Materials Letters 150 (2015) 35–38

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

Characterization and friction-reduction performances of composite coating produced by laser cladding and ion sulfurizing

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ARTICLE INFO

Article history:
Received 17 November 2014
Accepted 20 February 2015
Available online 27 February 2015

Keywords:
Laser cladding
Ion sulfurizing
Ni-based alloy
Sulfide
Solid lubrication
Wear and tribology

ABSTRACT

The microstructure and friction-reducing performance of a novel composite coating produced by laser cladding and ion sulfurization was investigated in this paper. It can be seen that a micro–nano sulfide solid lubrication film of about 3–4 μm thickness was successfully prepared on the surface of Ni-based alloy deposited coating. The surfaces of sulfurizing layers are loose and uneven, and the sulfurizing layers are well bonded with the laser cladding layer. The result of friction and wear test indicates that the friction coefficient and wear loss of sulfurizing composite coating decrease apparently under dry and oil lubrication condition. The sulfurizing layer of FeS and WS_2 phase on the hard Ni-based alloy layer played an important, beneficial role for improving the friction-reducing performance of laser cladding coating.

1. Introduction

Laser cladding is a novel surface treatment technology which takes possession of advance features, such as minimal dilution, dense coating, metallurgical bonds with base material and high process flexibility [1,2]. With the addition of carbide, oxide, rare earth, etc., laser cladding Ni-based alloy can obtain high hardness coating [3,4]. However, such coatings are easy to excessive wear of mating plate [5]. In order to provide optimum wear protection for easily worn components, it is necessary to adopt a solid lubricant coating so as to reduce friction and protect the opposing surface. Low temperature ion sulfurizing has become a widely used preparation method of sulfide solid lubricant because of its good anti-friction and self-lubrication property [6,7]. In order to improve wear reduction, ion sulfurizing often complexes with the surface hardening treatment process [6,8–10]. In addition, ion sulfurizing is used to process the surface of iron and steel materials to form the FeS solid lubrication film [11,12], and hence researchers are conducting sulfurizing for pure metal [13–15]. However, to the best knowledge of the authors, the ion sulfurizing of Ni-based alloy metal ceramic have rarely been reported in open literature.

In this paper, a sulfurzing layer on the surface of Ni-based alloy deposited coating whose surface is soft, subsurface is hard was prepared by Laser cladding and low temperature ion sulfurizing. The microstructure and tribological performance of the novel composite coating were investigated.

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http://dx.doi.org/10.1016/j.matlet.2015.02.098
0167-577X/

2. Experimental details

A medium carbon steel with a composition of Fe–0.45C–0.3Si–0.6Mn (wt%) was adopted as the substrate for laser cladding treatment. The as-received powders were self-made Nickel-based alloy powder and its chemical composition was 0.5% C, 13.4% Cr, 0.1% Mn, 2.3% Si, 1.7% B, 12.5% Fe, 51.5% Ni, 13% WC and 5% Cr_3C_2. The laser cladding was carried out with a DL-HL-T5000 type cross-current CO_2 laser in an argon shielding atmosphere. The specific parameters were spot size of 10 mm × 1 mm, power 3600 W, scanning speed 150 mm/min, preheating temperature of substrate 200 °C,preset spread powder thickness 1 mm, overlapping rate 30%. The hardness of laser cladding layer was about 55HRC. Before ion sulfurizing treatment, the surface of laser cladding layer was grinded and polished, and rinsed with ethanol followed by acetone. The low temperature ion sulfurizing was carried out in LDMC-15A type multifunctional ion chemical heat treatment furnace. H_2S was the sulfur gas, and Ar and H_2 were the auxiliary gases, the purity of gas was no less than 99.9%. Ion sulfurizing test parameters were gas ratio H_2: Ar: H_2S = 150: 50: 15, voltage 560–700 V, current 0.5 A, temperature 280 °C and time 2 h.

JEOL JMS – 6380LA Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectrometer (EDS) and TMX 2000 Atomic Force Microscope (AFM) were employed to analyze the morphologies of surface and cross-section of sulfurizing composite coating. X'Pert PRO MPD type X-ray Diffraction (XRD) was utilized to analyze the surface phase structure.

The bonding strength between sulfide layer and deposited coating was carried out by the scratch test method using a WS-2005 scratch tester (Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences). A diamond tip with a radius of 0.2 mm was slid at a scratch speed of 2 mm/min on the sulfurizing layer. The total length of the scratch scar was 5 mm. The critical load value which is defined as the normal load that causes the films to fail or detach from the deposited coating was recorded [16]. The friction and wear tests were carried out on a pin-on-disc tester of MMU-5G model. The upper specimen was a GCr15 pin with 4 mm in diameter and a hardness of 60 HRC, and the lower specimens were the 1045 steel discs with laser cladding coating or sulfurizing composite coating with dimension Φ 40 mm $\times$ 10 mm. For oil lubrication condition, the lubricant was No. 40 lubrication oil with drip lubrication and the oil supplying rate of 2 ml/min. Fixing the test load of 50 N and the test velocity of 50 r/min for measuring the variation of friction coefficient with time, the during time was 60 min, friction coefficient was automatically collected by computer. The specimens were thoroughly cleaned with acetone in an ultrasonic cleaner before and after the wear test. After the wear test, the weight loss was measured using a Sartorius electronic weighing scales with an accuracy of $\pm$0.1 mg, all the experiment results were the average of three samples.

3. Results and discussion

Microstructure: Fig. 1 shows the surface morphologies of laser cladding coating and sulfurizing composite coating. The typical microstructures of the surface of laser cladding coating are the solid solution cellular dendritic crystal and the interdendritic eutectics as shown in Fig. 1a. After sulfurizing treatment, there is a layer of sediment attached to the deposited layer surface which is dense and with a lot of pits and particles as shown in Fig. 1b. It also can be seen that the surface topography fluctuation of sulfurizing layer is related with the deposited coating and then the morphologies of cellular dendritic crystal of laser deposited layer was reflected clearly. Fig. 1c is the SEM surface morphology, revealing the loose and porous characteristics. The bottom of sulfurizing layer is the original sulfide particles of micro–nano scale (average particle size of 87 nm). Fig. 1d shows the surface morphology of sulfurizing layer by AFM. It can be seen that the grain dimension is at micro to nano scale level, illustrating the sulfurizing film possesses the micro–nano structure and the surface roughness Ra is 0.08 μm.

The cross-section morphologies and S element distribution of sulfurizing layer is shown in Fig. 2. It shows that the sulfurizing layer is continuous layer of gray and black strip distribution, with thickness of about 3–4 μm. S content of the surface is significantly higher than in the inner region, indicating that S produce enrichment in the surface and the thickness of S-rich layer is about 4 μm, consistent with the morphology results.

The component phases of the laser cladding coating and sulfurizing composite coating identified by the X-ray diffraction analysis are illustrated in Fig. 3. The major phase of laser cladding coating were (Ni, Fe) solid solution and Cr_7C_3, and owing to pyrolyzed there was a small amount of WC phase retained, and nearly no Cr_3C_2 could be detected. In terms of sulfurizing composite coating, both FeS and FeS_2 were produced, the WS_2 phase was

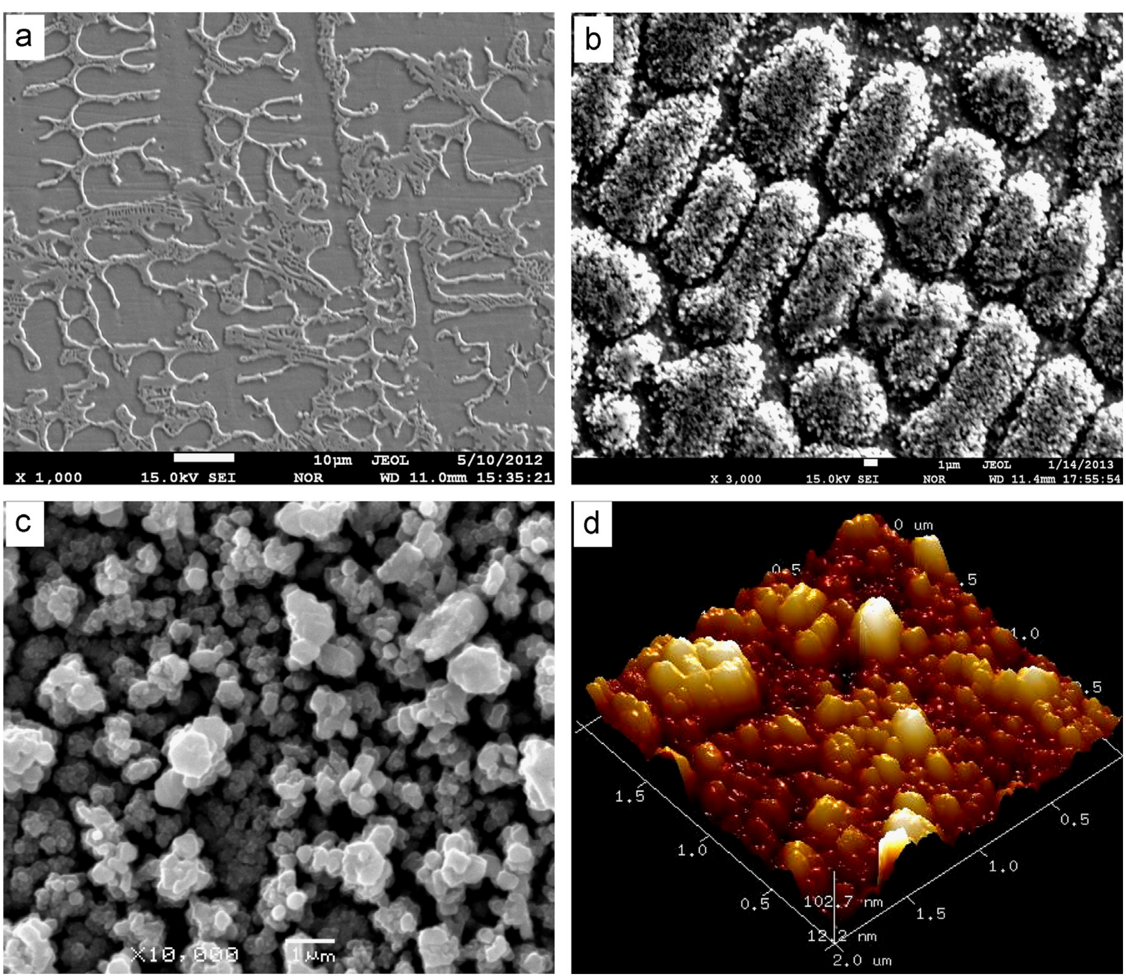

Fig. 1. Surface morphology of (a) Laser cladding coating; SEM (b and c), AFM (d) images of sulfurizing composite coating.