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Corrosion behaviors of $Cr_{13}Ni_5Si_2$ based composite coatings prepared by laser-induction hybrid cladding

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ABSTRACT

Crack-free $Cr_{13}Ni_5Si_2$ based composite coatings were prepared by laser-induction hybrid cladding. Corrosion resistances of the coatings were investigated by dynamic polarization, electrochemical impedance spectroscopy and immersion tests in 1 N HCl solution. Results indicate that the coatings have better corrosion resistance than the stainless steel 1Cr18Ni9Ti, and the corrosion mechanism of the coatings is micro-galvanic corrosion between the $Cr_{13}Ni_5Si_2$ and the Ni_ based solid solution. Compact passive film was formed on the surface of the coating owing to its high content of Cr and Si, which can effectively protect the $Cr_{13}Ni_5Si_2$ based composite coatings from severe chemical attacking.

1. Introduction

Corrosion is a surface related degradation phenomenon that results in failure of mechanical components working under aggressive corrosion conditions [1–3]. It is a great and continuous challenge for the researchers and engineers to improve corrosion resistance of materials further.

Metal silicides such as $Cr_{13}Ni_5Si_2$, Cr_3Si, Mo_3Si/Mo_5Si_3, Ni_2Si, etc. have attracted extensive attentions due to their high corrosion resistance [4–8]. However, brittleness at room temperature is a main drawback of the metal silicide [9,10]. Composite is an effective way to improve toughness of the metal silicide, and by the introduction of a second ductile phase, its room-temperature brittleness was decreased effectively and the metal silicide based composite was hence developed [11,12]. Over the years, $Cr_{13}Ni_5Si_2$, Mo_3Si/Mo_5Si_3, Ni_2Si have been modified by composite successfully, and the metal silicide based composite with high mechanical properties and corrosion resistance has been developed [4–6,8]. Compared with binary metal silicide, the ternary metal silicide $Cr_{13}Ni_5Si_2$ has relative weaker atom bonding and better toughness. Besides, the high chromium content in the $Cr_{13}Ni_5Si_2$ can promote the formation of stable passive film in corrosive electrolyte [13,14]. Thus, the $Cr_{13}Ni_5Si_2$ based composite is anticipated to be a promising wear and corrosion resistant materials. In the past few years, Yuan and Wang have prepared $Cr_{13}Ni_5Si_2$ based composite by induction melting and die casting, results indicated that it has excellent corrosion resistance [4,15].

Compared with fabricating block $Cr_{13}Ni_5Si_2$ based composite, cladding metal silicide based composite coating on a commonly used steel substrate by surface engineering technique is lower cost and more resource saving. Laser cladding (LC) is a potential way for fabricating high performance coatings owing to its low dilution with the substrate, fine grain size, and small heat affected zone [16–18]. Wang and Duan have prepared Cr_3Si reinforced composite coatings by laser cladding, results showed that the coatings have high corrosion resistance [5]. Besides, Cai and Wang have clad $Ni_2Si/NiSi$ composite coatings on a low carbon steel substrate, and the influence of chromium addition on corrosion resistance of the coating was investigated. Results indicate that the addition of chromium enhanced corrosion resistance of the composite coating greatly [19]. However, low deposition rate is a main drawback for laser cladding [20].

Laser-induction hybrid cladding (LIHC) is a novel surface engineering technique, which combined both the laser beam and induction heat source together. Because of the synergistic effect of the two heat source, LIHC can not only significantly improve deposition rate of conventional LC, but also can effectively mitigate residual stress in the LC coatings [21-26]. Recently, we have prepared $Cr_{13}Ni_5Si_2$ based composite coatings by LIHC. Results showed that the deposition rate of the LIHC is 3.8 times higher than that of the LC, and crack in the coatings was completely eliminated. Furthermore, the composite coatings exhibit high wear resistance [27–30].

Previous works showed that preparing $Cr_{13}Ni_5Si_2$ based composite coatings by LIHC have bright prospect in industrial applications.

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Table 1
Processing parameters for LIHC.

Parameters	
Laser power (kW)	4
Laser spot size (mm × mm)	15 × 1
Laser scan speed (mm/min)	361.7
Induction preheating temperature (°C)	750
Powder feed rate (g/min)	42.5
Overlap rate (%)	30

However, report about corrosion behaviors of $Cr_{13}Ni_5Si_2$ based composite coatings by LIHC is rare. In this paper, $Cr_{13}Ni_5Si_2$ based composite coating was prepared by LIHC, corrosion behaviors of the coating were investigated by dynamic polarization, electrochemical impedance spectroscopy (EIS) and immersion tests in 1 N HCl solution.

2. Experimental procedure

2.1. Specimen preparation

The $Cr_{13}Ni_5Si_2$ based composite coatings were prepared using a CO_2 laser based LIHC system, which has been introduced in our previous work [27]. The raw material is argon atomized Ni-Cr-Si elements powders with composition of 43Ni-50.8Cr-6.2Si (wt%), and its particle size is 50–150 μm. In the process of LIHC, the raw powders were delivered into the molten pool by a co-axis powder feed nozzle, and argon with flow rate of 5 *l*/min is acted as powders carrying gas and laser molten pool shielding gas. Tool steel 9Cr2 is widely used in molds and rolls services under aggressive conditions, preparing wear/corrosion resistant coatings on its surface is an effective way to improve its service life. Here, tool steel 9Cr2 with diameter of 96 mm is selected as the substrate, and its nominal chemical composition is 0.9C-2.0Cr-Fe (wt%). $Cr_{13}Ni_5Si_2$ based composite coating was prepared on the substrate surface by LIHC, and processing parameters are listed in Table 1.

2.2. Morphology and microstructure characterization

Cracks in the composite coatings were inspected by dye penetrant testing. Then, the composite coatings were machined by electrical spark cutting and the metallographic analysis was taken from the cross-section with the standard polished method. The microstructure of the composite coatings was characterized by Scanning Electron Microcopy (SEM, JSM-7600F) coupled with an energy dispersive spectroscopy (EDS, IncaX-Max 50), volume fraction of the $Cr_{13}Ni_5Si_2$ in the composite coating was measured by a commercial software imaging-plus 6.0. The phases in the coatings were identified by Bruker D8 Advance Automatic X-ray Diffractometer (XRD) with Cu target.

2.3. Corrosion test

The corrosion samples were epoxy resin sealed except only one surface for testing. Dynamic polarization curves and EIS of the samples in 1 N HCl were carried out by a standard three-electrode electrochemical workstation (CS-310, Corrtest Ltd., Wuhan, China), with a platinum sheet as the auxiliary electrode (AE), a saturated calomel electrode (SCE) as the reference electrode, and the samples as the working electrode (WE).

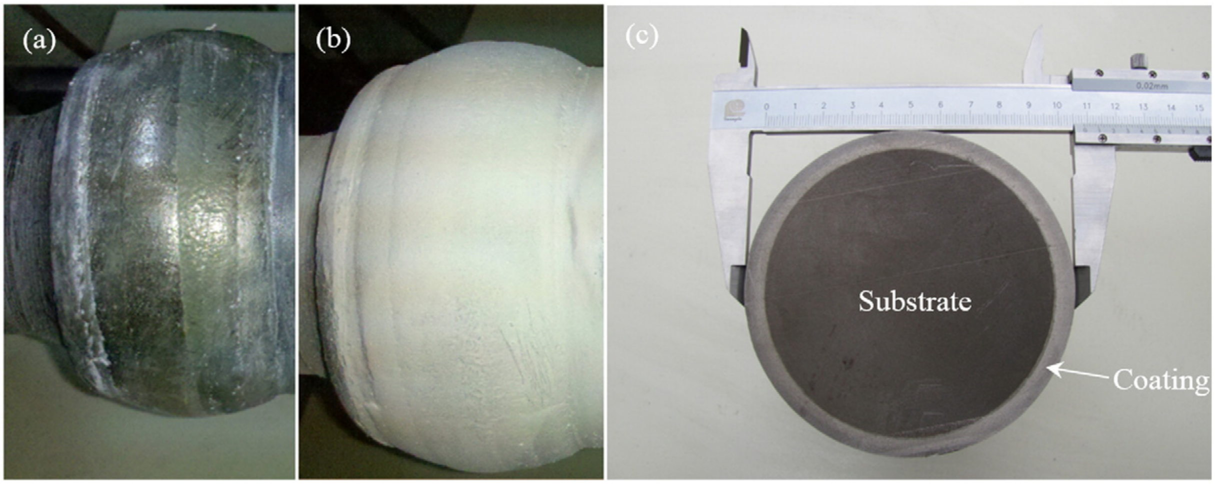

Fig. 1. (a) Morphologies, (b) dye penetration inspection and (c) cross-section of the $LIHC_{ccs}$.

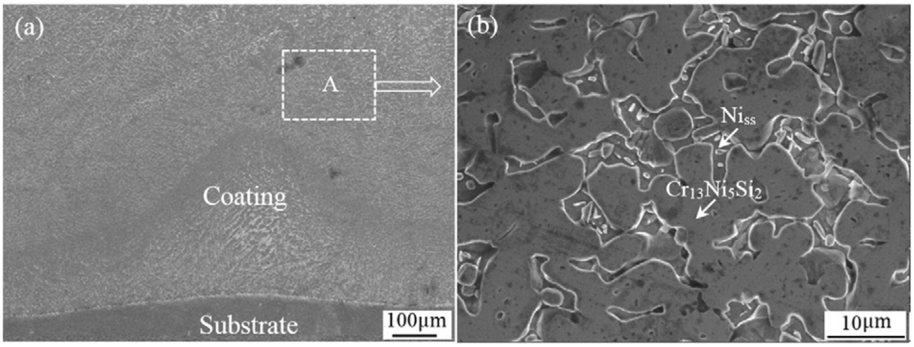

Fig. 2. (a) microstructure of the $LIHC_{ccs}$ (b) magnification of area A.