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Effect of Ni content on stainless steel fabricated by laser melting deposition

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ABSTRACT

The novel stainless steel + x wt.% Ni ($x = 0$, 3.05, 6.10, 9.15) specimens were successfully fabricated by laser melting deposition, aiming at investigating the influence of Ni content on stainless steel structure and property. The effects of Ni content on phase compositions, microstructure, microhardness, wear and electrochemical corrosion resistance of as-deposited stainless steel were studied systematically using XRD, OM, SEM, microhardness tester, friction-wear tester and potentiodynamic polarization measurement, respectively. Experimental results showed that with the increase of Ni content, the constituent phase of the as-deposited specimen changed from ferrite phase (specimen for $x = 0$) to austenite phase (specimen for $x = 9.15$). The microstructure growth followed the principle of dendrite growth. However, the dominant microstructure varied from equiaxed dendrite to columnar dendrite with increasing Ni content. Phase transition from ferrite phase to austenite phase with the addition of Ni content resulted in the decrease of microhardness value from 643HV to 289HV. Meanwhile, the wear resistance of as-deposited specimens decreased gradually with the increasing of Ni content, which might be attributed to the fact that the wear resistance is proportional to microhardness according to Archard's law. It was noted that corrosion resistance of as-deposited stainless steel was extremely improved with the increase of Ni content. The higher Ni content specimen (specimen for $x = 9.15$) exhibited the best corrosion resistance among the tested specimens based on corrosion rate, which was one order of magnitude lower than that of the lower Ni content specimens (specimens for $x = 0$, 3.05).

1. Introduction

Recently, laser additive manufacturing (LAM) has been acknowledged as one of the most promising manufacturing technologies due to its advantages compared with conventional manufacturing technologies [1–3]. LAM is a manufacturing process combined rapid prototyping and laser cladding, which utilizes computer-aided system to fabricated products with complex geometry, high flexibility and high automation [4,5]. LAM enables to fabricate near-net-shape metallic parts with full density, low thermal inputting, low dilution rate without the need of post-processing treatment compared with the conventional technologies [6,7]. In accordance with the different ways of powder feeding, the LAM technology is divided into two categories: selective laser melting (SLM) and laser melting deposition (LMD) [8]. Because of its advantages which are low cost, short working time, high efficiency and excellent mechanical properties, LAM technology is widely applied in the fields of aviation, aerospace, automobile industries and medical industries [9,10]. At present, the amount of investigations have been conducted to study the effect of process parameters, microstructure morphology and phase composition on mechanical properties of the LAM fabricated samples.

The microstructure heterogeneity of Inconel 718 alloy fabricated by the direct laser additive manufacturing was studied by Tian et al. [11]. This study revealed that compared with grains of the lower region, it can be seen that grains in the top region are observed to possess higher misorientation. The microstructure heterogeneity was attributed to primary solidification, remelting, solute segregation and thermal history during solidification. Liu et al. [12] investigated the influences of process parameters on the microstructure, internal defects, relative density, microhardness and tensile properties. Experimental results indicated that the optimal parameters were laser power 1000 W, powder feeding speed 25 V, scanning velocity 8 mm/s. The form restoration of groove defect has been achieved by the LMD process. They found that the LMD process significantly improved the properties of TC17 titanium alloy. Tensile strength and elongation could reach

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91–98% that of conventional TC17 wrought material. In previous studies, both Suo et al. [13] and Vastola et al. [14] have explored the additive manufacturing of Ti-6Al-4V. The outcomes indicated that the microstructure of Ti-6Al-4V mainly consisted of large columnar β grains grew epitaxially along the building direction. Annealing treatment was hardly effected for tensile properties. In addition, hot isostatic pressing treatment enhanced ductility and toughness, but tensile property was decreased to a certain degree. Residual stress played a major role in the properties of titanium alloy, which was remarkably minimized through adjusting process parameters. Jukka-Pekka Järvinen et al. [15] have analyzed two kinds of structures: web and tube supports, which one of them was reasonable for dental application and jewellery application. The study indicated that web supports were suitable in the field of medicine and jewellery industries due to the mobility of web supports. The build of Inconel 718 and 316 stainless steel has been successfully manufactured by Alejandro Hinojos et al. [16] through electron beam melting additive manufacturing technology. The results suggested that the stress between the IN718 substrate, and the build resulted in the formation of cracking in the 316L SS/IN718. Further work should be focused on the influences of process parameters on the cracking. Guan [17] and Wang [18] have investigated the effect of processing parameters on 304 stainless steel and 304L stainless steel fabricated by additive manufacturing. It was found that adjusting parameters highly impact on mechanical properties. Previous literatures reported that the amount of materials that have been used to manufacture industrial parts is stainless steel. It is the combination of high strength and hardness, good thermal stability, excellent resistance to corrosion, wear and fracture properties [19,20]. However, few researches [21,22] have investigated the effect of alloying element on microstructure and mechanical properties of as-deposited components fabricated by additive manufacturing.

The nickle element is austenite forming element, which leads to the formation of the face centered cubic phase. Further to this addition of Ni element would affect microstructure, microhardness, cracking susceptibility, wear and corrosion resistance, and oxidation resistance of as-deposited samples. In this study, a new type of stainless steel powder, mixing with different Ni content, was used as raw materials to fabricate as-deposited specimens using laser melting deposition. The current study aims to investigate the impact of the increase of Ni content on phase composition, microhardness, wear and electrochemical corrosion resistance of fabricated stainless steel. However, this new type of stainless steel possesses high hardness but poor corrosion resistance. Adjusting Ni content improves the corrosion resistance of stainless steel to optimize the Ni content with the best properties, providing essentials for further research and applications of this new type of stainless steel in various working conditions.

2. Experimental materials and methods

An as-received 35CrMo steel in the form of a plate with the diameter of 150 mm and the thickness of 15 mm was selected as the substrate material, with the nominal composition in wt.%: 0.32–0.40 C; 0.80–1.10 Cr; ≤0.30 Ni; 0.17–0.37 Si;:0.15–0.25 Mo; 0.40–0.70 Mn; ≤0.30 Cu; ≤0.035 S; ≤0.035 P and balance Fe. The as-deposited specimens with different Ni content were manufactured using a Ytterbium Laser System (YLS-6000) with a wavelength of 1070 nm and maximum output power of 6 kW. Four types of alloy powders were made of a novel stainless steel powder and purity 99.9% nickel powder which were weighed and mixed in different proportions to obtain the experimental alloy powders (novel stainless steel + x wt.% Ni, x = 0, 3.05, 6.10, 9.15). And novel stainless steel and nickel powder mixture were thoroughly mixed with the aid of a ball milling equipment in an argon atmosphere for 2 h before LMD. The chemical composition of the experimental alloy powders with a particle size ranged from 53 to 150 μm was shown in Table 1. The alloy powders were dried for 8 h in a vacuum furnace at 80 °C and the oxide scale of the substrate was removed before LMD. The processing parameters in study were summarized as following: laser power 2 kW, scanning velocity 7 mm/s, powder feed rate 7 g/min, shielding gas (Ar) 400–500 L/h, spot diameter 4 mm, and scanning interval 2.3 mm.

Phase identification was performed by X-ray diffraction (XRD, Rigaku, XRD-7000) at a scanning speed of 4°/min ranging from 20° to 100° with Cu Kα. For metallographic observation, the fabricated specimens were cut, resin mounted, polished and etched with aqua regia. Microstructures and chemical composition were characterized using optical microscopy (OM, ZEISS, HAL-100), scanning electron microscopy (SEM, Hitachi, S-3400N) equipped with an energy dispersive spectrometer (EDS, Hitachi, S-3400N).

The microhardness along the building direction was measured using Vickers hardness tester (HV, Huayin, HVS-1000) with a dwell time of 10 s and a load of 2 N. Dry sliding wear tests of the as-deposited samples were carried out on a linearly reciprocating friction and wear tester (Lanzhou Institute of Chemical Physics, MFT-4000) in the ball-on plate configuration. A Si_3N_4 ball with diameter 5 mm was selected as wear material in the test, with a stroke length of 7 mm, a normal load of 10 N, a sliding velocity of 120 mm/min and a duration of 60 min. The profiles across the wear tracks and the wear volume were measured using a surface profilometer (KLA-Tencor Corporation, Micro XAM-3D). The product of the cross-section area and the stroke length was used to act as wear volume. The electrochemical corrosion resistance of the four as-deposited specimens fabricated by LMD was investigated by potentiodynamic polarization measurements (PARSTAT 2273) in 3.5% NaCl solution, which were conducted using a three-electrode cell composed of a working electrode (the as-deposited specimens), a platinum counter electrode taken as auxiliary electrode, and a saturated calomel employed as reference electrode. The electrode potential was increased at speed of 1 mV/s, beginning from a potential which was −500 mV vs. SCE below the open-circuit potential. To reach a steady-state condition, the specimens used to electrochemical corrosion were immersed in the electrolyte for 15 min before polarization.

3. Results and discussion

3.1. Constituent phase

The XRD spectra of novel stainless steel + x wt.% Ni specimens fabricated by LMD are shown in Fig. 1. It can be seen that four as-deposited specimens have phase evolution from bcc solid

Table 1
Elemental composition of novel stainless steel + x wt.% Ni (x = 0, 3.05, 6.10, 9.15) alloy powders (wt.%).

Specimen	Cr	Ni	C	B	Si	Mo	Mn	Fe
x = 0	16.50	1.70	≤0.18	1.25	1.15	1	≤0.50	Bal.
x = 3.05	16.00	4.70	≤0.17	1.21	1.11	0.97	≤0.48	Bal.
x = 6.10	15.50	7.70	≤0.17	1.17	1.08	0.94	≤0.47	Bal.
x = 9.15	14.99	10.70	≤0.16	1.14	1.04	0.91	≤0.45	Bal.

“Bal.” is the abbreviation of “Balance”.