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Microstructure and wear resistance of laser cladded composite coatings prepared from pre-alloyed WC-NiCrMo powder with different laser spots

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ABSTRACT

The distribution of WC particles in laser cladded composite coatings can significantly affect the wear resistance of the coatings under aggressive environments. In this study, pre-alloyed WC-NiCrMo powder is deposited on SS316L via laser cladding with circular spot and wide-band spot, respectively. The microstructure and WC distribution of the coatings are investigated with optical microscope (OM), scanning electron microscopy (SEM), energy dispersive spectrometer (EDS), and X-ray diffraction (XRD). The wear behavior of the coatings is investigated under dry sliding-wear test. The experimental results show that the partially dissolved WC particles are uniformly distributed in both coatings produced with circular spot and wide-band spot, respectively, and the microstructures consist of WC and $M_{23}C_6$ carbides and γ-(Ni, Fe) solid solution matrix. However, due to Fe dilution, the two coatings have different microstructural characteristics, resulting in different hardness and wear resistance. The wide-band spot laser prepared coating shows better performance than the circular spot laser prepared coating.

1. Introduction

Metal components often operate in corrosion and wear conditions, which results in surface-initiated failure. Therefore, it is necessary to apply a protective coating on the surfaces of the parts to enhance wear resistance. Laser cladding as an advanced surface modification technique has been widely employed in surface engineering [1–3]. Ni-based composite coatings reinforced with different ceramic particles such as WC [4], SiC [5] and Cr_3C_2 [6,7] exhibit high hardness and good wear resistance. Farahmand et al. [8] studied the Ni-WC coating fabricated via laser cladding and they found that the addition of Nano-WC, La_2O_3, and Mo could improve the hardness, wear resistance and corrosion resistance of the matrix material. Ma et al. [9] prepared a Ni60/WC composite coating using laser cladding. This coating had a cored-eutectic structure and exhibited excellent wear resistance and high hardness. It has been reported that dispersive ceramic particles in composite coatings can significantly enhance wear resistance by dispersion strengthening [10,11]. However, it is difficult to fabricate a composite coating with uniform distribution of the reinforcing particles due to different gravity densities of the phases in the composite. For example, WC particles easily sink at the bottom of cladding layer due to higher density than the nickel matrix [12–15]. Wu et al. [11] and Van Acker et al. [15] produced a Ni-WC composite coating, but hardly obtained homogenous distribution of WC particles in the metal matrix.

Recent research reported that the microstructure evolution of ceramic-reinforced composite coatings can be controlled by utilizing s several newly developed technologies, such as induction heating [16], mechanical vibration [17], ultrasonic [18], magnetic field [19] and other assistant technologies, which can achieve a homogeneous distribution of ceramic particles in the matrices. However, there are still problems in applying these methods to practical industrial applications due to various limitations, for example, equipment and environment. Furthermore, the application of coated powders, especially Ni-coated WC particles, in laser cladding may solve the problems. Tobar et al. [20] and Guo et al. [21] studied the morphology and characteristics of the composite coating NiCrBSi reinforced with Ni-coated WC using laser cladding technique. They found that WC particles were uniformly distributed in the coating and the tribological properties of conventional Ni-based alloy coatings were effectively improved by introducing Ni-coated WC reinforcement. Although these studies

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had examined the performance of Ni-coated WC, most studies used composite powders with WC particles as single phase. In the present research, the WC-NiCrMo composite coating was proposed using pre-alloyed WC-NiCrMo powder instead of a mixed powder of Ni-coated WC powder and NiCrMo alloy powder. Since the Micro-WC particles in the pre-alloyed WC-NiCrMo are previously dispersed uniformly, under agitation in the bath during the laser cladding they are easily distributed uniformly in the cladding layer when the molten pool is solidified with continuous powder feeding. Compared with the traditional means, the proposed pre-alloyed WC-NiCrMo powder can easily achieve the dispersion distribution of WC particles in the matrix without need of an external field attachment device, thus it is more applicable in industry.

It is acknowledged that the composite coating fabricated via laser cladding with different laser spots may result in different microstructure and wear performance. Ma et al. [9] proposed that Ni60/WC composite coating fabricated via wide-band spot laser shows better performance than the circular spot laser prepared one. Zhou et al. [16] prepared a Ni-based WC composite coating by laser induction hybrid rapid cladding with elliptical spot. This coating had a uniform distribution of WC structure and exhibited excellent hardness. As it mentioned before, pre-alloyed WC-NiCrMo powder exhibits much enhanced performance due to the characteristics of dispersion distribution of WC particles in the powder matrix. However, the coating prepared via circular spot laser may have higher dilution rate due to its inherent limitation, which is detrimental for coating properties [22,23]. On the basis of the literature [9,24], the wide-band laser spot usually have a uniform energy distribution than circular spot, which usually result in lower dilution rate during laser cladding process. Therefore, it is necessary to compare the WC-NiCrMo composite coatings prepared via laser cladding with circular spot and wide-band spot. However, the research on Ni-based alloy coatings produced using pre-alloyed WC-NiCrMo powder via circular spot and wide-band spot laser has been rarely reported. For this reason, pre-alloyed WC-NiCrMo powder was used to prepare the WC-NiCrMo composite coating on SS316L via circular spot and wide-band spot laser cladding, respectively, in the present research. The focus of the investigation was on the microstructure and wear properties of the coatings. Additionally, the microstructure evolution of the coatings and the associated mechanisms were studied in detail.

2. Experimental

2.1. Coating and substrate materials

The SS316L stainless steel plate with dimensions of 100 × 20 × 60 mm was used as the substrate and pre-alloyed WC-NiCrMo powder was used as the laser cladding material. The coating powder has a spherical shape with particle size of −53 + 30 μm, as shown in Fig. 1a. Fig. 1b shows the SEM image in the BSE mode of the cross-section of a pre-alloyed WC-NiCrMo particle after etched using a chemical method with a corrosive liquid of $FeCl_3$ (5 g) + HNO_3 (6 ml) + HCl (20 ml). The chemical compositions of the SS316L stainless steel plate and pre-alloyed WC-NiCrMo powder are listed in Table 1.

2.2. Lasers

A LDF400-2000 flexible fiber coupled diode laser system with 4 mm circular spot and a FL-DLight-3000-976 diode laser system with 12 mm × 2 mm rectangular spot were used in this research. The parameters of the laser systems are given in Table 2. Laser beam profiles (energy distribution across the beam) of both systems are shown in Fig. 2. The energy densities of the two laser beams are uniformly distributed, which is suitable for fabricating coatings.

2.3. Coating fabrication

Before laser cladding, the powder was dried in a furnace at 200 °C for 30 min and the surface of SS316L substrates was treated by a planar grinder, and then cleaned with alcohol to remove oil or grease. The WC-NiCrMo coating specimens were fabricated via laser cladding using a LDF400-2000 flexible fiber coupled diode laser system with 4 mm circular spot and a FL-DLight-3000-976 diode laser system with 12 mm × 2 mm rectangular spot, respectively. Argon gas was used as the protective and shielding gas to avoid oxidation during the laser cladding process. The powder was fed into the laser spot of the projection head using a boiling type powder feeding system.

In order to compare the performance of the coatings fabricated via different laser spots, the experiment was designed with same energy density (E) and solidification time (τ) according to Eq. (1) [25] and Eq. (2) [16].

$$E = \frac{P}{S} \tag{1}$$

$$\tau = \frac{L}{V} \tag{2}$$

where E represents laser energy densities, P stands for laser power, S is the area of laser spot, τ is the time of stirring and convection in the molten pool, L stands for the spot dimension in the longitudinal direction which is parallel to the direction of the laser scanning speed and V is laser scanning speed.

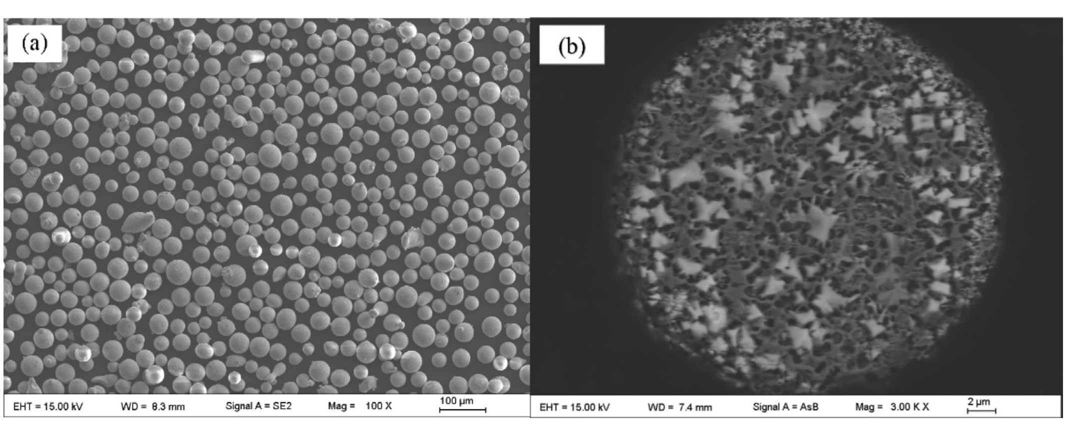

Fig. 1. Pre-alloyed WC-NiCrMo powder particles: (a) SEM morphology, (b) BES image of a powder cross-section after etched chemically.