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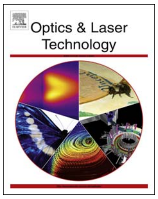

Full length article

Influences of pulse laser parameters on properties of AISI316L stainless steel thin-walled part by laser material deposition

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ABSTRACT

Laser material deposition (LMD) which combines laser cladding and rapid prototyping technique has been widely used to build full density metal parts directly without using modules or tools. There are many parameters affecting the quality and properties of the LMD parts through changing the energy distribution. Pulse laser provides the user an added degree of controlling over the energy distribution which seriously affects the solidification of molten pool and eventual part formation. In the present study, a series of AISI316L stainless steel thin-walled parts are successfully produced by LMD with different pulse laser parameters to investigate the effects of energy distribution on characteristics (microstructure, hardness, residual stress and tensile properties). The results show that the characteristics of LMD parts are obviously influenced by laser mode (pulse or continuous wave laser) and pulse laser parameters (T_pulse and T_pause). The microstructure of parts presents various grain sizes with the different pulse laser parameters. The different value (D-value) between the hardness of edge and central region varies considerably with the pulse laser parameters. The maximum D-value of hardness is presented in the part deposited by continuous wave laser. The maximum hardness is presented in item 4 (T_pulse=10 ms, T_pause=10 ms) and the minimum hardness is presented in part fabricated by continuous wave laser where the residual stress on Z-component presents tensile stress at the edge region and compress stress at the central region but opposite trend happens to the residual stress on Y-component. Tensile stress on Z-component at the edge region increases even presents compress tensile with the decrease of T_pulse. The stress on Y-component presents a periodic variation between tensile stress and compress stress in the Y-direction of the part fabricated by pulse laser. The ultimate tensile strength (UTS) of the part fabricated using pulse laser is higher than the part fabricated using continuous wave laser. The specimens paralleled to scanning speed present higher UTS values but lower elongation than the specimens perpendicular to scanning speed.

1. Introduction

Laser material deposition (LMD), an most common type of additive manufacturing (AM) technology based on laser cladding and rapid prototyping, is capable of fabricating the near fully-dense metal part with high strength and duration directly from computer aided design (CAD) model without attendance of any molds or tools [1,2]. During the LMD process which also is referred to as direct metal deposition (DMD) [3], laser engineered net shaping (LENS) [4], and laser solid forming (LSF) [5] depending on the change of laser power, laser type, powder delivery method and feedback control scheme etc., the high power laser beam is utilized to melt the deposition region where the metallic powder carried by gas is simultaneously injected into the molten pool to create metallurgical bounding with the thin surface of substrate or previous layer [6]. A 3D Part is constructed layer by layer accompanied by the raising of laser/nozzle assembly in the vertical direction under the computer guidance. Non-equilibrium microstructure which contributes to the highlighted properties of the fabricated full-density part can be acquired that attributes to the high temperature gradient and high cooling rate in the solidification of the molten pool during high-energy laser beam scanning [7]. Benefiting from the advantages such as high production flexibility, low thermal inputting, high geometry freedom compared with the conventional technologies, LMD technology has been considered as an effective and efficient

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technique in the fabrication of metal parts, and gains more and more attention in the area of aviation, aerospace, die and mould, etc [8,9].

The laser used for present LMD researches is normally a continuous wave laser where relatively low inputted heat which can conduce to the high temperature gradient and high cooling rate during laser beam scanning and lead to the refined microstructure and the superior erosion resistance compared to other conventional process. The obvious characteristics of LMD parts present the typical solidification structure which consists of the planar interface followed by columnar, dendritic region in the central section and cellular region in the external surface of the deposition layers, high hardness, high strength and low ductility. According to these characteristics of LMD parts, numerous studies have made efforts to optimize the LMD process in the aspect of quality controlling, numerical modeling, microstructure features and mechanical properties. El Cheikh et al. investigated the effects of velocities and laser shift-distance between two successive layers on the clad geometry of LMD part. They obtained a relationship between the process parameters and the wall height with a good correlation [10]. Ferguson et al. fabricated LMD parts from AISI420 and AISI4140 steel alloys to study how processing parameters affect porosity and deposit dimensions. Based on the results of various experiments, a semi-empirical model which can predict the trend in deposit sizes for parameters was presented [11]. Peng et al. investigated the fabrication of thin-walled parts of nickel alloy using open-loop LMD process. They discovered that the deposition thickness of the nozzle was nearly linear with the increase of the defocusing distance in a certain range, and the difference in build height of a thin-walled part can be compensated automatically in one or several layers during process [12]. Liu et al. developed a model of effects of powder concentration distribution on the fabrication of thin-wall parts in coaxial laser cladding. They pointed out that changes in the fluctuation of powder feed rate and deviation of powder flow stream lead to changes in wall thickness and wall growing rate [13].

However, it is well known that the domain drawback in mechanical properties is the residual stress created by the repeated rapid heating and rapid cooling along with the moving of high power laser beam, which remains in the LMD metal part and could lead to the pool properties in corrosion, fracture resistance and fatigue performance of the LMD part [14]. Furthermore, residual stresses can cause component distortion resulting in a mismatch between the final geometry and the designed geometry [15]. Quite a number of studies have made efforts to give reasonable explanations and reduce the residual stress. Rangaswamy et al. measured the residual stress in LMD samples of AISI316stainless steel and Inconel 718 by both neutron diffraction and the contour methods. They compared two methods in the context of the growth direction and discovered the uni-axial residual stress [16]. Klingbeil et al. studied how residual stress develop and how they lead to tolerance loss from the warping experiments results created by two direct metal deposition methods. The results suggested that a combination of initial substrate preheating and part insulation can be applied to limit warping deflections [17]. Yu et al. investigated the influences of fractal, offset and raster depositing patterns on the parts' deformation, interior quality and mechanical properties. It is found that the fractal deposition pattern generated the smallest parts' deformation, followed by offsetout and the parts interior quality investigation with fractal and offsetout deposition patterns showed that the overlap should be increased to 50% to avoid pore defects [5]. Hu et al. deposited AISI316 stainless steel powders on AISI321 stainless steel substrate to investigate the effects of pre- and post-clad heat treatment on the residual stress. They found that the effects of lead time (time interval between pre-clad heat treatment and cladding) for pre-clad heating and delay time (time interval between cladding and post-clad heat treatment) for post-clad heating on residual stress are significant and there exist specific values of lead time and delay time for which residual stress of coatings surface is minimal [18].

Therefore, more effort should be made for the optimization of LMD process to obtain superior properties. S. Sun pointed that pulse laser offers significantly lower inputted heat in the workpiece and the laser power-off period between two pulses allows the melt pool to solidify to create a faster cooling rate which contributes to the more refined microstructure and higher hardness than the continuous wave laser [19]. However, the higher cooling rate during pulsed LMD process results in higher residual stress which might contribute to dislocation and lead to pool mechanical properties [20]. Therefore, the characteristics of pulsed LMD part should be investigated intensively. However, the detailed research work about pulsed laser is rare. Sun et al. carried out a systematic parametric research of the cladding of satellite 6 on stainless steel by pulsed Nd: YAG laser cladding. It was found that both the clad height and penetration into the substrate increase with the pulse energy, spot overlap and pulse frequency, but the effects of these parameters on dilution are complex [19]. Gharbi et al. studied the influence of a pulsed laser regime on the surface finish induced by LMD on a widely used titanium alloy (Ti6Al4V). Their finding confirms that high mean power improves surface finish and the use of a pulsed mode with large duty cycles is clearly shown to provide smoothening effects [21]. Up to now, few investigations are reported about pulsed laser cladding as well as pulsed LMD.

In the present study, the characteristics (microstructure, hardness, residual stress, and tensile properties) of AISI316L LMD parts fabricated by continuous wave laser and pulse laser were investigated and compared in detail.

2. Experimental procedures

2.1. Materials and apparatus

The LMD AISI316L parts were carried out on laser material deposition system, which consists of a Kuka six-axes robot (ZH 30/60III), a LaserLine diode laser generator (LMD 4000-100) with 4000 W maximum power supply, a Precitec laser cladding head (YC52) with four coaxial nozzles, a Raycham mental powder feeder (RC-PGF-D). The powder of AISI316L stainless steel with the size of 45–150 μm and spherical shape, produced by Höganäs, was laser deposited on AISI316L stainless steel substrate with the dimension of $130\times20\times15$ mm^3. The composition of the powder is shown in Table 1. Pure argon with 99.99% purity was used as the carrier gas and shielding gas in all the experimental processes with flow rate of 400 L/h and 600 L/h, respectively.

2.2. Production of LMD part

In order to investigate the effects of T_pulse and T_pause in pulse laser mode on the characteristics (microstructure, hardness, residual stress, and tensile properties) of AISI316L LMD thin-walled parts, several parts were fabricated by LMD with different parameters in reciprocating scanning way where the scanning path is parallel to the surface of the substrate as shown in Fig. 1. Referring to the experimental material, the research needs and our previous research works, the processing parameters which includes laser peak power (P_{peak}), scanning speed (V), powder feed rate (Q_m), T_pulse and T_pause are determined as listed in Table 2. As a comparison, the part fabricated by LMD with continuous wave laser mode was also carried out as shown in Table 2 (Item 5). The Z-increment is 0.2 mm between two layers in all deposited parts. The finished LMD parts possess the dimensions of 120 mm×60 mm (length×height) with different width.

Table 1
Chemical composition of AISI316L stainless steel powder.

Element	Cr	Mn	Ni	Mo	Si	C	Fe
wt%	17.1	1.6	12.5	2.5	0.7	0.022	bal.