Microstructure and wear resistance of TiC carbide-reinforced composite coating prepared by laser surface alloying

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Abstract To strengthen the wear resistance of AISI321 stainless steel, the TiC carbide-reinforced composite coating was produced by laser surface alloying. The microstructure, microhardness, and wear resistance of the composite coatings were investigated using optical microscopy, X-ray diffraction (XRD) meter, scanning electron microscopy (SEM), microhardness tester, and sliding wear tester. The results show that the composite coating is metallurgically bonded to the substrate and the microstructure is fine and uniform. The hardness of the composite coating is up to 400 HV, which is 2.5 times that of the substrate. Under room temperature and oil lubrication condition, the sliding wear tests indicate the friction coefficient and weight loss of the composite coating are smaller than those of substrate. The worn surface of the composite coatings is much smoother than that of the substrate, without grooves and crater. The wear resistance of the material has been greatly improved by laser surface alloying.

Key words laser technique; laser surface alloying; microstructure; microhardness; wear.

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1. Introduction

AISI321 austenitic stainless steel is widely applied due to its excellent corrosion resistance. Because of its low hardness and an austenitic structure, which can not be strengthened by conventional heat treatment, and the poor ability of the wear resistance, its application as engineering tribological components[1] is restricted.

TiC carbide as one of the common ceramics has many exceptional advantages[2~5], such as high melting point and thermal stability, high hardness, high energy absorption for the laser beam, good compatibility with γ-Fe, high electrical and thermal conductivity etc. TiC carbide is widely used as the reinforcing phase of the wear resistance composite coating.

Laser surface alloying is a novel technology to improve the corrosion and wear resistance of the metal substrate among the different surface treatments. It makes successful application in Ti-6Al-4V alloy, cast iron, stainless steel, etc.[6~9]. Compared with the conventional surface treatments, it has some outstanding advantages[10], such as high input energy, low distortion, and high process flexibility. Composite coatings produced by laser surface alloying are thicker than those produced by other conventional surface technologies, and those are metallurgically rather than mechanically bonded to the substrate[11~16].

Laser surface alloying with TiC carbides has been successfully used on aluminum alloy and AISI316 stainless steel to improve the hardness and wear resistance[2,3,17,18]. In this letter, laser surface alloying was adopted to produce TiC carbide-reinforced composite coating on AISI321 austenitic stainless steel. The microstructure, microhardness, and wear resistance of the composite coating were investigated .The formation mechanism of composite coating has been also discussed.

2. Experiment procedure

The samples of AISI321 austenitic stainless steel with size of 100 × 100 × 12 (mm) were abraded with SiC grit paper prior to the laser surface alloying. The alloying powder was a mixture of TiC, CaF_2, and Re, grain size$\leq$ 127 μm, as shown in Table 1. They were mechanically mixed. The mixed powder was pasted on the sample surface with an organic binder, whose thickness is about 0.3 mm. Laser surface alloying was carried out using a 1.5 kW continue-wave CO_2 laser with Gaussian mode. The laser beam spot and scanning speed were 3 mm and 5 mm/s, respectively. To protect the alloy surface from oxidation, high purity argon was used as a shielding gas through a coaxial nozzle.

The laser surface alloying samples were cut transversely to the laser scanning direction, polished by usual metallographic procedure, and etched in a solution containing 20 ml HCl, 20 ml HNO_3, and 10 ml C_2H_6O. The phase composition of the coatings was identified using X'Pert MPD X-ray diffract (XRD) with Cu Ka radiation operated at a voltage of 40 kV, a current of 50 mA, and a scanning rate of 5 °/min. Microstructure of the coatings was characterized using Philips XL30 scanning electron microscopy (SEM) and MBS optical microscopy (OM). The chemical composition of the compounds in the coatings was analyzed by energy dispersive spectrometer (EDS). The hardness was measured using HXD-1000 digital microhardness tester with a load of 200 g. Sliding wear were tested using MM-200 wear test machine with a load of 200 N in oil lubrication condition. The rotational speed is fixed at 200 r/min. A GCr15 ring was selected as the wear couple. The weight loss was evaluated every 10 min using a BS210S electron balance with an accuracy of 0.1 mg.

Table 1. Alloying Powder Components

Powder	TiC	C	CaF_2	Re
Mass Fraction /%	90	$5\sim6$	$2\sim3$	$1\sim2$

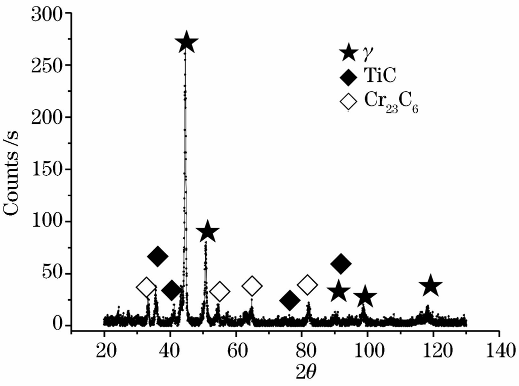

Fig. 1. XRD spectra of alloying layer.

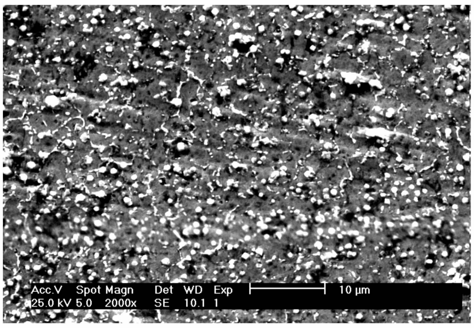

Fig. 2. Secondary electron imaging of alloying coating.

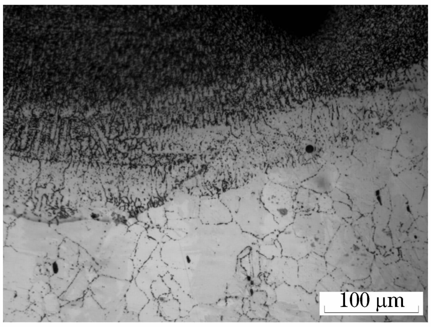

Fig. 3. Optical micrograph of alloying coating.

3. Result and discussion

3.1 Microstructure

The XRD of the laser surface alloying composite coating is shown in Fig. 1. After laser surface alloying, the composite coating mainly consists of TiC, $Cr_{23}C_6$ and γ (austenitic) phase.

Typical microstructure of the laser surface alloying composite coating is shown in Fig. 2. The composite coating has a very fine microstructure, in which the particles of TiC and $Cr_{23}C_6$ distribute in γ-(Fe, Ni)(austenitic) phase.

Figure 3 shows the microstructure characteristics of the composite coating. Between the γ-(Fe, Ni) and TiC carbide-reinforced composite coating, there are a lot of columnar crystals, so the composite coating is metallurgically bonded to the AISI321 austenitic stainless steel substrate.

3.2 Microhardness

Figure 4 indicates the microhardness versus the depth of the TiC carbide-reinforced composite coating. Because of the high volume fraction of the hard primary TiC uniformly distributed in the composite coating, the average hardness of the composite coating is up to 400HV, which is 2.5 times that of the substrate.

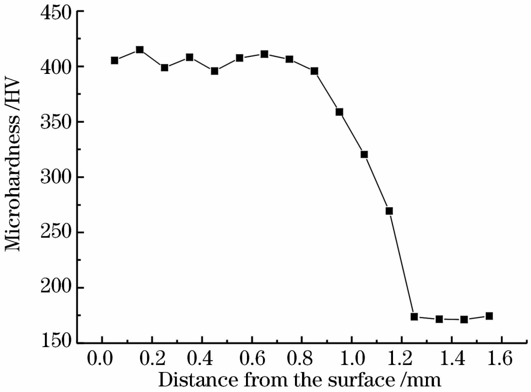

Fig. 4. Microhardness distribution of alloying coating.

3.3 Wear resistance

The sliding wear test results show the relative wear resistance of the TiC carbide-reinforced composite coating is about 28 times higher than that of the as-received austenitic stainless steel. A conclusion can be reached that the TiC carbide-reinforced composite coating produced by laser surface alloying has excellent friction and wear resistance at room temperature and in oil lubrication condition. Figures 5(a) and (b) are the worn surfaces of the AISI321 austenitic stainless steel substrate and TiC carbide-reinforced composite coating in the tribological properties test. The wearing test was performed under a load of 200 N, rotating speed of 200 rpm, ambient temperature of 25 °C, and a 30-min testing with oil lubrication. Figure 5(b) shows the worn surface is very shallow, suggesting that wearing resistance is better than that in Fig. 5(a). An appreciable improvement of wear resistance was observed with a TiC carbide-reinforced composite coating. As shown in Fig. 5(a),the worn surface of the as-received AISI321 austenitic stainless steel sample is very rough with numerous adhesive craters

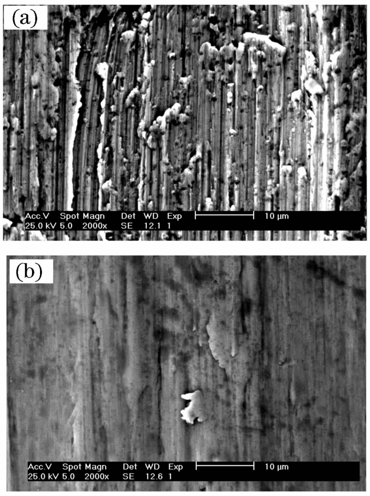

Fig. 5. SEM micrographs of the worn surface of substrate (a) and composite coating (b).

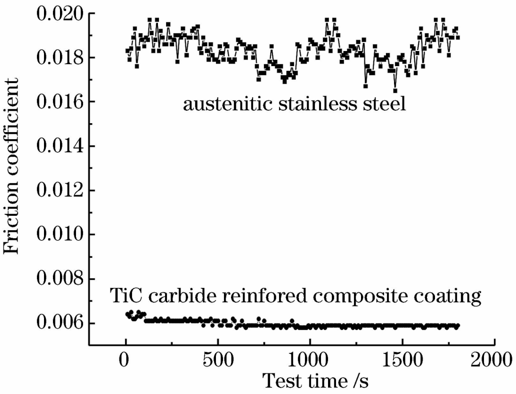

Fig. 6. Effect of time on the friction coefficient in the condition of the oil lubrication.

and deep ploughing grooves. On the contrary, the worn surface of the TiC carbide-reinforced composite coating is relatively much smoother, as shown in Fig. 5(b). In the TiC carbide-reinforced composite coating produced by laser surface alloying, the TiC carbides play an important role.

Figure 6 shows the effect of time on the friction coefficient of the TiC carbide-reinforced composite coating and the AISI321 austenitic stainless steel as-received samples under a load of 200 N and oil lubrication condition. The friction coefficient of TiC carbide-reinforced composite coating is lower than that of the AISI321 austenitic stainless steel as-received samples. The average friction coefficient of the TiC carbide-reinforced composite coating is 0.0064, and the average friction coefficient of the AISI321 austenitic stainless steel as-received samples is 0.0185. It can be concluded that the TiC carbide-reinforced composite coating produced by laser surface alloying has excellent friction and wear properties under sliding wear condition.

4. Conclusions

TiC carbide-reinforced composite coating was fabricated on the substrate of AISI321 austenitic stainless steel by laser surface alloying. The composite coating is composed of predominantly TiC, $Cr_{23}C_6$ and γ (austenitic) phase. TiC and $Cr_{23}C_6$ carbides uniformly distributed in γ (austenitic) phase. The composite coating, which has a high and uniform hardness distribution, exhibits excellent wear resistance at room temperature and in oil lubrication condition.

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