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Microstructure and properties of heat treated 1Cr17Ni4MoB steel fabricated by laser melting deposition

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ABSTRACT

A 1Cr17Ni4MoB steel was fabricated on the 40CriNiMoA surface by laser melting deposition (LMD), and then underwent heat treatment. The microstructure evolution and properties of laser deposited 1Cr17Ni4MoB steel and that underannealing temperatures of 500 °C, 700 °C, 900 °C for 1 h were characterized, especially their interface properties. The strength mechanism of laser deposited steel was analyzed. The results show that the microstructure of deposition is comprised of martensite dendrite, interdendritic carbon-boride (M_2B) and retained austenite. The overlap of layer reduces cracks and coarsening equiaxed grains are observed between layers for the epitaxial grown from unmelted dendrite. The microhardness of deposition reaches up to approximately 600 HV, which is attributed to martensitic transformation, solution strengthening, carbon-boride and fine dendrites. With the increase of annealing temperature, martensite decomposes into ferrite and precipitated $(Fe,Cr)_{23}C_6$ along martensite lath, resulting in the decrease of microhardness. Meanwhile, lamellar eutectic borides go through fusing and spherification. The appearance of retained austenite was explained by carbon partitioning. Composition analysis shows that carbon segregate in plane grain and C-depletion area was observed in substrate. The increase of annealing temperature facilitates carbon diffusion from substrate, and carbon content exceeds deposition with the annealing temperature of over 700 °C.

1. Introduction

Laser melting deposition (LMD) is one of rapid prototyping technologies that based on layer-by-layer overlap. Compared with conventional manufacturing technology, LMD is of better processing flexibility and usually is adopted to fabricate and repair components with complex geometry and difficult-to-process materials. The mechanical properties of laser melting deposited parts with fine microstructure can be comparable to forged ones [1]. Due to the lower productivity and high cost, LMD is mainly applied to the fabrication and repair of high-value components, such as turbine blades, dies and so on [2–5]. Laser deposited components were produced by various materials [6–10]. Sun systematically studied the microstructure and properties of laser deposited AISI 4340 steel and the evolution of fracture was characterized [11]. Liu found that heat treatment improved homogeneity and tensile properties of laser deposited AISI 431 stainless steel [12]. Zhang investigated properties of IN718 alloy fabricated by laser melting deposition under heat treatment and obtained optimized heat treatment procedures [13].

Fe-Cr-B stainless steel (MSS) exhibits excellent mechanical properties and moderate corrosion resistance. Besides, tailored properties of MSS can be obtained by heat treatment owing to the hardenability. Juliano Soyama modified superduplex stainless steel by adding 3% boron, and the excellent wear resistance, similar to that of the cobalt-based Stellite 1016 alloy, was obtained for the existence of borides [14]. Sun shida blended AISI 420 stainless steel and Fe-C-Cr-Nb-B-Mo steel powders to fabricate laser cladding layer and found the microhardness and wear resistance were improved with the increase of Fe-C-Cr-NB-B-Mo steel [15]. Extensive researches focused on the microstructure and properties of Fe-Cr-B in conventional processing, while, few studies on LMD were mentioned [16,17]. Furthermore, much attention was paid on heat treatment of laser melting deposition. Liu Fenggang researched the effect of tempering temperature on mechanical properties of 300M steel fabricated by LMD [18]. Wang reported that Laser melting deposition of 1Cr12Ni2WMoVNb steel subjected to quenched-and-tempered treatment was characteristics of desirable mechanical properties superior to the as-deposited steel and wrought one [1].

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In the present research, a 1Cr17Ni4MoB steel plate was deposited on 40CrNiMoA surface which is used as the material of mine sprocket. The evolution process of microstructure and properties of deposition during varied annealing temperature was analyzed. Furthermore, the defect evolution is characterized and the strengthen mechanism is proposed. The results lay a theoretical foundation for sprocket repairing in remanufacturing fields.

2. Experiment procedure

Laser melting deposition was performed by semiconductor laser with rectangular spot of 3 × 12 mm. According to previous studies [19], the optimized process parameters were as follows: laser power 4 kw, scanning speed 10 mm/s, powder feed rate 10 g/min, overlapping ratio 50%. Deposition with 8 layers were built up on 40CrNiMoA substrate with a dimension of 140 × 120 × 20 mm and the time interval between layers was 7 min. Table 1 shows the composition of 40CrNiMoA substrate and self-developed gas atomized powder particle with diameter size of 75–145 μm. Prior to deposition, substrate surface was ground by abrasive paper and then degreased with acetone to remove contaminants, and powders was dried for 1 h at 50 °C. A thick plate of 1Cr17Ni4MoB steel with a dimension of 140 × 120 × 20 mm was fabricated, as shown in Fig. 1. the deposition with dimension of 140 × 48 × 7 mm was divided into four sections and then three specimens were annealed at 500 °C, 700 °C and 900 °C for 1 h, respectively.

The specimens were sectioned in the transverse directions, with cross sectional dimensions of 10 × 10 mm. All specimens were ground on silicon papers of 400–2000 grit and then polished. The ZEISS optical microscope was used to observe the microstructures of cladding layer etched by 3% $FeCl_3$, 15 ml hydrochloric acid and 75 ml deionized water. The annealing process was carried out in a muffle furnace. The phases were identified by X-ray diffraction (XRD; D8 ADVANCE; Bruker Corporation) with Cu Kα radiation generated at 40 kV and 30 mA, and the diffraction angle ranges from 30° to 100° at the scanning speed of 1 deg/min. The microhardness was measured by HVS-1000A Vicker hardness tester at a load of 1 kg and a dwell time of 10 s. The test points were obtained, perpendicular to the fusion line per 0.1 mm. The electron probe microstructure analysis (EPMA; 8050G, Shimadzu) equipped with Wavelength-Dispersive X-Ray Spectroscopy (WDS) was applied to quantitatively measure the composition of different areas and elements distribution in depositions.

3. Results and discussion

3.1. Phases analysis

Laser melting deposited specimen and those annealed at 500 °C, 700 °C, 900 °C are denoted as "as -deposited", "500 °C", "700 °C" and "900 °C", respectively. As XRD patterns of as-deposited and annealing specimens described in Fig. 2, deposition is comprised by α-(Fe,Cr)、γ-Fe、M_2B (M mainly represents Chromium and Fe). It is difficult to distinguish martensite and ferrite by XRD resulted from similar crystal structure. Therefore, the phases should be identified in consideration of microhardness shown in Fig. 3. α-(Fe,Cr) is indexed as martensite in as-deposited and 500 °C specimens, due to the micohardness of around 600HV, while indexed as ferrite in 700 °C and 900 °C specimens, attributed to decrease of microhardness to approximately 400HV, which reveals that at annealing temperature of 700 °C and 900 °C, martensite decomposes into ferrite and carbide. The retained austenite was obtained under rapid cooling. Regarding the poor content of retained austenite and widened diffraction peak caused by fine microstructure, further XRD analysis under lower scanning velocity were employed with diffraction degree from 40° to 50°, which indicates that the content of retained austenite reduces with the increase of annealing temperature. The $(Fe,Cr)_{23}C_6$ was found at annealing temperature of 700 °C and 900 °C. According to the decomposition of martensite, it can be speculated that $(Fe,Cr)_{23}C_6$ started to nucleate and grow under annealing temperature of 700 °C.

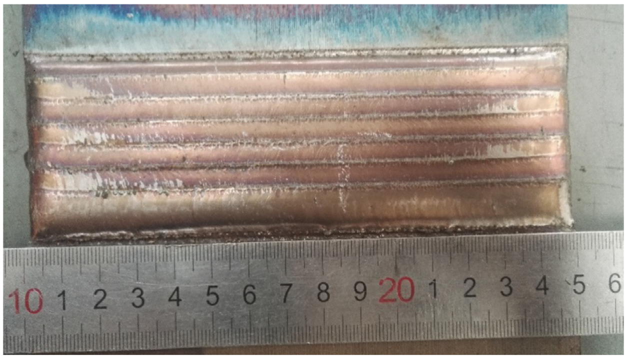

Fig. 1. Morphology of laser melting deposited 1Cr17Ni4MoB steel.

3.2. Microstructure evolution of the as-deposited steel

Fig. 4 shows the microstructure of as-deposited 1Cr17Ni4MoB steel, mainly comprised of fine dendrite grain with secondary arm spacing ranging from 5 μm to 10 μm. There are different microstructures at the interface of deposition and substrate (shown in Fig. 4(d)), where plane grain with width of 6 μm generated by epitaxial growths and transforms to celluar grain, along the deposition direction.

Laser melting deposited components are built up layer-by-layer. It is seen that consecutive layers will induce remelting of the previous layer. Apart from the top layer with height of 1.7 mm, other layers around 0.9 mm undergo remelting, which reveals that the remelting width is approximately 0.8 mm. According to the overlap area in Fig. 4(c), there exists coarsening equiaxed grain between dendrites in adjacent layers, and dendrites uncleating at interface are finer than the ones at the top of the previous layer. In the track overlapping area of the top layer, dendrites grown perpendicularly to deposition direction owing to the curved outline of molten pool, as shown in Fig. 4(b). The remelting brings about the elimination of tilting dendrites, and breaks down and fuses the long dendrites. Therefore, laser deposited parts is characterized by uniform microstructure of fine dendrites with consistent growth direction.

Fig. 5 presents the microstructure of as-deposited 1Cr17Ni4-MoB steel, and corresponding element distribution of Chromium,

Table 1
Composition of 40CrNiMoA and Fe-based powder.

Sample	C	Si	Mn	Cr	Mo	Ni	B
40CrNiMoA	0.37–0.44	0.17–0.37	0.5–0.8	0.6–0.9	0.15–0.25	1.3–1.7	–
Fe-based Powder	0.10–0.15	1.0–1.5	0.3–0.7	16–18	1.5–1.9	3.5–4.0	0.7–1.2