	Si	Mn	Cr	Mo	Fe
0.32–0.40	0.17–0.37	0.40–0.70	0.8–1.1	0.15–0.25	Bal

The cladding process was conducted by continuous wave CO_2 laser system (DL-HL-T5000). With a series of optimization trial runs, the following parameters at workpiece were selected for subsequent laser processing: laser power = 4 kW, laser spot diameter = 4 mm, scanning speed = 600 mm/s, overlapping ratio = 50% and high purity argon gas at a flow rate 15 L min^{-1} was used as shielding gas to prevent oxidation. The schematics of laser cladded system was used in this paper had been shown in Fig. 1.

After laser cladding, cross-section of Fe-based alloy coating transverse to the laser tracks was prepared by the usual metallographic techniques. For microstructural observation, sample was etched with 10 mL $FeCl_3$ + 10 mL HCl + 80 mL H_2O solution for about 30 s. The microstructure of the coating was investigated using scanning electron microscopy (SEM, Hitachi, S-3400N) equipped with an energy dispersive spectrometer (EDS). The constituent phases of the Fe-base coating was identified using an X-ray diffractometer (XRD, Shimadzu XRD-7000) at a scanning speed of 4° min^{-1} range from 20° to 100°, with Cu Kα radiation at 45 kV and 35 mA.

Microhardness of the coating were performed by using a microhardness tester (HV, Huayin, HVS-1000) from the top of the coating to substrate with a load of 300 g and a duration time of 15 s. Three measurements were made at each depth, and the average hardness was calculated as the final results. The wear behavior of the substrate and coating was evaluated using the MMU-5G pin-on-disk dry sliding wear tester (Jinan HengXu Testing Machine Technology Co., Ltd., China) under room temperatures. An illustration of the wear tester is shown in Fig. 2. The tested specimens with a diameter of Φ4 × 15 mm were against a quenched 45 steel disk with a diameter of Φ43 × 3 mm, the hardness of it was about HRC 55. The following parameters were used for the wear test: normal loads = 150 N, sliding distance = 200 m, the outer radius of the circular test ring = 21 mm, the sliding speed = 150 r/min, and the time of abrasion = 30 min. Before the test, all the specimens were ground on emery paper up to 600 grade to achieve a smooth and flattened surface. Then, all the specimens were cleaned in ultrasonic cleaner and then dried to remove any contaminants. In order to ensure the accuracy of the wear test, wear test for three same specimens were conducted and the ultimate wear results were determined from three specimens. The test samples were weighed using an electronic balance with an accuracy of 0.01 mg before and after the wear tests. The relative wear resistance could be expressed as:

$$\varepsilon = \frac{\Delta W_1}{\Delta W_2} \tag{1}$$

where ΔW_1 and ΔW_2stand for 35 CrMo steel specimen weight loss, and coating specimen weight loss, respectively.