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Microstructure and wear resistance of laser cladded Ni-Cr-Co-Ti-V high-entropy alloy coating after laser remelting processing

Zhaobing Cai [a,b], Xiufang Cui [a,*], Zhe Liu [b], Yang Li [a], Meiling Dong [a,b], Guo Jin [a,*]

[a] Institute of Surface/Interface Science and Technology, Key Laboratory of Superlight Material and Surface Technology of Ministry of Education, College of Material Science and Chemical Engineering, Harbin Engineering University, Harbin 150001, China

[b] College of Material Science and Chemical Engineering, Harbin Engineering University, Harbin 150001, China

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ABSTRACT

An attempt, combined with the technologies of laser cladding and laser remelting, has been made to develop a Ni-Cr-Co-Ti-V high entropy alloy coating. The phase composition, microstructure, micro-hardness and wear resistance (rolling friction) were studied in detail. The results show that after laser remelting, the phase composition remains unchanged, that is, as-cladded coating and as-remelted coatings are all composed of (Ni, Co)Ti_2 intermetallic compound, Ti-rich phase and BCC solid solution phase. However, after laser remelting, the volume fraction of Ti-rich phase increases significantly. Moreover, the micro-hardness is increased, up to ~900 HV at the laser remelting parameters: laser power of 1 kW, laser spot diameter of 3 mm, and laser speed of 10 mm/s. Compared to the as-cladded high-entropy alloy coating, the as-remelted high-entropy alloy coatings have high friction coefficient and low wear mass loss, indicating that the wear resistance of as-remelted coatings is improved and suggesting practical applications, like coatings on brake pads for wear protection. The worn surface morphologies show that the worn mechanism of as-cladded and as-remelted high-entropy alloy coatings are adhesive wear.

1. Introduction

High-entropy alloy (HEA), proposed by Yeh et al. [1,2], is being a hot area of research in materials field. Owing to the remarkable performance, such as outstanding mechanical properties [3–5], good corrosion resistance [6–9], and excellent wear resistance [10–12], it is reasonable think that HEAs are considered as a new generation of optional coating materials. So far, so many HEA coatings/films have been successfully prepared by laser processing [13–16], plasma cladding processing [17,18], magnetron sputtering [19,20], spaying processing [21,22], electro spark processing [23], and so on. Compared to other methods for preparation of HEA coatings/films, laser processing with high heating temperature and rapid cooling rate, can prepare coatings with unlimited size and larger thickness (≥1 mm) and by laser processing, it is easy to synthesize the HEA phase with admired performance, which are more beneficial for engineering applications.

Because the extremely fast cooling rate and high temperature in laser cladding and laser remelting is ideal to retain or develop non-equilibrium microstructure, it is an effective way to improve the performance of materials with the united technologies of laser cladding and laser remelting. In the previous works [24–27], the focus is on amorphous alloy coatings, including the synthesis of amorphous composite coatings, the effect factor of amorphous phase formation and properties characterization of amorphous alloy coatings. Zhang et al. [27] have synthesized Fe–Ni–B–Si–Nb amorphous and crystalline composite coatings by laser cladding and remelting and the results show that the highest micro-hardness of these coatings is 1369 HV. Moreover, wear resistance of the substrate has been improved remarkably. Li et al. [24] have studied dilution effect on the formation of amorphous phase in the laser cladded Ni–Fe–B–Si–Nb coatings after laser remelting process, and the coatings with low dilution ratio exhibit the highest micro-hardness of 1200 $HV_{0.5}$ due to their largest volume fraction of amorphous phase.

However, there are few literatures concerning on the study of HEA coatings prepared by the united technologies of laser cladding and laser remelting. In this work, an attempt, combining the technologies of laser cladding and laser remelting, has been made to develop a Ni-Cr-Co-Ti-V HEA coating. The evolution of microstructure, phase and composition, mechanical properties (in terms of micro-hardness and wear resistance) of laser complex processed Ni-Cr-Co-Ti-V HEA coatings were studied In detail. The chemical composition chosen for this Ni-Cr-Co-Ti-V HEA are based on the

* Corresponding authors at: 145, Nantong Ave, Nangang Distinct, Harbin, Heilongjiang 150001, China.

E-mail addresses: cuixf721@163.com (X. Cui), jinjg721@163.com (G. Jin).

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following points: (1) Ni, Cr, and Co are primary elements in most HEAs and the HEA containing Ni, Cr and Co with similar atomic radii can form solid solution easily. (2) Ti and V have a bigger atomic radii, which are used to bring about large lattice distortion. To some content, the performance of HEAs with the addition of Ti or V element are improved [28–30].

2. Experimental

The nominal compositions of the $NiCrCoVTi_{0.5}$ powder for laser cladding were prepared by mixing Ni, Cr, Co, V, and Ti powder with purity higher than 99.95%, bought from Changsha Tianjiu Metal Materials co., LTD in China. The average particle sizes were about 75–150 um. The raw powders were mixed for 0.5 h through the aid of a planetary ball milling machine with 2:1 mass ratio of ball-to-powder and 300 r/min speed and then dried in a vacuum oven for the next process. The TC4 titanium alloy (Ti-6Al-4V) was used as the substrate material with the original size of 100 mm × 100 mm × 10 mm. Before the experiment of laser cladding, the substrate was first roughened with a steel wire brush in order to decrease its reflectivity to laser radiation and then cleaned using alcohol and acetone in an ultrasonic cleaner to remove the surface contaminants, followed by pre-heating in a muffle furnace at 400–500 °C. Laser cladding/laser remelting was carried out with a laser cladding system shown in Fig. 1, consisting of a YLS-3000 laser, a coaxial powder delivery nozzle and a computer-controlled multi-axis positioning system. The parameters of laser cladding are as follows: laser power of 2 kW, laser spot diameter of 3 mm, and laser speed of 10 mm/s. Parallel laser tracks with ~40% overlap were fabricated to form a coating over the whole substrate surface and the obtained sample was denoted as as-cladded HEA coating. After laser cladding, the laser remelting was also processed using the laser cladding system with parameters: laser power of 2 kW or 1 kW, laser spot diameter of 3 mm, and laser speed of 10 mm/s. Thus, these obtained samples were named as as-remelted-1 kW HEA coating and as-remelted-2 kW HEA coating, respectively.

Fig. 1. Laser cladding system for laser cladding/remelting processing.

After laser cladding and laser remelting, the phase of coatings were analyzed by PANalytical X'Pert Pro MPD X-ray diffraction with Cu Kα radiation (γ = 0.15406 nm), and the tube voltage was 40 kV, the tube current was 40 mA, the scanning speed was 5 °/min. Microstructure observations were performed on scanning electron microscopy (SEM, FEI Quanta 200, Netherlands) with an acceleration voltage of 20 kV, equipped with an energy-dispersive X-ray spectroscopy (EDS). The micro-hardness was tested by a micro hardness tester (HVS-1000) with a load of 300 g and a loading time of 15 s. The wear tests were carried out using the MMS-2A roller friction wear tester (Jinnan Yihua Tribology Testing Technology co., LTD, China) at room temperature with a rotation speed of 200 r/min, a test load of 200 N, and a duration time of 30 min and the counter body of roller was a W18Cr4V steel (~790 HV) with the diameter of 40 mm. The wear mass loss was measured by precision balance instrument through weighing the samples before and after wear tests.

3. Results and discussion

Fig. 2 shows the XRD patterns of as-cladded and as-remelted HEA coatings. It reveals that the as-cladded HEA coating is mainly

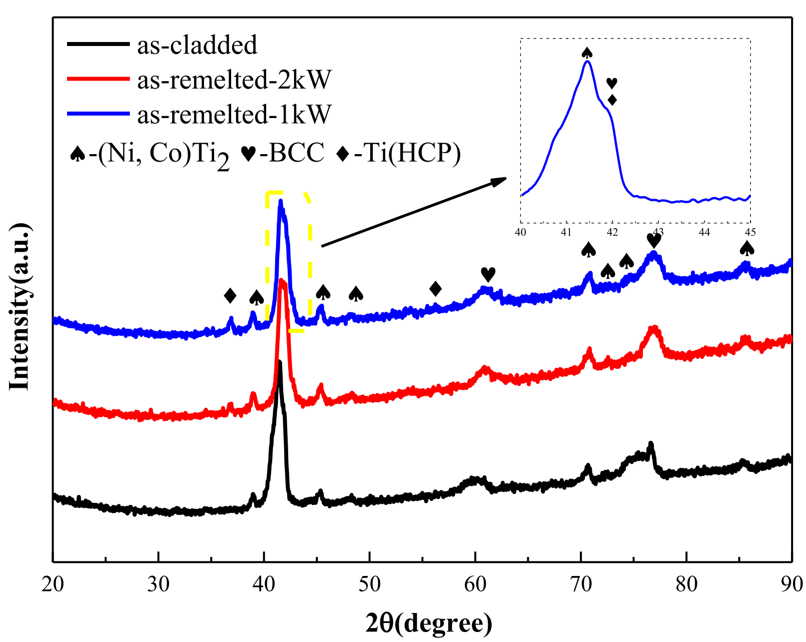

Fig. 2. XRD patterns of as-cladded and as-remelted HEA coatings.

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