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Characterization of stainless steel parts by Laser Metal Deposition Shaping

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ABSTRACT

Laser Metal Deposition Shaping (LMDS) is a new rapid manufacturing technology, which can build fully-dense metal components directly from the information transferred from a computer file by depositing metal powders layer by layer with neither mould nor tool. Typically, performed with stainless steel (SS) 316 powder, the orthogonal experiments combining with the ideal overlapping model were applied to ascertain the optimal processing parameters. Then the characteristics of microstructure, composition and phase of as-deposited cladding layers were analyzed through Scanning Electron Microscope (SEM) and X-ray diffraction (XRD), as well as relative model. Furthermore, the cooling rate and the solidification velocity during LMDS were evaluated based on empirical method. With the optimal parameters, some parts were fabricated without obvious defects, and then the mechanical properties of them were tested. Finally, the influencing regularities of critical parameters on microstructure and properties were concluded by comparison. The results prove that the microstructure of SS 316 deposits is composed of the slender dendrites growing epitaxially from the substrate, the mechanical properties are favorable and anisotropic, and the composition is uniform. Besides, the microstructure morphology and the mechanical properties are affected by the varied processing parameters at different degrees. Among them, the scanning speed shows the most remarkable effects on microstructure morphology, characteristic microscale, mechanical properties, as well as geometric shape of as-deposited parts.

1. Introduction

Different names for laser direct rapid manufacturing techniques are used including Laser Engineered Net Shaping (LENS) [1,2], Direct Metal Deposition (DMD) [3,4], laser solid forming (LSF) [5,6] and Laser Metal Deposition Shaping (LMDS) [7,8]. With coaxial powder injection, all these similar techniques are applied for the complete fabrication of 3-D, near-net-shape and solid freeform metallic components through layer by layer deposition of melted metal powder [9]. They utilize the laser energy to form a small molten pool on the substrate surface or a previously deposited layer, into which metallic powder is delivered by coaxial nozzle carrying a shielding inert gas [10]. Depending upon the alignment of the focal point of nozzle versus that of laser, powder is then melted either mid-stream or as it enters the pool. Due to the relative movement, driven by the sliced 3-D CAD model, between the substrate and the laser, the molten material quickly solidifies owing to heat dissipation mainly from the substrate and forms a strong metallurgical bond with the original surface. Thus, the programmed tool paths of each slice leave a solidified deposit representing a 2-D outline of the cross section of desired solid object. The laser/nozzle assembly then ascends in the vertical direction so that the next layer can be added [11]. Consequently, a 3-D object is formed layer by layer.

The single-step ability of these techniques to manufacture products at near net shape has the potential to revolutionize the production of small-lot metallic products by decreasing the time and expense associated with intermediate procedures and equipment [12,13]. They can also be implemented to perform repair operations in situations that would otherwise require fabrication of replacement parts or molds [14,15]. Furthermore, based on the state-of-the-art techniques, functionally graded material can be easily obtained through adjusting the multi-channel powder feeder [16–18] or combining powder and wire deposition [19,20].

Constrained by the forming theory and processing equipment, the traditional Rapid Prototyping (RP) technologies have the unfavorable limitation to produce the components with the full functionality that a design requires including accuracy, strength and surface finish. Generally, these as-fabricated components can be only considered as models or samples, which can become fully functional parts by means of other auxiliary technologies, or even

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cannot make this transition due to the lack of suitable post-processing techniques. Accordingly, combined the RP with the laser cladding, the laser direct rapid manufacturing techniques should be investigated to accomplish the capability of directly fabricating the complex metal parts and improve the competitiveness of manufacturing enterprises. Since stainless steel has a relatively high mechanical properties and better high-temperature performance, and is the main material suitable for laser direct deposition experiment, it is very necessary to carry out the study on laser additive manufacturing of stainless steel. For example, Mahmood and Pinkerton [21] investigate the role that particle size and morphology have in determining the final characteristics of a stainless steel 316L part produced by laser direct rapid manufacturing. Ganesh et al. [22] study the pitting corrosion and sensitization in laser rapid manufactured stainless steel 316L specimens and make a comparison with its wrought and weld deposited counterparts. Ma et al. [23] address the control of shape and performance for the precision large-scale metal parts with stainless steel 316L by the similar technology. Alimardani et al. [24] concentrate on the effects of the main processing parameters on the surface finish of stainless steel 303L thin walls through reducing the thickness of the deposited layers. These relevant literatures all put meaningful efforts on one or more research aspects of the laser rapid manufacturing of stainless steel parts, either the effects of powder particle size and shape or the performances of pitting corrosion and sensitization, either the control of geometrical precision or the improvement of surface finish, but lack of systematic experiments and comprehensive analyses of as-fabricated stainless steel samples to grasp the characteristics of microstructure, composition and phase of as-formed stainless steel parts, master the influence rules of processing parameters on microstructure morphology and mechanical properties of them, and then optimize the technological process. Accordingly, a kind of this technique, named Laser Metal Deposition Shaping (LMDS), was developed to fulfill the experimental study on laser direct rapid manufacturing process, and then the depositing results and the fabricating characteristics were theoretically discussed in detail.

2. Experimental condition and procedure

2.1. Experimental setup

The schematic diagram and real photograph of LMDS setup are shown in Fig. 1. As illustrated in Fig. 1, the experimental setup is primarily composed of four components: energy supply system, motion control system, powder delivery system, and computer control system. The laser power supply system, produced by Dalu Laser Group, is a console mounted to provide energy supply and associated with a cooling system. A crosscurrent, pipe sheet, multimode, 3 kW CO_2 laser, whose wavelength is 10.6 μm, is employed in the deposition setup as the power source. In addition, a semiconductor laser, whose wavelength is 0.633 μm, is used as the red calibration laser. The motion control system is manufactured by Shenyang Machine Tools Co., Ltd., and mainly consists of a six-axis NC machine tool, namely three precisely controlled linear axes (i.e., x, y, and z) and three free rotation axes that rotate around the x, y, and z axes individually. Accordingly, the motion control for directly fabricating 3-D parts can be performed through the NC worktable. The powder delivery system, manufactured by SIASUN Robot & Automation Co., Ltd., is chiefly made up of a coaxially powder nozzle, two powder hoppers, and some auxiliary apparatus. The computer control system is mostly comprised of two components: software and hardware. The software, known as the system application program, produces a CLI (Common Layer Interface) file from a CAD solid model, and then orderly achieves the entire part shaping process according to the CLI file. The software provides a graphical user interface (GUI) for the control of CAD data processing, stage motion, and powder regulation, as well as the safety and processing shutters. The hardware includes an industrial computer, several motors, and two PCI-1240 motion control cards exploited by Advantech Co., Ltd., in Taiwan. One PCI-1240 card is used to realize 4-axis linkage of the worktable, and the other one is employed to drive two motors of the powder feeder. These subsystems have their specified functions, but work in association with each other. Only in this way can the 3-D object be achieved successfully.

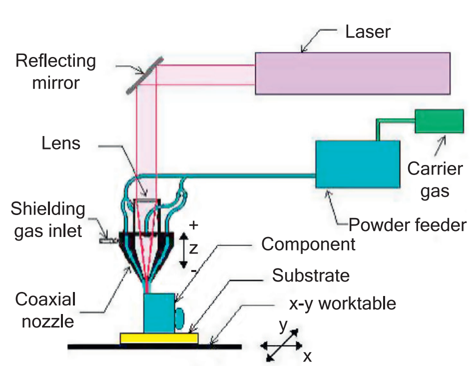
The deposition process is started on a substrate that is cut off after deposition is complete. Typically, the laser beam is rastered onto the substrate before powder feeding starts. Powders are then fed into the focal zone and the part is deposited in a continuous fashion.

2.2. Experimental material

The experimental material for LMDS process is stainless steel (SS) 316 whose powder size is about 200 mesh. SS 316 is a kind of commercially available alloy, and is widely used and very suitable for building structural parts. The substrate used for this experiment is A3 steel plate with the dimension of 200 mm × 200 mm × 10 mm. The chemical compositions of employed powder and substrate are listed in Table 1.

2.3. Experimental parameters

Referring to the experimental material, the research needs and the allowable load of the equipment, the processing parameters are determined as listed in Table 2.



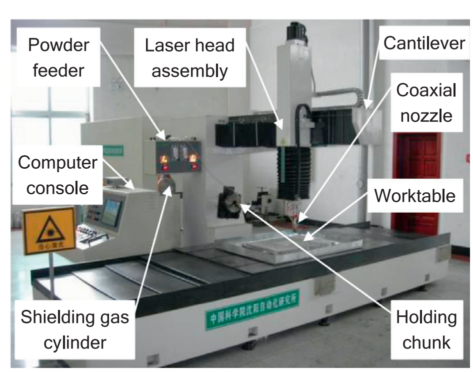


Fig. 1. LMDS setup: (a) schematic diagram; (b) real photograph.