

Influence of yttrium on microstructure and properties of Ni–Al alloy coatings prepared by laser cladding

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Received 4 November 2013; revised 25 December 2013; accepted 26 December 2013

Available online 8 January 2014

Abstract

Ni–Al alloy coatings with different Y additions are prepared on 45[#] medium steel by laser cladding. The influence of Y contents on the microstructure and properties of Ni–Al alloy coatings is investigated using X-ray diffraction, scanning electron microscopy, electron probe microanalyzer, Vickers hardness tester, friction wear testing machine, and thermal analyzer. The results show that the cladding layers are mainly composed of NiAl dendrites, and the dendrites are gradually refined with the increase in Y additions. The purification effect of Y can effectively prevent Al₂O₃ oxide from forming. However, when the atomic percent of Y addition exceeds 1.5%, the extra Y addition will react with O to form Y₂O₃ oxide, even to form Al₅Y₃O₁₂ oxide, depending on the amount of Y added. The Y addition in a range of 1.5–3.5 at.% reduces the hardness and anti-abrasion of cladding layer, but improves obviously its wear and oxidation resistances.

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Keywords: Laser cladding; Ni–Al alloy; Yttrium; Microstructure; Property

1. Introduction

In recent years, the ordered B2-Ni–Al intermetallic compound has attracted considerable attention owing to its high melting temperature, good oxidation resistance, high thermal conductivity, and low density for potential high temperature structural application [1–3]. Therefore, many researchers have tried to use the intermetallic compound as protective coating material, and the adopted techniques mainly include thermal spraying, magnetron sputtering, electron-beam physical vapor deposition, hard facing, and laser cladding, etc [4–10]. Amongst these, laser cladding, as an advanced surface modification technique, has been used to prepare the coatings with high density and almost zero porosity content [11].

In the present study, the Ni–Al alloy coatings with different Y additions were prepared on the 45[#] medium steel (containing about 0.45 wt.% C) by laser cladding, and the influences of Y contents on the microstructure and properties of the Ni–Al alloy coatings were systematically investigated.

2. Experimental procedure

45[#] medium steel with dimension of 20 mm × 10 mm × 10 mm is chosen as a substrate material. The powders of Ni (99.99% purity, -200 mesh), Al (99.90% purity, -200 mesh), and Y (99.99% purity, -200 mesh) are blended using ball milling according to the chemical compositions of cladding powders listed in Table 1. The powders are placed on the surface of the 45[#] steel to form a 1 mm thick layer, and are melted using a 5 kW continuous wave CO₂ laser beam. The laser cladding is performed with 3 mm diameter laser beam at a laser power of 3.8 kW and a scanning velocity of 4 mm/s. Argon gas is introduced into a melt pool to prevent the penetration of exterior oxygen during the laser cladding process.

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Peer review under responsibility of China Ordnance Society



Table 1
Chemical compositions of cladding powders (at.%).

Element	Sample no.			
	Sample 1	Sample 2	Sample 3	Sample 4
Ni	50	49.25	48.75	48.25
Al	50	49.25	48.75	48.25
Y	0	1.5	2.5	3.5

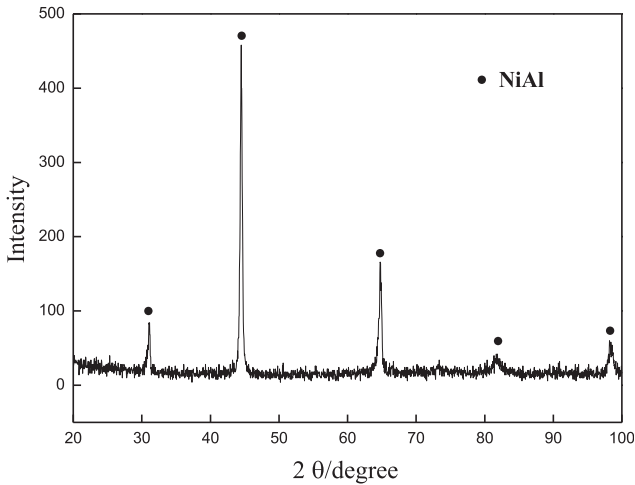


Fig. 1. X-ray diffraction pattern of the Ni–Al cladding layer.

Phase identification of these coatings is carried out using Cu $K\alpha$ radiation by means of XRD-6000 X-ray diffractometer. The microstructure characteristics and compositions of coatings are analyzed using JEOL-5600LV scanning electron microscopy (SEM) and EPMA-1720 electron probe microanalyzer (EPMA). The Vickers hardness of coating is measured with DMH-2LS micro-hardness tester under a load of 0.981 N and a dwell time of 15 s. The ball-and-disk friction and wear test of the cladding layers is carried out on CETR UMT-2 testing machine. A bearing steel ball (GCr15) with a diameter of 5 mm and a hardness of 55HRC is selected as wear couple. The experiment is performed with a normal load of 5 N, a sliding speed of 2 mm/s, and a wear time of 30 min. Continuous variable-temperature oxidation experiment is performed on SDT-Q600 thermal analyzer at a heating rate of 1.33 K/s and a temperature range of 150–1000 °C. The specimens (3 mm × 2.5 mm × 0.4 mm) for test are cut from the laser cladding layers.

3. Results and discussion

3.1. Microstructure

Fig. 1 shows an X-ray diffraction pattern taken from the Ni–Al cladding layer. Only Ni–Al intermetallic compound with the ordered cubic B2 crystal structure is identified from the diffraction pattern, indicating that the cladding layer mainly consists of NiAl phase.

Fig. 2 shows a cross-sectional SEM micrograph taken from the cladding layer. It can be found that the microstructure of the cladding layer is featured with dendrites (Fig. 2(a)). Further, EPMA analysis reveals that the NiAl dendrite contains a small amount of Fe besides Ni and Al, and its composition is $\text{Ni}_{41.78}\text{Al}_{53.75}\text{Fe}_{4.47}$. This indicates that the cladding layer is diluted by the substrate during laser cladding. In addition, oxygen element distributed between dendrites is also found in the cladding layer. From the EPMA area analysis shown in Fig. 3, it can be deduced that O may react with Al to form Al_2O_3 due to the higher binding energy between O and Al. The interface region between the cladding layer and the substrate is located at a region in which the substrate material is re-melted and reheated and new cladding material begins to be added. This makes the microstructure of the interface region totally different from that of the cladding layer, as shown in Fig. 2(b). High dilution and low cooling rate result in the formation of flat crystal with an average thickness of 21.7 μm , and the composition of the flat crystal measured by EPMA is $\text{Ni}_{39.51}\text{Al}_{45.25}\text{Fe}_{15.24}$. Above the interface, because the heat is flowing out of the cladding layer towards the substrate, the dendrites are more columnar and perpendicular to the interface. In the heat-affected of the substrate, because austenitic transformation takes place at higher temperature, on a subsequent cooling, a martensitic structure is formed, as shown in Fig. 2(c).

Fig. 4 shows the X-ray diffraction patterns of cladding layers with different Y additions. When the atomic percent of Y addition is 1.5%, the phase constituents of the cladding layer remain unchanged, which still consist of NiAl phase. However, when the atomic percent of Y addition exceeds 1.5% limit, the phase constituents of the cladding layers change obviously. Besides the NiAl phase, a Y_2O_3 phase in the cladding layer with 2.5 at.% Y addition and an $\text{Al}_5\text{Y}_3\text{O}_{12}$ phase in the cladding layer with 3.5 at.% Y addition are observed.

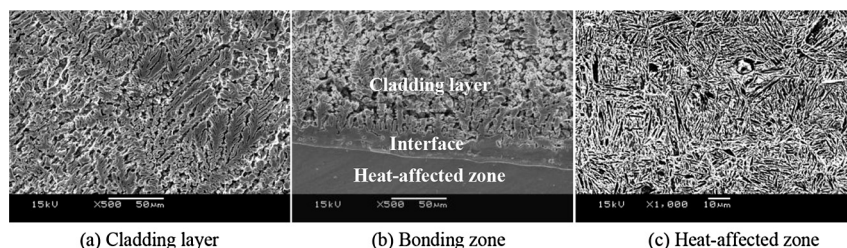


Fig. 2. Cross-sectional SEM micrographs of the Ni–Al cladding layer.

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