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Microstructure and mechanical properties of laser melting deposited 1Cr12Ni2WMoVNb steel

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ABSTRACT

1Cr12Ni2WMoVNb martensitic stainless steel was fabricated by laser melting deposition (LMD) process. Microstructure was characterized by optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Vickers microhardness and room-temperature tensile properties were evaluated as well. Results indicate that the laser deposited steel has a fine well-aligned dendritic structure with a primary dendrite arm spacing of approximately 13 μm. In the interdendritic regions there are fine phases which have a core–shell structure consisting of ferrite and many carbide particles. During the LMD process, the depositing layer has a reheating treatment on the top un-melted region of the previous layer, resulting in the formation of interlayer heat-affected zone (ILHAZ). Due to the existence of the ILHAZ, microstructure and microhardness of the laser deposited steel are non-uniform. The adjacent layers have the same crystallographic orientation, revealing that epitaxial growth of the depositing layer on the previous layer is not interrupted by the ILHAZ. Room-temperature ultimate tensile strength of the laser deposited steel reaches 1223 MPa, which is comparable to the wrought bar.

1. Introduction

1Cr12Ni2WMoVNb steel is a martensitic stainless steel with excellent mechanical properties and moderate corrosion resistance. The steel is widely used as key components such as compressor blade, disc, shaft in gas and steam turbines [1].

Laser melting deposition (LMD) is a rapid forming technology for building metallic components. The technology is also referred to as laser engineered net shaping (LENS) [2], direct light fabrication (DLF) [3], and direct metal deposition (DMD) [4], etc. During the LMD process, the motion of laser beam is controlled by computer numerical control (CNC) motion system based on the slice data from the computer aided design (CAD) model. Metal powders from delivery nozzles are fed into the laser focal zone, and are subsequently melted and then re-solidified. The laser beam moves side-by-side until a layer is deposited, then the following layer is stacked on the previous one. This process is repeated until a fully dense near-net-shape component is built [5–7]. Compared to conventional manufacturing routes like forging or casting, the LMD process significantly reduces the processing steps and the production time when manufacturing complex components of difficult-to-process materials. Moreover, the laser deposited metal parts have fine microstructure, and the mechanical properties of the laser deposited parts are usually comparable or even superior to the forged materials [6–21].

The laser deposited components have been fabricated from a variety of materials including titanium alloys [9–13], nickel-based alloys [9,14–16], austenitic stainless steel [9,16,17], low-alloy steels [4,18,19], ultra-high strength steels [20,21], etc. However, only a few studies on laser deposited martensitic stainless steels have been reported. Costa et al. [22] developed a thermo-kinetic model to study the influence of substrate size and idle time between the deposition of consecutive layers on the microstructure and hardness of a laser deposited AISI 420 steel wall. Wang et al. [23,24] developed a thermo-mechanical three-dimensional finite element model to predict the temperature history and the residual stress field in laser deposited AISI 410 steel during LENS process. Their works mainly focused on the simulation using finite element analysis. In the present study, a thick plate of 1Cr12Ni2WMoVNb steel was fabricated by the LMD process. Microstructure and room-temperature tensile properties were investigated. The effects of microstructure on tensile properties were discussed.

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Table 1
Chemical compositions (wt.%) of 1Cr12Ni2WMoVNb steel before and after laser melting deposition.

Element	C	Mn	Si	Cr	Ni	W	Mo	V	Nb	S	P
Powders	0.16	0.16	0.33	11.76	2.06	0.82	0.98	0.25	0.23	0.0025	0.016
Laser deposited part	0.15	0.20	0.30	11.70	2.38	0.80	0.98	0.27	0.23	0.0034	<0.0050

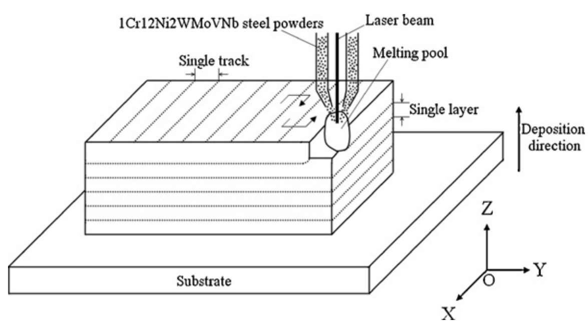

Fig. 1. Schematic illustration of laser melting deposition process for a thick plate of the 1Cr12Ni2WMoVNb steel.

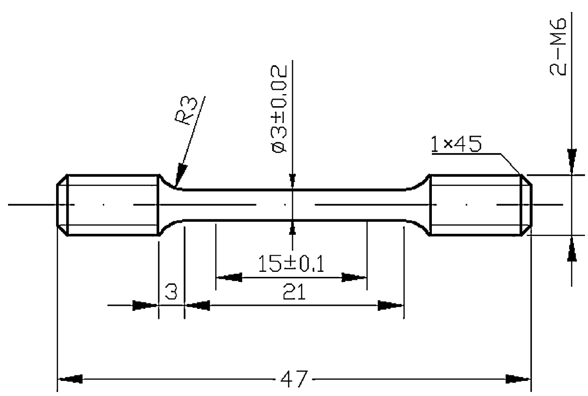

Fig. 2. Geometric shape and size of room-temperature tensile specimen in mm. The test standard is based on ISO 6892: 1998.

2. Experimental procedure

A thick plate of 1Cr12Ni2WMoVNb steel with a geometrical size of 150 mm × 75 mm × 20 mm was fabricated by the laser melting deposition process using a LMD system. The LMD system consisted of a GS-TFL-8000 CO_2 laser (maximum output power 8 kW), a BSF-2 powder feeder together with a co-axial powder delivery nozzle, a HNC-21 M CNC multi-axis motion system and an argon-purged processing chamber with oxygen content less than 100 ppm. The raw materials were plasma rotation electrode preparation powders with a particle size ranging from 75 to 250 μm. Chemical compositions of the original powders and the deposited final part were shown in Table 1. Few changes in chemical composition of the laser deposited part were detected in comparison to the original powders. The substrate was a 15 mm thick A3 steel, and its surface was ground with SiC abrasive paper and then degreased with acetone before the LMD process. The processing parameters were as follows: laser beam power 4.5–5 kW, scanning speed 4–5 mm/s, beam diameter 5 mm, powder delivery rate 6.5–7.5 g/min. The scanning mode was to-and-fro scanning. When a track or layer had been deposited, the following track or layer was deposited immediately. Schematic illustration of laser melting deposition process for a thick plate of the 1Cr12Ni2WMoVNb steel was shown in Fig. 1.

The newly deposited plate was directly tempered at 580 °C for 2 h in order to eliminate residual stresses and obtain a tempered microstructure. In this paper, this state would be referred to as the "laser deposited" state.

Metallographic samples were prepared using standard practices and were examined by optical microscopy (OM) and scanning elec-

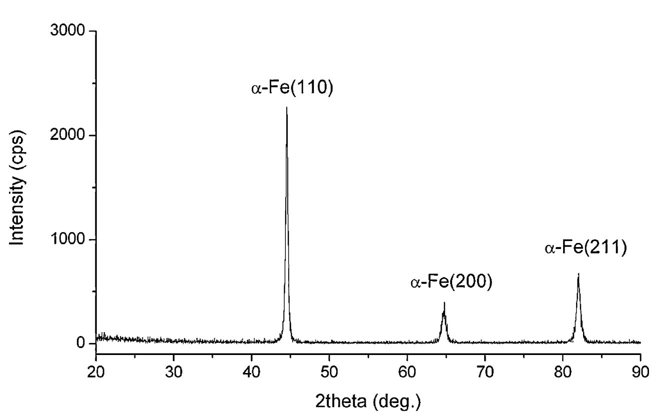

Fig. 3. X-ray diffraction pattern of the laser deposited 1Cr12Ni2WMoVNb steel.

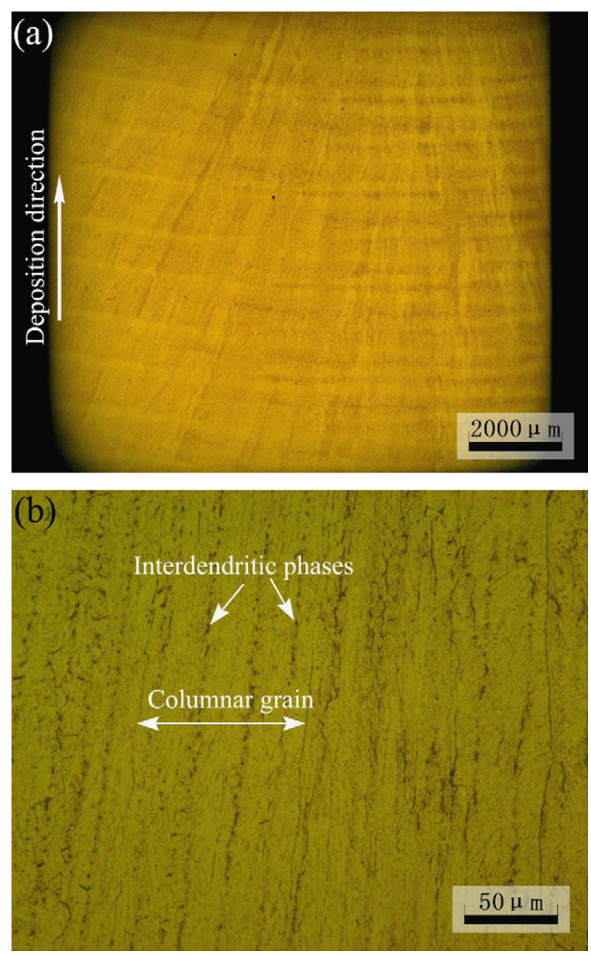

Fig. 4. Solidification structure of the laser deposited 1Cr12Ni2WMoVNb steel on longitudinal (XOZ) section: (a) Optical micrograph of multiple layers showing the well-aligned dendritic structure, growth direction of the dendrites is almost parallel to the deposition direction; and (b) columnar grain morphology and interdendritic phases in a single deposition layer.