Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-01-0041

Effect of Melt Pool and Particle Dynamics on As-built Qualities in Laser Powder Bed Fusion Process

Min-Kyeom Kim[1], Taehwan Kim[1],Jonghwan No[1]and Jonghwan Suhr[1]
1 Department of Mechanical Engineering, Sungkyunkwan University, 2066, Seobu-ro, Jangan-gu, Suwon-si, Gyeonggi-do,Republic of Korea
Corresponding Author / Email: suhr@skku.edu, TEL: +82-31-299-4066

KEYWORDS: Particle dynamics, Melt pool dynamics, Microscale process design, Simulation, In-situ monitoring

Laser powder bed fusion (LPBF) is a manufacturing technique in which a laser selectively melts spread powders for building a component. The manufacturing process induces complex phenomena and an interaction between melt pools and the particles. As the complex process makes it hard to control the as-built qualities, the detailed investigation of the melt pool and particle dynamics is needed. In this work, melt pool and particle dynamics were analyzed via the in-situ monitoring and ex-situ characterization. The size and stability of Melt pools were characterized via the optical microscopic images along with a denudation zone. Additionally, spattering was observed via the in-situ thermal imaging camera for a better understanding of melt pool and particle dynamics. The complex behaviors were comprehensively explained via a thermal fluid dynamics simulation. It was found that the stability of melt pool was dominant factor to determine a density of the as-built parts, while the spatter and denudation zone significantly affected the surface quality. This work could give the fundamental understanding of microscale process in the LPBF technique so that high quality products can be produced.

1. Introduction

Laser powder bed fusion (L-PBF)is the promising technique which is capable of building complex structures and prototypes with saving time and cost[1]. The L-PBF technique, however, requires a delicate design of the process in a multiple scale, because various defects can easily occur at the poor process conditions[2, 3]. Therefore, understanding of the processin a melt pool scale is essential to build the products with high quality and properties[4]. Here, the melt pool and particle dynamics were characterized via in-situ monitoring and ex-situ characterization methods. The melt pool size and morphologies were characterized via optical microscopic (OM) images and particle dynamics were analyzed via OM images and thermal imaging camera. It was confirmed that the melt pool and particles significantly determined the qualities and corresponding properties of as-built products.This study quantitatively showed the effect of melt and particle dynamics on the as-built qualities and properties, in order to systematically design the L-PBF process parameters.

2. Material and Methods

2.1.Material and manufacturing

17-4 PH stainless steel was prepared from AMC powder company. The diameter of 17-4 PH powders ranged from 15 to 53 μm, and were manufactured in N_2 atmosphere. The powders were selectively melted on a baseplate in N_2 atmosphere, where the laser power and scan speed varied from 50 to 500 W and 200 to 2000 mm/s, respectively.

Single tracks and Cubic samples having 8x4x4 mm size were fabricated under the process conditions (Fig. 1a), while observing the heat affected zone by a spattering using a thermal imaging camera (Fig. 1b).They were cut and polished for measuring the melt pool size, density, and hardness, wherethe melt pools were characterized after etching the polished samples.

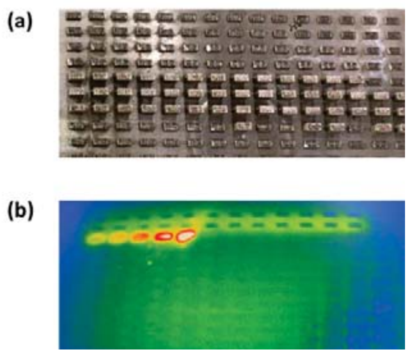

Fig. 1. (a) As-built 17-4 PH samples with 8x4x4 mm size, and (b) in-situ monitoring of the process using a thermal imaging camera.

2.2. Simulation model

Melt pool behaviors were numerically analyzed through multi-phase fluid dynamics. The simulation model included a heat source, shielding gas, evaporation, and multi-reflection model. The Gaussian heat source model melted the powders and baseplate, and evaporating pressure was activated at a higher energy density. In the simulation, temperature dependent properties such as surface tension coefficient, thermal conductivity, specific heat, viscosity, and density were considered for the further accurate model.

3. Conclusions

Several defects such as keyholing, balling, humping and spattering were observed in the inappropriate conditions (Fig. 2 and 3). It was confirmed that higher energy density caused not only keyholing but also substantial spattering, which might deteriorate the qualities and properties of as-built parts (Fig. 2a and 3). The insufficient energy density along with the higher speed induced the balling defects on the previous layer, which increased the surface roughness and generated the lack-of-fusion defects in the parts (Fig. 2b).

Finally, the appropriate printing region was derived to avoid the aforementioned defects during the process. In the region, the as-built qualities and properties were comprehensively investigated to obtain the desirable processing conditions; a desirable range of laser power and scan speed were described via a fully dense region (Fig. 4).

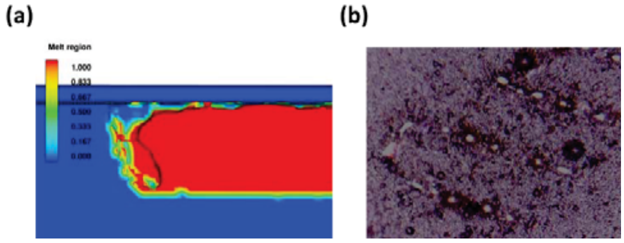

Fig. 2. (a) Keyholing phenomenon in the process simulation at the laser power of 400 W and scan speed of 400 mm/s, and (b) balling defects on the previous layer, observed via the OM, at the laser power of 50 W and scan speed of 1600 mm/s.

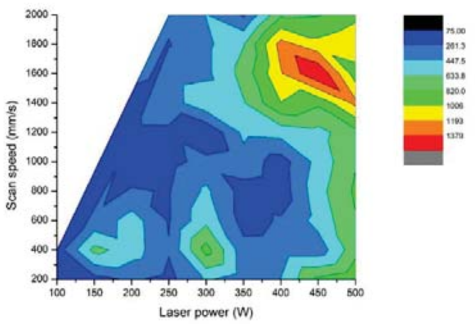

Fig. 2. Heat affected zone by the spattering, as a function of laser power and scan speed,during the process

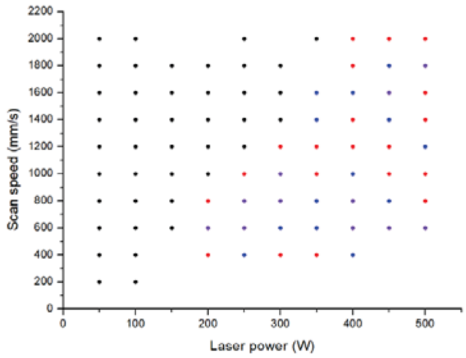

Fig. 4. Fully dense region as a function of laser power and scan speed. Note that black and red points indicate lack of fusion and keyholing defects, respectively, while purple and blue points show >99.5% and >99% relative density, respectively.

ACKNOWLEDGEMENT

This research was supported by the Commercialization Promotion Agency for R&D Outcomes(COMPA) funded by the Ministry of Science and ICT(MSIT), and byKOREA HYDRO & NUCLEAR POWER CO., LTD.

REFERENCES

[1] K.-T. Yang, M.-K. Kim, T. Kim, J.-H. Kim, J. Suhr, Design optimization of smartphone camera housing fabricated by laser powder bed fusion using thermal analysis, Journal of Mechanical Science and Technology 36(2) (2022) 699-708.

[2] J. Bae, M.-k. Kim, E. Oh, K.-T. Yang, J. Suhr, Experimental and numerical investigation of 17–4PH stainless steel fabricated by laser powder bed fusion and hot isostatic pressing, Materials Research Express 8(10) (2021) 106512.

[3] K.-T. Yang, M.-K. Kim, D. Kim, J. Suhr, Investigation of laser powder bed fusion manufacturing and post-processing for surface quality of as-built 17-4PH stainless steel, Surface and Coatings Technology 422 (2021) 127492.

[4] P. Bidare, I. Bitharas, R. Ward, M. Attallah, A.J. Moore, Fluid and particle dynamics in laser powder bed fusion, Acta Materialia 142 (2018) 107-120.