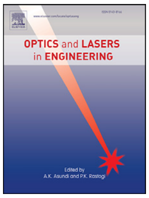
Optics and Lasers in Engineering 103 (2018) 34–45

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng



Investigation into the influence of laser energy input on selective laser melted thin-walled parts by response surface method

Yang Liu[a,*], Jian Zhang[b], Zhicong Pang[a], Weihui Wu[c]

[a] *Faculty of Mechanical Engineering & Mechanics, Ningbo University, Ningbo 315211, China*
[b] *Zhejiang Provincial Key Laboratory of Laser Processing Robot, Wenzhou University, Wenzhou, Zhejiang 325035, China*
[c] *School of Physics and Mechanical & Electrical Engineering, Shaoguan University, Shaoguan, Guangdong 512005, China*

ARTICLE INFO

Keywords:
Selective laser melting
Energy input
Thin-walled structure
Response surface methodology

ABSTRACT

Selective laser melting (SLM) provides a feasible way for manufacturing of complex thin-walled parts directly, however, the energy input during SLM process, namely derived from the laser power, scanning speed, layer thickness and scanning space, etc. has great influence on the thin wall's qualities. The aim of this work is to relate the thin wall's parameters (responses), namely track width, surface roughness and hardness to the process parameters considered in this research (laser power, scanning speed and layer thickness) and to find out the optimal manufacturing conditions. Design of experiment (DoE) was used by implementing composite central design to achieve better manufacturing qualities. Mathematical models derived from the statistical analysis were used to establish the relationships between the process parameters and the responses. Also, the effects of process parameters on each response were determined. Then, a numerical optimization was performed to find out the optimal process set at which the quality features are at their desired values. Based on this study, the relationship between process parameters and SLMed thin-walled structure was revealed and thus, the corresponding optimal process parameters can be used to manufactured thin-walled parts with high quality.

1. Introduction

Thin-walled part possesses characteristics of light-weight, materials-saving and compact-structure, which is extensively used as the radiators in areas such as aerospace, refrigeration, electronic equipment [1]. In order to enhance the cooling effect of the thin-walled radiators, it is needed to increase the number and specific surface within limited space, therefore, the thin wall is required as thin as possible. Simultaneously, the thin-walled parts are supposed to possess high mechanical properties. Actually, thin-walled parts are usually manufactured by traditional methods includes casting, welding, forging and stamping, etc., the rigidity and strength are relatively low, the dimensional accuracy usually cannot meet the actual requirement [2,3]. Thus, a new approach is urgently needed to manufacture thin-walled components with high quality.

Selective laser melting (SLM), as a recently developed additive manufacturing (AM) technology, is capable of directly manufacturing three-dimensional parts with complex structure in 'point-by-point, track-by-track, layer-by-layer' manner [4]. With such a manufacturing characteristic, SLM becomes the optimal choice for thin-walled components [5,6]. Among the process parameters of SLM, laser power, scanning speed and layer thickness play crucial roles in determining the dimensional accuracy, surface quality and mechanical properties of SLMed parts [7]. So far, considerable researches on the influence of process parameters on the SLMed parts have been conducted [8–10]. Most of the existing works were concentrated on the SLMed bulk samples, the optimized targets were usually the relative density, surface roughness or mechanical properties, etc., the considered process parameters were commonly the laser power, scanning speed, layer thickness, etc.

During the 'point→line→layer→entity' manufacturing process of SLM, the melting track is made up of molten pools, scanned layer is made up of melting tracks, while component is made up of scanned layers. The melting track are the basic constitutive elements of the SLMed parts, most existing works have been reported on the SLMed single-track [11–15]. They found that energy input affects the molten pool and single track significantly, thus affects the mechanical properties of the as-fabricated parts.

Some other researchers fabricated thin-walled parts by SLM [16–22]. Abele et al. [16] studied the influence of process parameters, such as laser power, scan speed and hatch spacing on the porosity, permeability and tensile strength of SLMed thin walls by using the DoE approach. Mumtaz et al. [17,18] manufactured thin-walled parts with pulse shape control, it was found that the width, top and side surface roughness of

---

[*] Corresponding author.
E-mail address: liuyang1@nbu.edu.cn (Y. Liu).

https://doi.org/10.1016/j.optlaseng.2017.11.011
Received 23 August 2017; Received in revised form 31 October 2017; Accepted 17 November 2017

thin walls can be improved significantly compared without pulse shape control. Brown et al. [19] studied the scanning strategy on the dimensional accuracy of SLMed thin walls, and found that reduction in tensile strength is a generic response to the reduction of wall thickness in SLMed thin walls. Yadroitsev et al. [20] manufactured porous 3D parts by SLM, they studied the influence of process parameters on the geometry accuracy, anisotropy and regularity of thin walls. Song et al. [21] manufactured thin walls with Cu alloy and used them as heat sink in automobile and air condition fields, the relationship between process parameters and wall thickness was revealed. Vilare and co-workers [22] investigated the influence of processing parameters on the laser powder micro-deposition (LPMD) of thin walls of stellite F alloy systematically, with regard to the control of part geometry and stability of the process.

As is known, laser energy input, namely determined by the laser power, scanning speed, layer thickness and hatch spacing affects the thin walls significantly. Although the above researches have studied these influences to some extent, the influencing rule of each process parameter on the thin wall's main properties, such as track width, side surface and hardness is still need to be revealed systematically. In this present work, response surface methodology (RSM) was applied to build up the relationships between the energy input and the thin wall's main parameters, such as track width, surface roughness and hardness. The effect of each process parameter on the responses and significant items (main factor, interaction factor and second-order factor) can be identified through the mathematical models. Finally, the desirable and optimal manufacturing conditions can be found by using desirability approach and the developed models, and then they were applied to manufacture thin-walled parts with high quality.

2. Experimental procedure

2.1. Equipment and materials

The experiments were performed on a SLM machine DiMetal-100, as shown in Fig. 1a. The machine is equipped with a maximum laser power of 200 W continuous wavelength of 1090 nm ytterbium fiber laser. A dual axis mirror positioning system and scanning galvanometer are used to direct the laser beam in the X- and Y-axis through a f-theta lens. Focusing optics employed a 163 mm focal length lens, which produces a focused beam spot size of 70 µm in diameter. A gas circulating system is used to make sure that the building chamber is filled with nitrogen and the content of oxygen no more than 0.05%, so the molten pool can be protected from oxidation. Fig. 1b shows the schematic diagram of thin wall manufacturing process. Thin walls are manufactured in layer-by-layer manner. The region that irradiated by laser beam is melted and solidified, forming scanned track, while the region that not irradiated by laser beam remain powder state.

The material used in this study was gas-atomized 316 L stainless steel spherical powder, as shown in Fig. 2a. Fig. 2b shows the particle size distributions (wt.%): $d_{50} = 15\,\mu\text{m}$ and $d_{90} = 30\,\mu\text{m}$, the average particle size is 17.11 µm, and the relatively density is 4.42 g/cm^3. The chemical compositions of the powder are shown in Table 2.

2.2. Experimental procedure

There are about 50 process parameters for SLM process along with the interactions between process parameters. Among these process parameters, energy input plays the key role in determining the SLMed parts by determining the shape and dimension of molten pool and track. Some researchers have proposed some mathematical models of energy input [23–25], one of them can be expressed as [24]:

$$\psi = \frac{P}{v \cdot h \cdot t} \quad (\text{units}: \text{J/cm}^2) \tag{1}$$

Where P represents laser power, v represents scanning speed, h represents hatching space and t represents layer thickness. In single-track style, the hatching spacing can be ignored. Thus, the considered process parameters in this study are laser powder P, laser scanning speed v and layer thickness t.

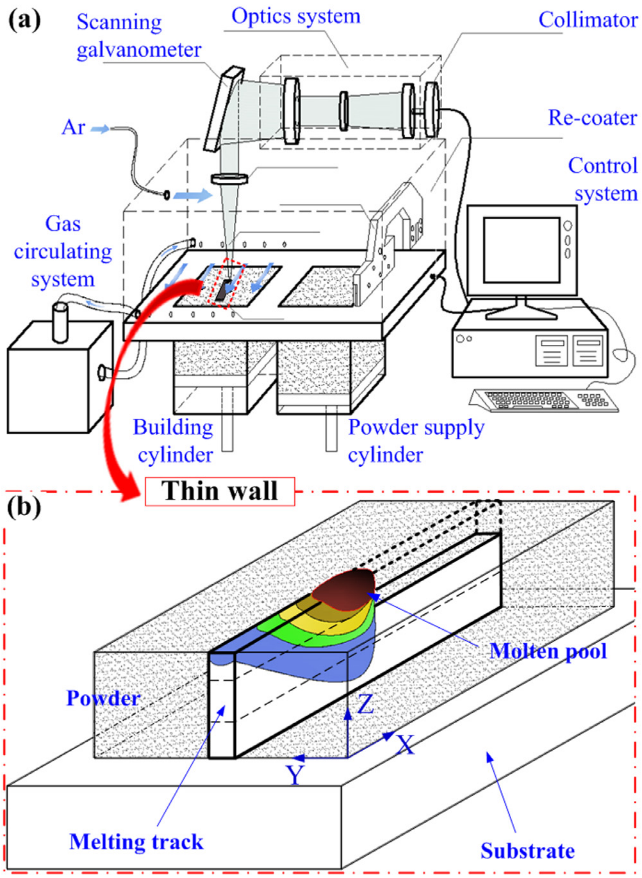


Fig. 1. Schematic of SLM equipment and manufacturing thin wall manufacturing process.

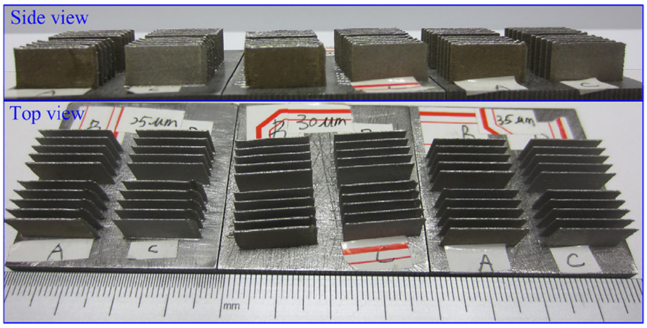


Fig. 2. The as-fabricated single track thin-walls.

Table 1
Main technical parameters of the DiMetal-100.

Items	Value
Wavelength	1090 nm
Max laser power	200 W
Beam coefficient M^2	≤1.1
Beam diameter	70 µm
Building envelop	100 × 100 × 120 mm^3
Focus length	163 mm

Prior to the design of experiments, the ranges of process parameters should be determined based on the equipment conditions and preliminary studies. Except the fixed parameters shown in Table 1, the range of each influencing factor is determined by trial and error, as shown in