

Laser Surface Alloying of Low Carbon Steel Using High-entropy Alloy Precursors

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Abstract: The Al_{0.5}CoCrCuFeNi high-entropy alloy powders with simple face-centered-cubic (FCC) solid solution structure were introduced into the surface layer of a low carbon steel during laser surface alloying. A high performance surface layer with extremely fine martensite as the dominant phase was obtained, resulting in a great improvement in microhardness, wear resistance, and corrosion resistance. The great enhancement of microhardness and wear resistance of the laser alloyed layer is mainly due to the formation of extremely fine martensite hard phase, the solid solution strengthening of the alloying elements in supersaturated α -Fe solid solution, and the existence of size effect and strain effect under rapid solidification. The enhancement of corrosion resistance is due to the alloying of Al, Co, Ni, Cr and Cu in the laser alloyed layer.

Key words: laser surface alloying; high-entropy alloy; hardness; wear; corrosion

In materials engineering applications, surface properties like wear and corrosion resistance are usually required especially under harsh service conditions. Thus, the surface modification of existing materials to enhance certain properties at the surface while not affecting the properties in the sub-surface region would be more economical than fabricating the bulk materials.

High-entropy alloys (HEAs) have promising properties including high hardness, as well as outstanding wear, corrosion and oxidation resistance, and are thought to have great potentials for hard facing applications^[1-7]. In this study, HEA surface layers have been fabricated on traditional alloys by various surface technologies, such as laser cladding, laser surface alloying, tungsten inert gas process and plasma transferred arc cladding process, etc.^[8-11]. Previous studies on the production of HEAs layers on the substrate by laser cladding (LC) or laser surface alloying (LSA) approaches used mixed pure elemental powders^[12,13]. Up to now, no LSA

studies using HEA powders as the alloying agents have been reported. In this study, the Al_{0.5}CoCrCuFeNi HEA powders were employed as the alloying material in an effort to evaluate the possibility of producing high hardness, as well as high wear and corrosion resistance layer on a low carbon steel by incorporating multiple elements in a form of simple solid solution into the substrate during LSA. The microstructure, phase constitution, hardness profile, and tribological and corrosion behavior of the laser alloyed zone have been investigated.

1 Experimental

A commercial low carbon steel with a chemical composition of C 0.17–0.24, Si 0.17–0.37, P \leq 0.035, S \leq 0.035, Ni \leq 0.25, Cr \leq 0.25, Cu \leq 0.25 in mass% and balanced Fe was used as the substrate. The Al_{0.5}CoCrCuFeNi HEA powders used in this study were synthesized using Al, Co, Cr, Cu, Fe and Ni elemental powders (purity of more than 99.5% and particle size of less than 45 μ m) by me-

chanical alloying approach. Before LSA, the low carbon steel planks with sizes of 40 mm × 15 mm × 10 mm were polished to obtain uniform roughness and ultrasonically cleaned in acetone. The HEA powders were uniformly mixed with an organic binder into a viscous slurry and then applied onto the surface of the low carbon steel planks. The coatings were dried in air for 2 d and then ground to a thickness of 0.5 mm by 1000 grit SiC paper under dry condition.

A Nd: YAG pulsed solid laser operating at a wavelength of 1064 nm was used to produce linear re-melting tracks on the pre-coated substrates which were cooled with water to evaporate the heat produced by the laser heating. An X-Y table with computer numerical control moved the samples at a constant rate under the stationary laser beam. Argon gas of 30 L/min blowing through a ϕ 4 mm jet and coaxial with the laser beam was used to shield the melt pool from oxidation and protect the laser optics from fumes and spattered particles. After a series of optimizations, the current, scanning speed and the defocus for LSA process in this paper were determined as 275 A, 3 mm/s and -14 mm, respectively. For multi-tracks re-melting, a 40% overlap between tracks was used.

X-ray diffraction (XRD) was used for the identification of the crystal structure of the precursor powders and the laser alloyed layer after LSA, and the scanning was performed at a 2θ range of 20° – 100° . The microstructures were observed using scanning electron microscopy (SEM) and the chemical compositions were determined by energy dispersive spectrometer (EDS) equipped with SEM.

The microhardness profiles from the laser track regions to the substrate were measured using a microhardness tester under a load of 0.49 N with dwell time of 10 s. The adhesive wear behaviors of the substrate and the laser alloyed layer were evaluated under dry sliding conditions at 500 °C by using an MT-2000 tester with a load of 100 N after 4000 rotations. The morphologies of the worn surfaces were examined by SEM.

The electrochemical measurements were carried out in CHI660C potentiostat. The substrate and the laser alloyed layer were degreased in benzene, cleaned ultrasonically and subsequently washed with distilled water prior to electrochemical tests. Their corrosion behaviors were examined with an exposed working electrode area of 1 cm² in 3.5 vol. % NaCl solution at (23 ± 1) °C open to air and repeated sev-

eral times to ensure the reproducibility of the data. DC105 corrosion software was used to analyze the Tafel region, while potentiodynamic polarization experiments were performed at a scan rate of 1 mV/s.

2 Results and Discussion

Fig. 1 shows the XRD pattern of the Al_{0.5}CoCr-CuFeNi precursor powders. Only face-centered-cubic (FCC) solid solution phase was detected under the resolution of XRD analysis. The average size of the powders is about 30 μ m and the powder has a homogeneous composition. The actual chemical composition, as indicated in Fig. 1(b), is multi-components and very close to the designed one. The differential scanning calorimetry (DSC) analysis indicates that the melting point of the HEA powders is 1381 °C.

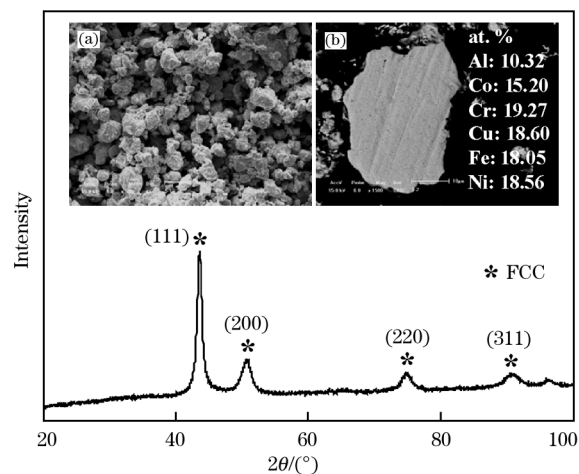


Fig. 1 XRD pattern of HEA powders by mechanical alloying; morphology of HEA powders (a) and cross-sectional micrograph of an HEA powder (b)

After LSA, the structure from the surface to the substrate could be separated into three characteristic zones; the laser alloyed layer, the heat-affected zone (HAZ) of the substrate and the non-affected substrate. A typical transverse section of a laser surfaced alloyed specimen is shown in Fig. 2(a). The thickness of the laser alloyed layer and the HAZ are about 300 μ m and 100 μ m, respectively. Figs. 2(b) and 2(c) represent high-magnification SEM micrographs of the laser alloyed layer and the HAZ as indicated in Fig. 2(a), respectively. The microstructure of the laser alloyed layer mainly consists of extremely fine martensites (Fig. 2(b)) and the HAZ observed below the laser alloyed layer results in a duplex microstructure composed of retained ferrite matrix and martensite islands (Fig. 2(c)). The bottom of Fig. 2(c) shows the microstructure of the sub-

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