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Characterization on laser clad nickel based alloy coating on pure copper

Yong-zhong Zhang *, Yi Tu, Ming-zhe Xi, Li-kai Shi

Center for Composites, General Research Institute for Non-ferrous Metals, Beijing 100088, PR China

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ABSTRACT

Nickel based alloy coating has been successfully deposited onto pure copper surface by laser cladding with coaxial powder feeding. Coating with thickness in the region of 1.5 mm can be obtained by depositing two layers of overlapping laser clad tracks. The microstructure observation from optical microscopy and scanning electron microscopy indicated that the coating was free of cracks and pores, and soundly bonded with the substrate. The X-ray diffraction analysis results showed that the coating was mainly composed of **γ**-(Ni, Cr, Mo, W) solid solution, some carbides and silicides. The average hardness of the coating was about $HV_{0.1}$ 360, which was about 5 times that of the pure copper. The dry sliding wear tests showed the wear resistance of copper was significantly improved after laser clad nickel based alloy coating.

1. Introduction

Currently copper and its alloys are widely used in daily life and modern industries due to their high electric and thermal conductivities as well as excellent corrosion resistance. Efforts to develop new copper alloys with high strength, high conductivity and high sliding wear resistance are arising to meet the tight requirements for electronic vacuum devices, lead frame materials for integrated circuit, casting mold, and crystallizer in continuous casting, etc. [1,2]. However, in many cases, the properties of corrosion and wear resistance are mainly required by the material's surface, therefore surface engineering including surface modification and surface repairing are attractive techniques to improve components' performance and reduce the consumption on resource and energy. The laser cladding process can locally prepare thick coatings with improved properties on common materials and can allow the automatic repair of high-value components with excellent quality [3–5]. While laser cladding on copper presents some difficulties due to its high reflectivity to laser beam and thermal conductivity [6–12]. Laser cladding with pre-coating is chosen as a feasible method to overcome the absorption problem. While the thickness of laser cladding with pre-coating is restricted as compared to laser cladding with powder feeding due to their different procedures of melt pool formation and heat transmission. It was reported that, with the introduction of a nickel intermediate layer, a 0.13 mm thick Mo/Ni layer was obtained on copper by a two-step laser clad of preplaced Ni and Mo layers. In this way the wear resistance of copper could be largely improved [6]. Ni-based claddings were obtained on Cu by a two-stage process, which included plasma spraying first for reflectivity reduction and then laser cladding [7]. Another way to overcome the above difficulties is preheating the substrate or using a laser beam with higher power or power density. It was found that a complex and uneven microstructure was formed during laser cladding of Cu–Fe–Al–Si on copper with a laser power of 8 kW [10]. A 0.4 mm thick nickel based alloy layer was prepared on Cu by plasma arc laser remelting the preheated plasma spraying layer. The morphology of the cross-sectional interface indicated the occurrence of heavy dilution by the substrate [11]. In view of the good dissolving capacity between nickel and copper, and that nickel based alloys have been widely used for surface coating due to their good wear and corrosion resistance, in this work a self-developed nickel based alloy was laser clad on copper to improve its surface hardness as well as wear resistance. To obtain thicker coating conveniently, laser cladding with powder feeding was adopted.

2. Experimental procedures

The substrates used were annealed pure copper plates with dimensions of 100 mm×50 mm×12 mm. The mean grain size of the substrates was about 60 μm. The substrates were surface machined, cleaned down with scratch wire brush for increasing surface roughness and then cleaned with ethanol before cladding. The powder used was gas atomized spherical nickel alloy powder with a nominated composition of C: 1.20–1.40, Cr: 17.5–19.5, Mo: 7.5–8.5, W: 4.2–4.5, Al: 2.7–3.2, Ti: 3.0–3.5, Si: 2.0–3.0, Zr: 0.03–0.08, Fe≤1.0, Mn<0.50, B≤0.001, Co≤0.01, Ni: balance. The powder was provided by Tianjin Zhujin Company, China. The size of the powder was in range of 45–100 μm.

Laser cladding was carried out using a laser powder deposition system, which consists of a 5 kW transverse flow continuous wave CO_2 laser, a coaxial nozzle for powder feeding, a GTV-PF 2/2 powder feeder

* Corresponding author. Tel.: +86 10 82241223; fax: +86 10 62355099.
E-mail address: yyzhang@grinm.com (Y. Zhang).

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(GTV, Germany), a computer-controlled multi-axis positioning system and stage. The laser beam was focused using a reflective copper mirror with a focal length of 350 mm, and the focusing point was maintained at 10 mm above the substrate giving a laser spot size on the substrate of approximately 2.5 mm. The offset distance between the coaxial nozzle and the substrate was about 16 mm. During cladding, the powder was fed by argon gas in flow rate of 2.5 L/min. And a shroud gas of argon in flow rate of 2.0 L/min was passed through the laser head along the laser beam to protect the mirrors from contamination and prevent the coating from oxidation.

The samples for microstructure observation were cut along the cross-section of the cladding and then prepared by standard metallographic procedure. Microstructure observation and composition analysis of the coating were carried out on Axiovert 200 MAT optical microscope (Zeiss, Germany) and S-4800 scanning electron microscope (Hitachi, Japan) equipped with Thermo Noran energy dispersive spectrometry (Horiba Emax-350). The XRD analysis was carried out using a D/max-2200 PC X-ray diffractometer (Rigaku, Japan) with Cu K_α diffraction generated at 40 kV and 40 mA, and a scan rate of 1°/min. The plane surface of the coating was polished for XRD analysis.

Microhardness test was performed along the cross-section of the coating using a HX-1 hardness tester (Wuzhong, China) with a 100 g load and a 15 s holding time. The dry sliding wear resistance of the clad specimen and Cu substrate was determined using a UMT-2 tribotester (Center of trobology, USA) in reciprocating style. The counterpart was a GCr15 steel ball in diameter of 4 mm with hardness of HRC 65. The specimens with dimensions of 30 mm × 20 mm × 10 mm were finally surface polished with grade 1000 grits sand paper before wear test. All tests were performed with a load of 150 g, a frequency of 3 Hz, a test time of 30 min, and a stroke of 4 mm. The width and depth of the wear track were measured using a Talysurf 5P-120 profilometer (Taylor Hobson, UK).

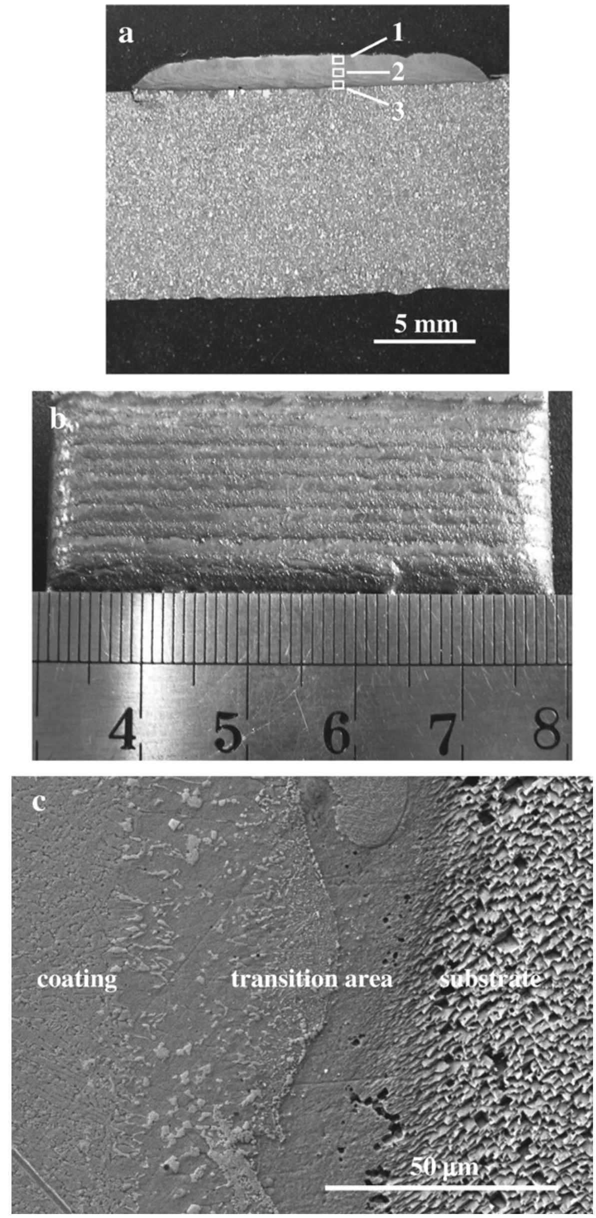

Fig. 2. Cross-section (a), surface (b) and its interface morphology (c) of two layer laser cladding of 12 parallel tracks.

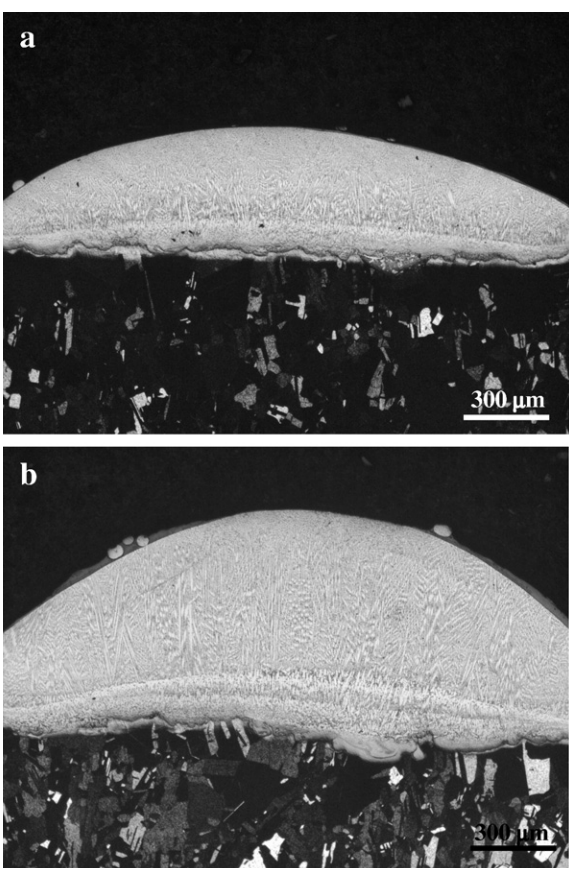

Fig. 1. Cross-section morphology of laser clad nickel based alloy coating on copper. a — One layer track, b — two layer track.

3. Results and discussion

As indicated above, the great obstacles for laser cladding on Cu are from the low absorptivity to infra-red wavelength laser and high thermal conductivity of the substrate. Our preliminary laser cladding efforts showed that no continuous coatings could be obtained on cold Cu substrate even with a laser power as high as 4 kW and a low scanning speed of 1 mm/s. For longer wavelength laser such as CO_2, the Hagen–Rubens equation as $A = k(\rho/\lambda)^{1/2}$ is applicable at normal incidence, where A is absorptivity of materials, k constant with a value of 0.365, ρ the electrical resistivity, and λ wavelength of laser radiation [13]. So the absorptivity of a material is proportional to the square root of its electrical resistivity, and the resistivity of the pure copper increases with the temperature. In this work, the substrate was preheated to 300 °C in air with electric resistance furnace before