

Effect of laser power and scanning speed on the microstructure and mechanical properties of SLM fabricated Inconel 718 specimens

Abstract

Inconel 718 is a typical alloy suitable for selective laser melting (SLM) method. The fabrication parameters have determined effect on the mechanical properties of the produced parts. The effects of laser power and scanning speed on the microstructure and mechanical properties of the fabricated bars of Inconel 718 alloy were investigated. With the increase of laser power and decrease scanning speed, the stacking of melt pools came to be in order, less pores appeared and mechanical properties increased. Laser energy density (laser power divided by scanning speed) is in positive relationship with the mechanical properties. At the combination of 200W and 1000mm/s or combination of 150W and 500mm/s best mechanical properties with yield strength of 775MPa, ultimate tensile strength of 1055MPa and elongation of 29.5% were achieved. But, for the same laser energy density, the variation of laser power has more significant effect on the pore defect than that of scanning speed.

Keywords: Selective laser melting, Inconel 718, Laser power, Scanning speed, Microstructure, Mechanical properties.

Volume 3 Issue 3 - 2019

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Received: May 20, 2019 | **Published:** May 23, 2019

Introduction

Selective laser melting (SLM), one of the main additive manufacturing techniques for metal materials, owns a series advantages in the fabrication of complex components with high precision and short procedure.¹⁻⁴ It is being widely used in aero plane, aerospace, medical equipments and automotive industries. Fabrication of nickel based super alloy Inconel 718 by SLM is one of the most active research areas in additive manufacturing. The researches focus on the investigation of effect of fabrication parameters on the pore defect, microstructure and mechanical properties. The scanning speed and input power of laser beam are two key factors for the quality of parts. Qiu et al.,⁵ found that the laser power was in a positive relationship with the fabrication capability of strut diameter while the laser scanning speed had the nonlinearly inverse effect. Wu et al.,⁶ concluded that reducing the scanning speed and increasing the laser power could effectively increase the amount of remelting and make dense parts. Deng et al.,⁷ found that the SL Med Inconel 718 specimen had fine cellular-dendrites and relatively weak texture. Vertically built samples showed lower tensile strength but higher ductility than horizontally built samples, which may be caused by their different levels of residual stress and numbers of dislocations. McIlough et al.,⁸ found that the laser focal shift used in SLM can change the microstructural morphology

by altering the laser's interaction with the material. Strossner et al.,⁹ observed niobium micro segregation in the dendritic microstructure. Chlebus et al.,¹⁰ found the as-built specimens was characterized by columnar grains of supersaturated solid solution with internal micro segregation of Nb and Mo. In this paper, the effect of laser power and scanning speed on the pore defection, microstructure and mechanical properties of Inconel 718 samples were investigated.

Experimental

Inconel 718 powder ranging from 15~53μm was used in the fabrication of specimens. Its chemical composition is listed in Table 1. Several bars, 17mm×17mm×80mm, with the length in the building direction, were manufactured by an EP-M250 3D printing machine equipped with a 500W Yb-fiber laser beam (made by Beijing ePlus 3D Technology Co. Ltd). Laser power and scanning speed were varied at three levels, as listed in Table 2.

Table 1 Chemical composition of Inconel 718 Powder (wt.%)

Ni	Cr	Nb	Mo	Ti	Al	Co	C	Fe
52.99	18.31	5.11	2.97	0.99	0.52	0.14	0.02	bal

Table 2 Fabrication parameters

No.	Laser power (P) /W	Scanning speed (V)/mm/s	Laser energy density (E=P/V) J/mm
1	150	500	0.3
2	150	1000	0.15
3	150	1500	0.1
4	100	1000	0.1
5	200	1000	0.2

Unidirectional scanning strategy was adopted, with the scanning direction rotated 90° clockwise for next layer. The fabrication process is under argon atmosphere. One fabricated bar is shown in Figure 1. Segments of 10mm long were cut from the specimens; the surface at an angle of 45° to the scanning direction was taken for microstructure analysis, as shown in Figure 1. Standard tensile bars of 70mm long and 10mm in diameter along the fabrication direction were machined and tested by an Instron machine for tensile strength test.

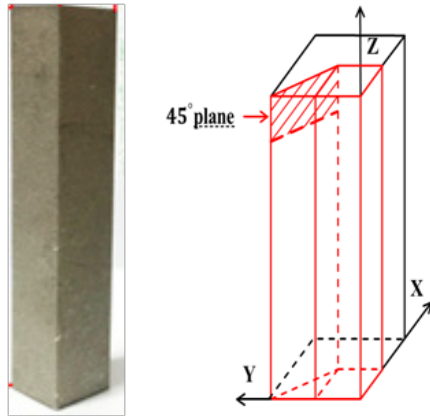


Figure 1 The fabricated specimen and the position of samples.

Results and discussion

Effect of laser power and scanning speed on pore and microstructure

From the top layer of the microstructure, the shape of melt pool can be seen very clear, as shown in Figure 2. The typical shape of a melt pool is bowl full of food with a bulge. Its width and depth are around 138μm and 80μm, respectively. Their variation with laser power and scanning speed is shown in Figure 3. The laser power has more significant effect on them than scanning speed. The effect of laser power and scanning speed on the microstructure and pore defect is shown Figure 4 & Figure 5, respectively. Under high scanning speed and low laser power such as specimen # 3 and #4, there is a number of big cavities between the melt pools. The cavities are long in the building directions, spanning two or three layers, their width is about 20μm to 50μm in #3 and #4, respectively. The melt pools are flat and of irregular shape, their stacking is in poor order. Partially melt power particles can be found in #3 and #4, which means the insufficient of laser energy. With the increase of scanning speed or the decrease of laser power, all of the powder particles are melt, the melt pool comes to be bowl shape, their stacking gets into good order, and there is less or no pores. The size of melt pool increased from 54.8μm to 83.9μm as laser power increased from 100W to 200W. For specimens #1 at the combination of 150W and 500mm/s or #5 at the combination of 200W and 1000mm/s, there is almost no pore.

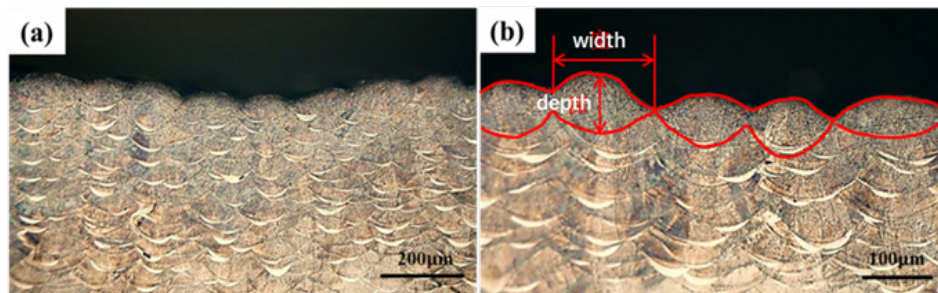


Figure 2 The profile of melt pools.

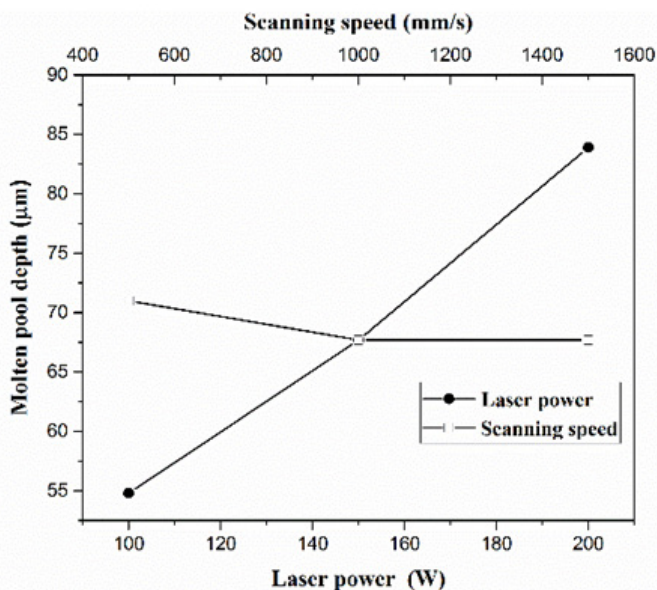


Figure 3 The relationship of melt pool depth with laser power and scanning speed.

Laser energy densities are used in the analysis of the effect of fabrication parameters on microstructure and properties. There are volume, area and linear laser energy densities. Deng et al.,¹¹ used linear energy density instead of laser power and scanning speed to investigate the microstructure and properties of CuSn10 alloy and found it is significantly in relationship with microstructure and properties. Here linear laser energy density, laser power divided by scanning speed, is used for analysis, as listed in Table 2. From Figure 4 & Figure 5, the increase of laser power or the decrease of scanning speed increases the laser energy density. Therefore, high laser energy density is beneficial for the reduction of pores. However, for #3 and #4 with same laser energy 0.1J/mm, their pore levels are different. Laser power makes more contribution to the pore defect. The microstructure by SEM of specimens #4, #5 and #1 are shown in Figure 6. For #4, the laser power is low, partially melt particles can be found in Figure 6A, in which there is typical equiaxed dendrites with bigger dendrite arms in contrast with the columnar dendrites of the base microstructure. Compared to #4, the laser power of #5 and #1 was increased to 150W and 200W, thus, no powder particles are found in them. Their space of primary dendrite arms are 0.39μm, 0.53μm and 0.62μm, respectively, as shown in Figure 6D & 6E & 6F. High laser power and slow scanning speed mean high energy densities, which can sufficiently melt powder particles and give more time for the grain growth. The

heat flux is from the melt to the melt bottom, therefore, the dendrites grew from bottom to top radially.

Effect of laser power and scanning speed on mechanical properties

The variation of mechanical properties, including tensile strength, yield strength and elongation, with scanning speed and laser power is shown in Figure 7. The mechanical properties increase with the increase of laser power or the decrease of scanning speed, which is in agreement with the microstructure. The best mechanical properties reached yield strength 775MPa, tensile strength of 1055MPa and elongation of 29.5% in #1 at the combination of 150W and 500mm/s and #5 at the combination of 200W and 1000mm/s. These mechanical

properties are higher than that by casting and forging. The variation of mechanical properties with laser energy density is plotted in Figure 8. Although the laser energy density of #1 and #5 are 0.3 J/mm and 0.2 J/mm, their mechanical properties are almost the same. That means the laser power has stronger effect on the mechanical properties. On the other hand, the laser energy densities of #3 and #4 are the same 0.1 J/mm, but, the mechanical properties of #3 is higher than that of #4 because the laser power of #3 is higher than that of #4. Therefore, laser power has stronger effect on the mechanical properties, which complies with its more significant effect on pore defect. Thus, it is better to increase laser power and increase scanning speed to achieve less pore defect, bigger melt pool and higher mechanical properties and high efficiency meanwhile.

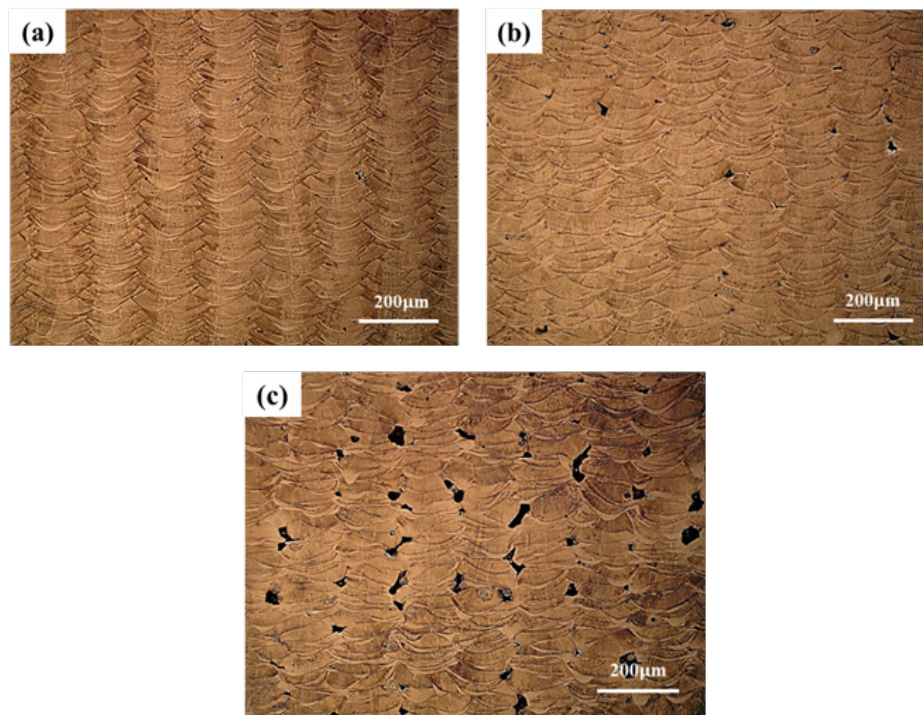


Figure 4 Microstructures of specimens with 150W and different scanning speeds (A) 500mm/s ;(B)1000mm/s ; (C)1500mm/s

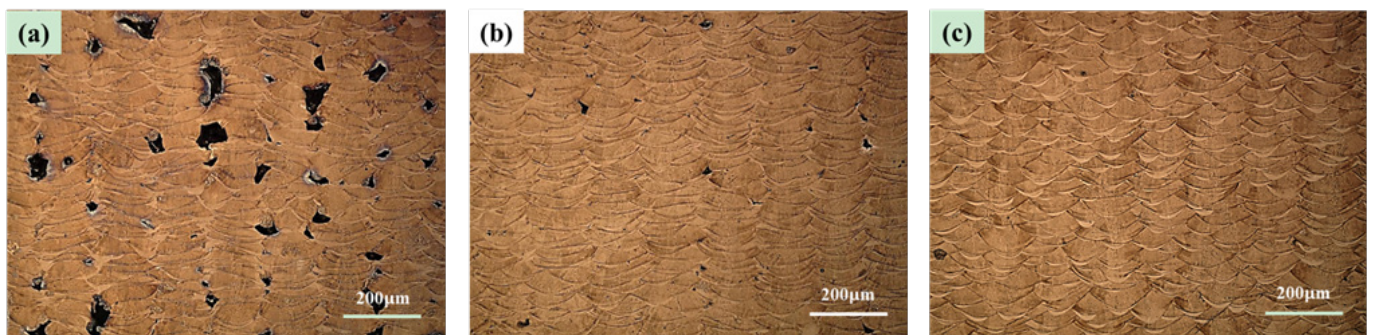


Figure 5 Microstructures of specimens with 1000mm/s and different laser powers (A) 100W; (B) 150W; (C) 200W

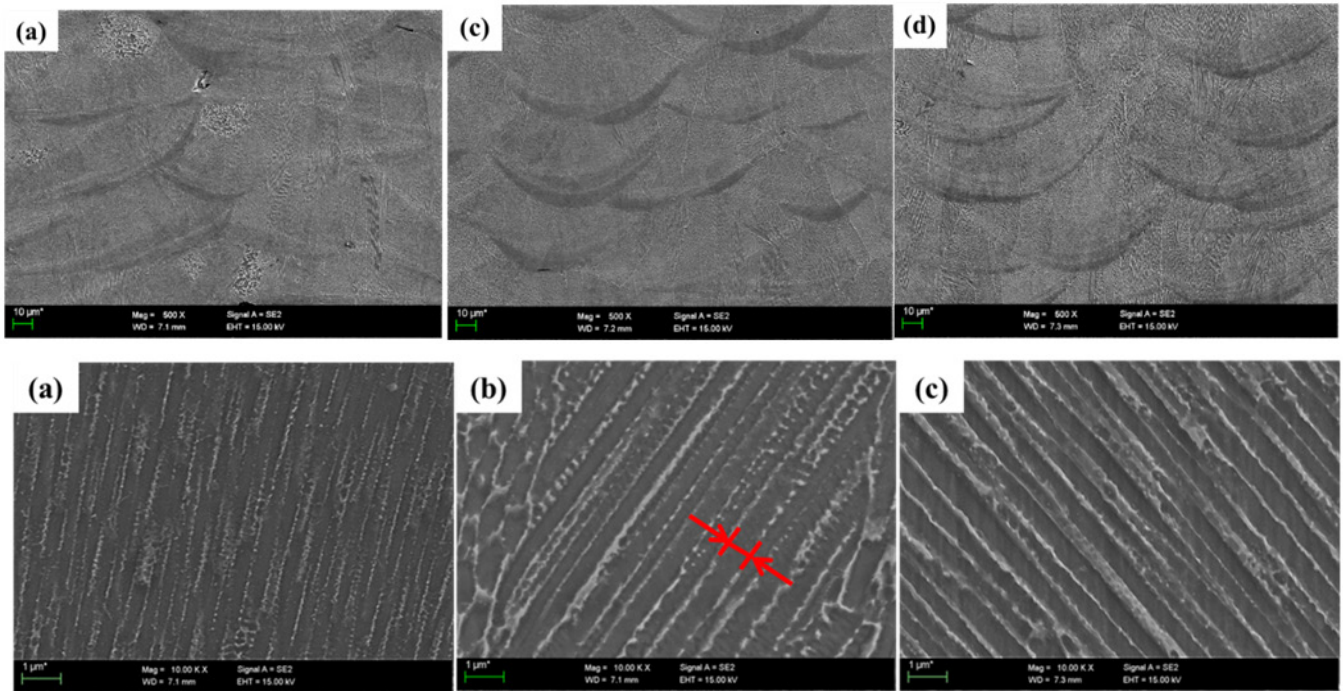


Figure 6 Microstructures of specimens with different laser powers and scanning speeds (500× and 50K×) (A) and (D) 100W 1000 mm/s 0.1 J/mm; (B) and (E) 200W 1000mm/s 0.2 J/mm; (C) 150W 500mm/s 0.3J/mm

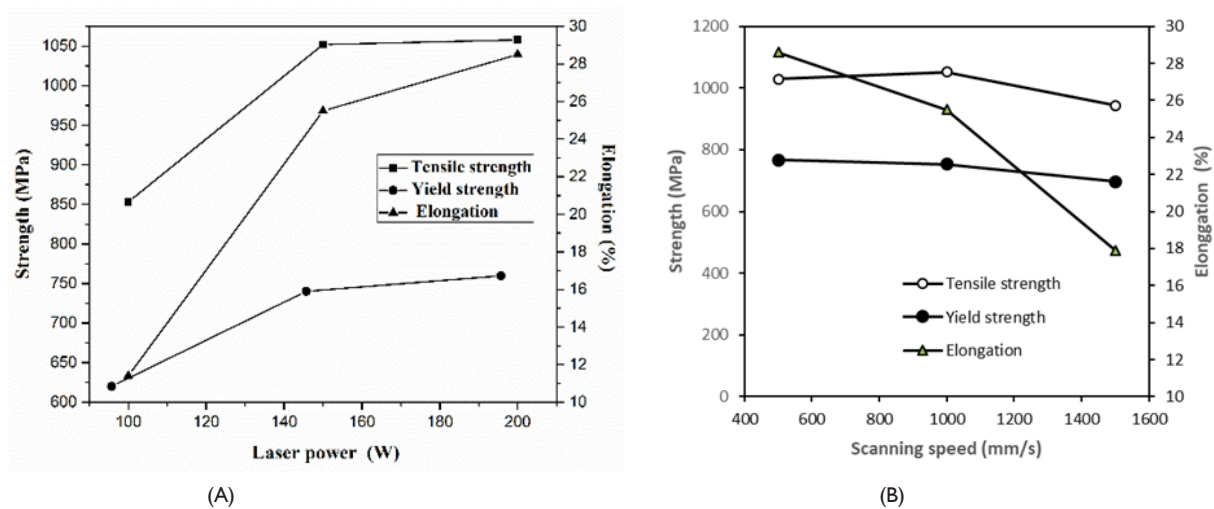


Figure 7 Comparison of mechanical properties of as-built Inconel 718 bars under different fabrication parameters: (A) Laser power; (B) Scanning speed.

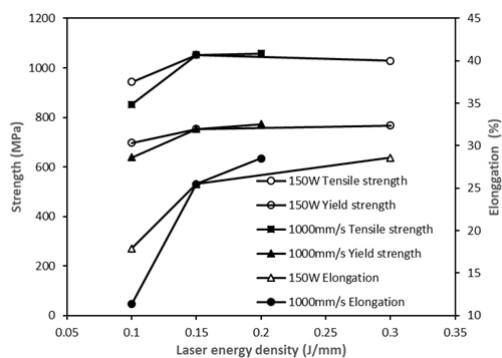


Figure 8 Comparison of mechanical properties of as-built Inconel 718 bars under different laser energy intensities.

Conclusion

The effects of laser power and scanning speed on the microstructure and mechanical properties of the fabricated bars were investigated.

- I. With the increase of laser power and decrease of scanning speed, the melt pool size increased, their stacking came to be in order, less pores appeared and mechanical properties increased. At the combination of 200W and 1000mm/s or the combination of 150W and 500mm/s best mechanical properties were achieved with yield strength of 775MPa, ultimate tensile strength of 1055MPa and elongation of 29.5%.
- II. Linear laser energy density (laser power divided by scanning speed) are in positive with the soundness, melt pool size and stacking, and mechanical properties. But for the same laser energy density, the variation of laser power has more significant effects than the

variation of scanning speed. Thus, it is suggested to improve the laser power and increase the scanning speed to reach high quality and high efficiency as well.

Acknowledgements

This research study was funded by the National Science and Technology Major Project of the Ministry of Science and Technology of China under Project No. 2016YFB1100703.

Conflict of interest

Author declares that there is no conflict of interest.

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