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DENSIFYING METHOD IN ADDITIVE MANUFACTURING PROCESS OF H13 TOOL STEEL: LASER RE-MELTING

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ABSTRACT: AISI H13 tool steel structures were fabricated by selective laser melting which is one of the metal additive manufacturing process. Scanning speed of laser was controlled in the ranging of 100-1000 mm/s to optimize the process parameter to fabricate the highly densified structure. Laser power, hatch space and layer thickness were fixed at 90 W, 80 µm and 25 µm. Under 200 mm/s, spherical shape pores were observed and irregular shape pores were observed in over 400 mm/s samples. Residual pores were not easily removed by changing laser scanning speed alone and laser re-melting technique was applied to solve the pore problem. Each layers were exposed twice to laser with various scanning speed before re-coating the powder for next layer. Spherical shape pores were observed from all of the specimen exposed under 200 mm/s irrespective of another exposed laser speed. While re-melting over scanning speed of 800 mm/s did not showed effect on the densification, the combination of first scanning speed (400 mm/s) and second scanning speed (600 mm/s) showed the significant reduction of pores.

KEYWORDS: Additive manufacturing, Selective laser melting, Tool steel, H13, Laser re-melting

INTRODUCTION

Additive manufacturing has benefit of fabricating a complex three-dimensional structure directly from CAD(Computer Aided Design) data. Powder, wire and sheet could be used as raw material of additive manufacturing of metallic materials. SLM(Selective Laser Melting) is one of the additive manufacturing technique using the power as the raw material. Figure 1 shows the brief schematic diagram of SLM process. Density of powder bed in building area is near the apparent density. Laser melt the powder bed and densify the AM(Additively Manufactured) part. As shown by Khatirallah et. al. (2016), melting and solidifying of material is processed in millisecond. Vacancy among the powders is not completely filled at an inappropriate process parameter and it resulted in a residual pore. Mechanical properties of AM parts affected by porosity. Feature accuracy and relative density of AM parts are key aspect for optimizing the process parameter of SLM.

![Schematic diagram of Selective Laser Melting process](image-url)
Laser re-melting process is one of the process parameter. Secondary laser exposed on the previously melted and solidified layer. Figure 2 shows the Schematic image of laser re-melting process. E. Yasa et al. (2011) showed an effect of laser re-melting process on AISI 316L stainless steel. Removal of residual porosities and reduce of surface roughness were the main effect of laser re-melting process. However, the effect of laser re-melting on the other material and parametric variety were not researched in their paper. In this study, AISI H13 was process by various scanning speed of laser to research the laser re-melting.

AISI H13 tool steel is used as a mold, die and others hot/cold work tooling applications. H13 has several advantages when the additive manufacturing is applied. H13 is hard to machining materials due to their high hardness and thermal resistance. Additive manufacturing could produce a complex feature without affecting by hardness of materials. Moreover, Maciej Mazur et. al. (2017) showed that conformal cooling channel in H13 mold, which could be realized by three-dimensional structural freedom of additive manufacturing, increased the cooling rate.

**MATERIAL AND EXPERIMENTAL PROCEDURE**

AISI H13 powder manufactured by sandvik was used in this study. Figure 3 shows the SEM image and particle size distribution of H13 powder. It has spherical shape and distributed by near Gaussian distribution. Median particle size of this powder(D$_{50}$) was 34.88 μm. Cubic samples, which have 10 mm length on each side, was manufactured by selective laser melting. Laser power, hatch space and layer thickness were fixed at 90 W, 80 μm and 25 μm, respectively. Scanning speed of laser were controlled from 100 mm/s to 1000 mm/s to change the inputted energy density on the powder bed. Re-melting process also used the scanning speed from 100 mm/s to 1000 mm/s. As shown in figure 2, re-melting process was process on the every layer. Optical microscopy (OM) was used to observe the pores size and distribution and free image processing program was used to measure the pore size and number from OM images.

![Figure 3. (a) SEM image of H13 powder and (b) particle size distribution.](image-url)
RESULT AND DISCUSSION
Cross-sectional Optical Microscopy images of samples without re-melting were shown in figure 4. Residual pores observed in OM images could be classified into three groups. Group A, spherical pores were observed under 200 mm/s. Wayne E. King et. al. (2014) showed a keyhole mode melting which were occurred in overmelting condition produce those pores. Group B, irregular shape and relatively wide pores were observed from 400 mm/s to 800 mm/s. Group C, irregular shape and aligned pores were observed in 1000 mm/s. Lore Thijs et. al. (2010) showed the pores like group C were produced when the melt pool width was not enough compared to the hatch space.

Re-melted sample also could be classified to the similar group. Figure 5 shows OM images of re-melted samples, which had 100 mm/s or 200 mm/s scanning speed of firstly exposed laser. They showed a spherical pore shape and distribution similar to group A. Re-melting with various scanning speed did not show an effect of decreasing the residual pores on the group A. Figure 6 shows the re-melted samples, which had 400 mm/s or 600 mm/s scanning speed of firstly exposed laser. Those samples showed the effect of re-melting on densification. Re-melting by 400 mm/s or 600 mm/s showed a higher density than the other condition. Re-melted with 100 mm/s and 200 mm/s showed a similar pore to group A. Pores like group B were observed at the secondary exposed laser speed over 800 mm/s. Figure 7 shows the re-melted samples which had 800 mm/s or 1000 mm/s scanning speed of firstly exposed laser. Those samples also showed a changing of pore by re-melting speed. However, highly densified samples like observed in figure 6 did not exist. Energy density of those samples were not enough to densify those samples. All of the re-melted samples involving the scanning speed of 100 mm/s and 200 mm/s in either firstly or secondary exposed laser showed a pores like group A.

Figure 4. OM images of AM H13 samples. (Below number means the scanning speed)

Figure 5. OM images of re-melted samples which scanning speed of firstly exposed were 100 mm/s and 200 mm/s. (Below numbers mean the scanning speed of firstly and secondary exposed laser, respectively)
Figure 6. OM images of re-melted samples which scanning speed of firstly exposed were 400 mm/s and 600 mm/s. (Below numbers mean the scanning speed of firstly and secondary exposed laser, respectively)

Figure 7. OM images of re-melted samples which scanning speed of firstly exposed were 800 mm/s and 1000 mm/s. (Below numbers mean the scanning speed of firstly and secondary exposed laser, respectively)

Figure 8 shows a pore number and average pore size of each sample, respectively. Number of pores increased when the samples were re-melted by 100 mm/s and 200 mm/s regardless of the firstly exposed laser speed. Samples of re-melted by 400 mm/s or 600 mm/s showed the least pores. Average pore size of and scanned by 400 mm/s and 600 mm/s samples without re-melting showed over 80 μm² average pore size. By applying the re-melting process, average pore size decreased under 20 μm² at 400 mm/s and 600 mm/s. Both number of pores and average pore size is the least at the firstly and secondary exposed scanning speed were 400 mm/s and 600 mm/s, respectively. It showed that not only re-melting parameter also combination of firstly and secondary exposed speed had an optimizing condition effect to the densifying behavior.

Figure 8. Number of pores (a) and average pore size (b). Zero in x-axis means that those samples were not re-melted.
CONCLUSION
In this study, the effect of re-melting process on AISI H13 were researched and following results were obtained. Residual pores observed in H13 without re-melting were classified into the three groups. Group A showed a spherical pores produced by over-melting, group B showed an irregular shape and group C showed a needle shape pores between the melt pool lines. All of the samples included the scanning speed of 100 mm/s and 200 mm/s regardless of the order of laser exposing showed a similar pores to group A. Samples that were manufactured by 400 mm/s and 600 mm/s without re-melting had average pore size, however, they decreased and showed the smallest pore size when re-melting was processed by 400 mm/s or 600 mm/s.

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