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Quality of Additively Manufactured As-built 17-4 PH Parts with respect to Process Conditions and Moisture Contents

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Laser powder bed fusion (LPBF) is one of the most commonly used additive manufacturing (AM) techniques using a scanning laser. This is because the complex structures and the high resolution can be attained compared with the other metal AM techniques. During the manufacturing process, process failures and defects, such as crack, delamination, low relative density, etc. occur because of the environment of the chamber/air, the inappropriate process conditions, and the condition of the metal powders. Among them, it has been reported that moisture has a detrimental influence on the qualities such as low powder flowability, agglomeration, hydrogen pores, oxidation of powder surface, etc. However, a fundamental understanding of the moisture effects on the qualities and properties of as-built parts is still lacking.

Therefore, in this study, the quality of the as-built 17-4PH stainless steel parts is quantitatively analyzed via ex-situ characterization of the relative density, hardness, and melt-pool geometry, while varying the moisture contents and processing parameters. As a result, the moisture caused detrimental effects on material properties in terms of relative density, hardness, and melt-pool geometry. Also, lack of fusion and detachment from the previously fabricated layer induced by agglomeration of each metal particle occurred with higher moisture contents.

This work showed how much the moisture affected the quality of the as-built 17-4 PH parts combined with the processing parameters. The results confirmed that the management of moisture is indispensable for printing.

NOMENCLATURE

P= laser power
v = laser speed
t = layer thickness
l = line spacing, hatch spacing

1. Introduction

Laser powder bed fusion (LPBF) technique, one of metal 3D (dimensional) printing methods, is commonly used for developing a new product called as prototyping. Since it has advantages in terms of producing complex structures without support structures and reducing a development cost, many studies and trials for commercialization were conducting. However, during fabricating process, there are many unresolved defects, such as cracks, delamination, low relative density, low surface roughness, etc. They were caused by selecting wrong process conditions (laser power, laser speed, line spacing, layer thickness, etc.) or controlling powder conditions and balance of a substrate.

Some researchers studied that the relationship between the mechanical properties and the process conditions, especially with respect to volumetric energy density (VED, it is calculated by $P/(v\cdot l\cdot t)$ [W/mm^3]). Z. Hu et al. [1] reported that low relative density of 17-4PH as-built parts was obtained when the specimens were manufactured at higher laser speed ($v \geq 1300$ mm/s). K.-T. Yang et al. [2] showed when VED is larger than 100 J/mm^3, surface roughness of the as-built parts was deteriorated. Also, Gu, Hengfeng, et al. [3] optimized process conditions (VED was in range of 44-81 J/mm^3) with maximum porosity (0.4 %) of 17-4PH products.

Also, there are some literatures in terms of the effects of powder conditions, such as amounts of moisture contents, flowability, etc. L.Cordova et al. [4] reported that moisture contents on metal particles caused low flowability of them, so moisturized powders showed low relative density and low spreadability during spreading them. Also, the moisture on the metal particles showed the oxidation during the fabricating process, so the quality of as-built parts was deteriorated [5]. However, there are not sufficient studies about quantitatively analyzing the effects of these moisturized powders on properties of the fabricated parts.

Therefore, in this study, the qualities of 17-4PH stainless steel parts in terms of relative density, hardness, and melt-pool geometries (width and depth) were estimated with respect to the humidity and VED. This work figured out how the moisture contents affects the quality of the fabricated 17-4PH metallic parts. Through the results of this study, the importance of managing the moisture contents on the metal powders could be emphasized.

2. Characterization of material properties of 17-4PH as-built parts

2.1 Materials and process parameters

In this study, 17-4PH stainless steel powder provided by AMC powder was used for fabricating specimens with two cases of process parameters in Table 1: The first one was 190-400 W of laser power with 1000 mm/s of laser speed and the second was 250-1000 mm/s of laser speed with fixed laser power (200 W).

Table 1. Processing parameters	Laser power [W]	Laser speed [mm/s]	Line spacing [mm]	Layer thickness [mm]
	190-400	250-1000	0.08	0.04

Also, the moisture contents of 17-4PH powder were measured by the moisture-meter and three conditions were selected: Air-dried (3.4 %RH), 1st moisturized (20.4 %RH), and 2nd moisturized (38.4 %RH).

2.2 Ex-situ characterization methods

The specimens for measuring material properties were fabricated by combining aforementioned process parameters and moisture contents in Fig. 1. The specimen dimension was 20x10x10 mm^3.

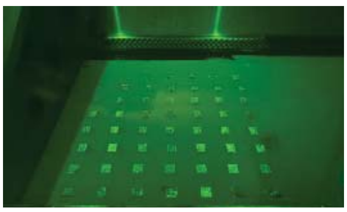

Fig. 1. As-built 17-4PH Parts with respect to process parameters

After manufacturing, ex-situ process data in terms of the relative density, the hardness, and the melt-pool geometries of as-built parts were measured, and the effects of moisture contents and VED were estimated, respectively. The schematic of the ex-situ characterization methods was depicted in Fig. 2. In order to estimate the hardness and the melt-pool geometries, optical microscope (OM) and etching solution (mixed with H_2O, HNO_3, HCl and $CuCl_2$) were used for measuring these ex-situ process data.

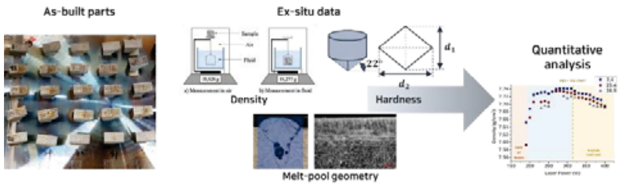

Fig. 2. The schematic of ex-situ characterization methods: Archimedes method, Vickers Hardness test, and optical microscope (OM) was utilized.

3. Conclusions

During the fabricating process, several defects occurred due to the wrong process conditions and the high moisture contents on the powder particles. They caused the manufactured parts to delaminate from the substrate or the previous layers and powder agglomeration inducing the lack of fusion. As a result, the quality of the fabricated 17-4PH stainless steel parts is quantitatively analyzed in terms of relative density, hardness, and melt-pool geometries with respect to the amount of moisture contents and VED in Fig. 3. The relative density and the hardness of the as-built parts increased with an increase in VED until 60-110 J/mm^3 and decreased at outer this region. Due to the moisture effects, the relative density and the hardness decreased from 0.07-7.86 % and 1.86-11.75 %, respectively. Also, the melt-pool width and the depth decreased by 2.43-10.12 % and 1.34-44.37 % induced by the moisture contents on the surface of the metal powders.

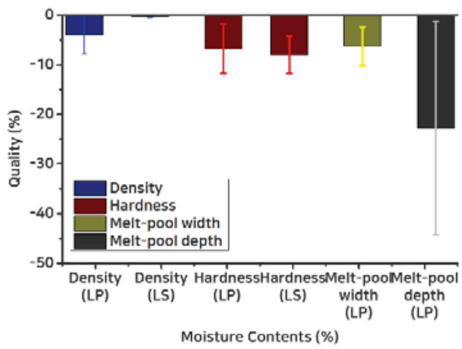

Fig. 3. Moisture effects on the quality of the as-built 17-4PH parts: the relative density, the hardness, and the melt-pool geometries were categorized by the quality of the specimens.

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