IOP Conference Series: Materials Science and Engineering

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To cite this article: P Ninpetch *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **526** 012030

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IOP Conf. Series: Materials Science and Engineering **526** (2019) 012030 doi:10.1088/1757-899X/526/1/012030

Thermal and Melting track Simulations of Laser Powder Bed Fusion (L-PBF)

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Abstract Laser powder bed fusion (L-PBF) process involves with the construction of phase transformation, melting, and rapid solidification of weld metal powder bed which affects the properties and the microstructure of final parts, e.g. density, dimension, mechanical properties, void, porosity, and non-fully melted particle. The aims of this work were to study the effect of process parameters, e.g. laser power and scanning speed, on the temperature field and melt pool geometry and the characteristics of single melting track in the L-PBF process by using the commercial CFD software simulation Flow-3D (Flow-weld). The laser power, scanning speed, laser spot diameter, and layer thickness varied in this study were 120 W, 140 W, 0.4 m/s, 0.6 m/s, 0.8 m/s, 80 µm and 50 µm respectively. The results stated that at the lower scanning speed, the temperature field has a region of heat distribution larger than that of the higher one. The geometry of melt pools can be changed from ellipse shape to tear drop shape when the scanning speed is increased. The width and depth of laser melting track is increased when the higher laser power and lower scanning speed are applied. The void is found underneath the laser melting track when the scanning speed changes from 0.4 m/s to 0.6 m/s.

1. Introduction

Laser Powder Bed Fusion (L-PBF) is a type of additive manufacturing process which uses laser source scanning as a moving heat source on powder bed to fully melt the metal powder layer fashion [1]. In this process, the powder bed is created by raking metal powder across the work space [2]. The cycle is repeated layer by layer, until the complete part is formed. Finally, the part is visible after eliminated

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the excess metal powder from powder cake [3]. This process can be used with various materials such as metal, plastic, ceramic, composites, and biomaterials [2]. The typical applications of this process are rapid prototype, complex topology parts, medical parts, aerospace parts and automotive parts, [4,5] The process parameters include laser power, power intensity, scanning speed, hatch spacing and the layer thickness. L-PBF process involves complex multiphysics such as the materials laser absorption, heat transfer, fluid dynamic, phase transformation, melting, and rapid solidification. These factors have significant influence on the properties and the microstructure of final parts, e.g. density, dimension, mechanical properties, void, porosity, and non-fully melted particle [6]. Several research studies used the CFD simulation method to predict the phenomena in the L-PBF process. The examples of CFD simulation software are Flow-3D, ANSYS, COMSOL Multiphysics etc. Y. Li and D. Gu [7] developed a 3D model to study thermal behavior of L-PBF of pure titanium powder with ANSYS software. The study considered the temperature-dependent thermos physical parameters and the Gaussian distribution of the heat flux. In the study, it indicated that the average temperature of the powder bed gradually increased during laser scanning because of the heat accumulation. Y.S. Lee and W. Zhang [6] solved the transient numerical mesoscale model of Inconel 718 powder bed with a mesh size of 3 micron considering volume of fluid method (VOF), Marangoni effect, particle size distribution and packing density. The commercial software Flow-3D was used in the study. It was found that too fast scanning speed and too low laser power can increase the chance of discontinuous molten pool and the balling defect.

The aims of this research are to study the effect of process parameters including Laser power and scanning speed on the temperature field and melt pool geometry and the characteristics of single melting track in the L-PBF process by using the commercial CFD software simulation Flow-3D (Flow-weld). The laser power, scanning speed, laser spot diameter, and layer thickness varied in this study are 120 W, 140 W, 0.4 m/s, 0.6 m/s, 0.8 m/s, 80 µm and 50 µm respectively. The results from this study will be validated with the experimental results from a previous research study on Fabrication and Characterization of AISI 420 Stainless Steel Using Selective Laser Melting [8].

2. Simulation model

Heat transfer simulation model in L-PBF process consists of heat conduction, heat convection, heat radiation respectively [9]. Considering the melting and solidification phenomena, the enthalpy including latent heat evolution arising from phase change effect during the process can be applied in modelling [10]. The molten fluid flow simulation model of L-PBF process based on numerical solution of mass, energy and momentum conservation and the Volume of Fluid (VOF) method is used to track the position and shape of the molten pool surface.

The Gaussian laser moving heat source model is described [11] as in equation (1)

$$q = \frac{2P}{\pi\omega^2} e^{-\frac{[(x-x_0)^2+(y-y_0)^2+(z-z_0)^2]}{\omega^2}} \quad (1)$$

q is heat flux on the surface, ω is radius of beam, P is laser power, (x_o, y_o, z_o) is instantaneous position of the center of the heat flux which is on the moving path at distance of x, y, z from start point, v is velocity of moving heat source, t is time.

3. Methodology

The 3D model simulation was performed by commercial CFD simulation software Flow-3D (Flow-weld). The material used in this study was AISI 420 martensitic stainless steel powder with the average particle size of 20 µm. The 3D computational mesh of around 375,000 cells was used in this simulation. Figure 1. shows the schematic of the powder bed and scanning direction of moving laser beam. The process parameters used in this study are listed in Table 1.

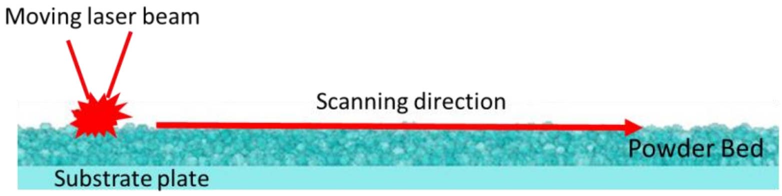

Figure 1. The schematic of the powder bed and scanning direction of moving laser beam

Table 1. Process parameters of this simulation

Process parameters	Value
Laser power (P)	120, 140 Watt
Scanning speed (v)	0.4, 0.6, 0.8 m/s
Layer thickness (t)	50 µm
Laser beam spot size (d)	80 µm

4. Results and Discussion

4.1 The effects of process parameters on the temperature field and melt pool shape

At the lower scanning speed, the temperature field has a larger region of heat distribution than that of the higher one as shown in figure 2 **(**a**)**, **(**b**).**When the scanning speed is increased, the geometry of melt pools changes from ellipse shape to tear drop shape**.** The phenomena from the process parameters have significant effect on the quality of final products**.**

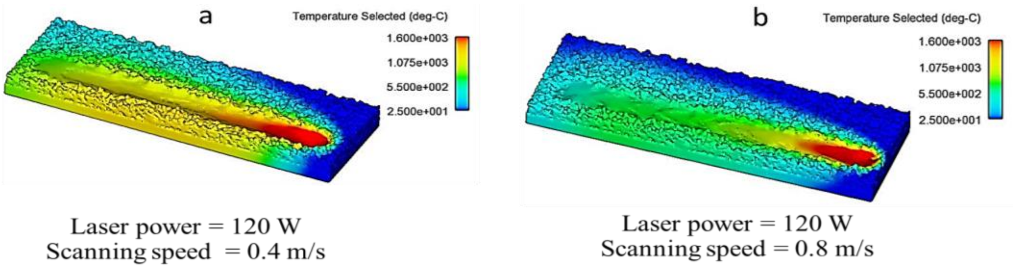

Figure 2. The temperature field and melt pools shape during L-PBF process

4.2 The width and depth of single melting track with different process parameters

Figure 3 (a), (b) and figure 4 (a), (b) show the effects of laser power and scanning speed on the characteristics of laser melting track**.** The width and depth of laser melting track is increased when the higher laser power and lower scanning speed are applied**.** The void is found underneath the laser melting track when the scanning speed changes from 0**.**4 m/s to 0**.**6 m/s**.** The results from the simulation are consistent with the experimental results with minor difference as shown in figure 4**.** (a)

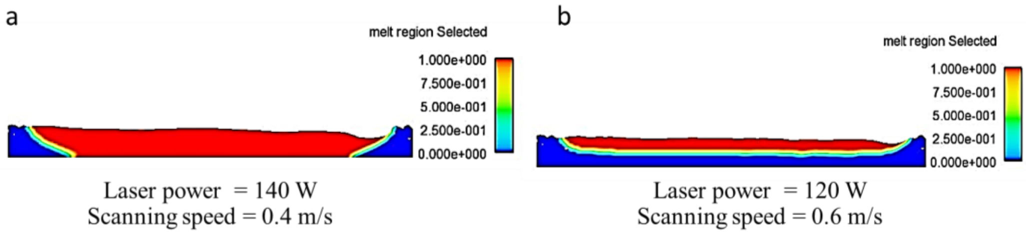

Figure 3. The depth of laser melting track in L-PBF process

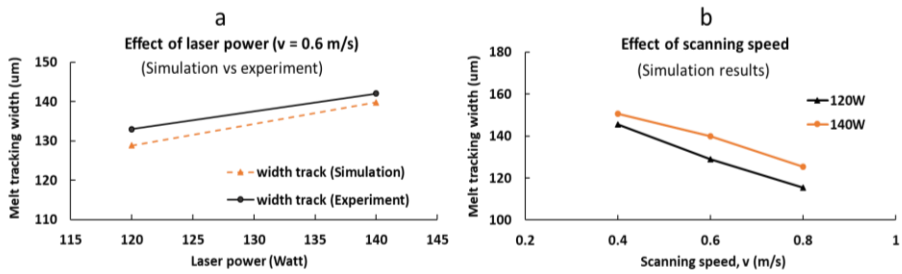

Figure 4. The effect of process parameters on melting track width; **(a)** The effect of laser power **(b)** the effect of scanning speed

5. Conclusions

In this research, the effect of process parameters on the temperature field and the melt pool geometry and the characteristic of single melting track in L-PBF process with laser power of around 120-140W was investigated through the numerical simulation method. The results from the simulation are consistent with the experimental results with minor difference. At the lower scanning speed, the temperature field has a region of heat distribution larger than that of the higher one. The geometry of melt pools can be changed from ellipse shape to tear drop shape when the scanning speed is increased. The width and depth of laser melting track is increased when the higher laser power and lower scanning speed are applied. The void is found underneath the laser melting track when the scanning speed changes from 0.4 m/s to 0.6 m/s.

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Acknowledgement

The authors would like to thank the fund support from Thailand Graduate Institute of Science and Technology (TGIST), National Science and Technology Development Agency (NSTDA) contract No. SCA-CO-2560-4552-TH, the Thailand Research Fund (TRF) and the Commission on Higher Education (CHE) under the TRF contract No. MRG6180164 and software license support from Flow Science, Inc, Flow Science Japan and Design Through Acceleration Co., Ltd.