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Investigation on laser cladding high-hardness nano-ceramic coating assisted by ultrasonic vibration processing

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ABSTRACT

Laser cladding Nickel–WC–CaF_2 coatings with high hardness were prepared on medium carbon steel assisted by ultrasonic vibration processing. The microstructure, element distribution, phase composition and microhardness as well as wear resistance of the cladding coatings were investigated. It is found that ultrasonic vibration during laser cladding could reduce the degree of WC particle aggregation. The laser cladding Ni–WC–CaF_2 coatings is composed of γ-(Fe, Ni) and WC particles while the cladding coating with ultrasonic vibration consists of γ-(Fe, Ni), $Cr_{23}C_6$, W_2C and WC. In addition, the coarse dendrite has been replaced by some fine grain structure at the bonding interface. When the ultrasonic vibration power of 800 W is applied, the average microhardness of cladding coating increase to $1235HV_{0.1}$ resulted from the combined effect of refined grain, dispersion strengthening from hard WC phase and solid solution strengthening. And the wear mass loss and friction coefficient of Ni–WC–CaF_2 coating are lower than the coating without ultrasonic vibration and the coating with the ultrasonic vibration power of 900 W. Especially, the worn mechanism on the surface is uniform ploughing.

1. Introduction

Most of failures in the components are caused by wear, fatigue and corrosion at the surfaces. Modern surface engineering techniques could provide excellent surfaces or coatings to improve the hardness and wear resistance, which prolongs the service life. In recent years, laser cladding (LC), as a relatively rapid manufacturing technique, has been widely applied to improve the surface properties of metal materials [1–4]. This technique offers high process flexibility and the possibility of selectively cladding small areas. Especially the presence of hard particles of carbides such as WC, Cr_2C_3, etc. in the matrix enable a much better wear resistance [5,6]. Compared to other carbides, WC processes many favorable properties such as high hardness, high melting point, low coefficient of thermal expansion, certain plasticity and good wettability with the Ni-based matrix[7,8]. Therefore, WC addition are widely used for producing composite coatings by laser cladding technique to improve properties of key parts [9].

Ultrasonic vibration, as external physical field processing technology, was used in the traditional casting field, and then gradually developed to melting and solidification fields, such as welding and laser cladding process [10,11]. This technology plays an important role in grain refinement and reducing residual stress, is one of the effective methods in improving solidification structure and mechanical properties. Many studies focusing on laser cladding Ni-based WC coating are reported, but ultrasonic vibration assisted laser cladding surface modification process has never been reported. In present study, Ni-based WC composite coatings are prepared by laser cladding with or without ultrasonic vibration, and the microstructure and wear resistance were investigated.

2. Experimental

As the substrate, medium-carbon steel bricks were prepared in the dimension of 60 mm × 30 mm × 8 mm, with the phase composition of ferrite and pearlit, and the chemical composition listed in Table 1. The cladding Nickel-based powder is a designed mixture of Ni-based powder, WC and CaF_2 in the proportions of 35:60:5, while the chemical composition of the Ni-based powder is listed in Table 2. Laser cladding was carried out using a continuous wave CO_2 laser processing system with the cladding powder pre-placed on the substrate surfaces. A laser power of 3.5 kW with a beam size of 10 mm × 1 mm and scanning velocity of 150 mm/min was used.

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Table 1
Chemical composition of substrate (wt%).

C	Si	Mn	Cr	Ni	Fe
0.42–0.50	0.17–0.37	0.50–0.80	0.25	0.25	Bal.

Table 2
The chemical composition of Ni-based powder (wt%).

C	Cr	Mn	Si	B	Ni	Fe	WC
0.55	14	0.13	2.5	1.9	46.7	14.2	20

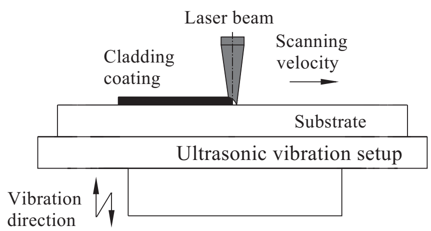

Fig. 1. Diagram of laser cladding assisted by ultrasonic vibration.

Ultrasonic vibration was used to the samples in laser cladding process and the vibration signal was a positive sine wave. The ultrasonic vibration setup is shown in Fig. 1. The detail vibration parameters were as follows: vibration frequency 20 Hz, the ultrasonic power 800 W and 900 W. For convenience, the laser cladding sample without ultrasonic vibration marked with symbol S1, and the laser cladding sample with ultrasonic vibration marked with symbol S2 (800 W) and S3 (900 W), respectively.

After laser cladding, the microstructure of the cladding coating was analyzed by scanning electron microscopy (SEM) attached energy dispersive spectroscopy (EDS) microprobe. The phase composition of laser cladding coatings with and without ultrasonic vibration was analyzed by X-ray diffraction (XRD). The hardness along the depth was tested on a Micro Vickers hardness test at a fixed load of 100 g. Specimens were mounted on a stationary holder and pressed onto an abrasive disc at a load of 50 N and tested for 60 min. After wear testing, the specimens were ultrasonically cleaned and then their weight losses of the specimens were recorded.

3. Results and discussion

3.1. Microstructure of lase cladding coating with and without ultrasonic vibration

Figu. 2a shows the low magnification image of the cross-section of laser cladding Ni45 + 60%WC + 5%CaF_2 coating (S1). After laser cladding the structure from the surface to the bottom could be separated into two regions: the cladding layer and the interface.

Microstructural examination of the laser cladding layer by SEM shows a lot of large white particles gathering at the upper region (Fig. 2b). As we can see in Fig. 2c, the rod-shaped particles are present at the middle region while few while particles at the bottom region and coarse dendrite in bonding interface appear (Fig. 2d).

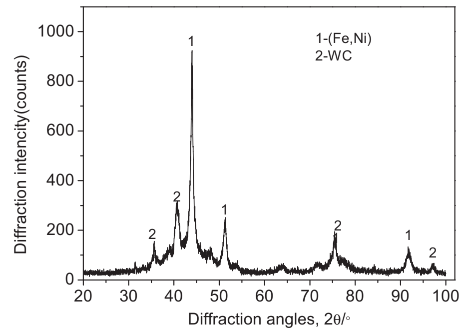

Fig. 3. X-ray diffraction profiles of the laser cladding Ni45 + 60%WC + 5%CaF_2 coating.

Table 3
EDS analysis results at the different positions in cladding coating (%).

Position	C	Si	Cr	Fe	Ni	W
A	10.69	2.31	0.45	2.53	–	83.97
B	4.44	2.68	3.41	19.74	6.04	63.67
C	7.27	1.47	2.26	43.97	7.12	37.90
D	5.14	1.12	1.66	72.51	13.32	6.25

As indicated in the XRD spectrum of the laser cladding Ni–WC–CaF_2 layer (Fig. 3), the cladding layer consists of γ-(Fe, Ni) phase and WC, while γ-(Fe, Ni) phase is the typical phase transformation of the fast quenching of steels from the liquid state for Ni-based materials.

The composition analysis was performed by means of EDS, and the results were listed in Table 3. We can see that the contents of C and W elements inside the particles (point A and B) are very high and the content of Fe element of point B is higher than that of Point A. According to the XRD profile in Fig. 3, the particles are deduced to be WC particles. At the bottom region (Fig. 2c), the contents of C and W elements of point D decrease while the contents of Fe and Ni increase, which are γ-(Fe, Ni) solid solution.

3.2. Microstructures of lase cladding coating with ultrasonic vibration

Fig. 4 illustrates the cross-section morphologies of laser cladding coating with ultrasonic vibration. As it can be seen, no porosity or crack was observed on the entire surface of the cross-section, and the cladding layer was separated into upper region and bottom region.

From Fig. 5, the distribution of particles in the ultrasonic vibration cladding coatings (S2 and S3) have change obviously. The coarse dendrites have been replaced by the fine grain at the bottom regions (Fig. 5e and f), this is because when the dendrite grow up with crystallization along the surface, vibration energy can break

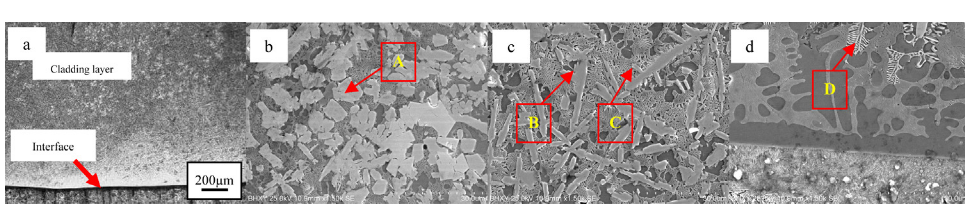

Fig. 2. Microstructures of cladding coating. (a) Cross-section morphology; (b) upper region; (c) middle region; (d) bottom region.