Effect of Line Energy Density and Wall Thickness on the Top Surface Quality of AlSi10Mg Sample Fabricated via Selective Laser Melting

Shimin Dai, Haihong Zhu* and Xiaoyan Zeng
Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, Hubei, P.R. of China
Email: zhuhh@hust.edu.cn

Abstract. The effect of line energy density (LED) and wall thickness on the top surface quality of AlSi10Mg sample fabricated by selective laser melting (SLM) has been investigated in this paper. It is observed that the surface morphology has great evolution which the molten track turns to regular and then to irregular with the increase in LED. The line roughness (Ra) and peak height (Rz) decrease first and then increase as the LED increases. The optimal LED for low Ra/Rz increases from 0.1389 J/mm to 0.30 J/mm with the wall thickness increases from 0.1 mm to 2 mm. This work can provide a guide of manufacturing complexity geometrical thin-walled parts with a fine top surface quality.

1. Introduction
Selective laser melting (SLM) is a promising fabricating method in additive manufacturing (AM). Based on the principle of discrete stacking, metal powder is irradiated with laser beams layer by layer to make them metallurgically combine to form parts [1]. It has the superiority which means high powder utilization, short parts from design to forming cycle, nearly net forming, and can not be restricted by complex geometry. AlSi10Mg is a metal material widely applied in aerospace for its superior mechanical properties and lightweight effect [2-4]. Nevertheless, poor surface quality of components fabricated via SLM has become a pivotal technical problem which constrains its further development. So, it is necessary to study the relationship between the process parameters and surface quality of the SLMed samples.

In fact, there were some research works focused on this field. Dai [5] found that surface tension played a crucial role in the formation of the surface morphology via establishing a mass and momentum transfer model. Kamarudin [6] tested the surface roughness and dimensional accuracy of the benchmark produced by SLM and found that SLM has the potential of application in molds. Volker Weißmann [7] found the surface orientation had a great effect in surface roughness. Ahmed H. Maamoun [3] designed a experiment to analyze the surface roughness according to the interaction effect between the SLM process parameters and found that there was a range of energy densities for the AlSi10Mg. Mohammadi [8] attained the appropriate process parameters (laser power, scan speed, hatch spacing) to deposit the AlSi10Mg-200C sample with low surface roughness by DMLS. Joźwik [9] studied the influence of laser power on morphological characteristics of the fabricated surface and found that the Sa/Sq was not linear with the laser power. However, the study of surface quality has not yet reached the level of small wall thickness and short scanning line segments to observe its surface morphology which affect the forming of complex thin-walled parts directly.
In this work, we investigated the effect of line energy density and wall thickness on the top surface quality of AlSi10Mg sample. The surface morphology, the line roughness and peak height were discussed.

2. Experiment Procedures

2.1. Materials
AlSi10Mg metal powders with an average particle size of 33.7 μm formed by the gas atomization process and spherical shape were applied in the experiments. The chemical ingredient (wt.%) was 10.05 Si, 1.41 Fe, 0.009 Cu, 0.225 Mn, 0.46 Mg, 0.009 Zn, 0.016 Ti and Al (balance).

2.2. SLM Process
The samples were prepared by a TS-SLM300A SLM system which was developed by Shanghai Techgine Laser Technology Company, China. The utilized laser was a YLR-500-LP Erbium fiber laser (IPG Laser GmbH, Germany) with a maximum power of 500 W and a spot size of 100 μm. All samples with length of 8 mm, width of 8 mm, height of 8 mm and different wall thickness were deposited on the commercially AA 2024 substrate in an argon environment with the concentrations of oxygen controlled below 200 ppm. The samples were fabricated by process parameters, e.g., the scanning space of 0.15 mm, initial phase angle of 45°, rotate angle of 90°, layer thickness of 40 μm, contour hatching power of 300 W, contour scanning velocity of 1500 mm/s. The additional variables for forming samples are shown in table 1. The schematic of hatching and contour of manufactured sample is illustrated in figure 1b.

![Figure 1](image)

**Figure 1.** The schematic of sample: (a) top and side surface of sample; (b) hatching and contour of sample.

| Designed wall thickness (mm) | Laser power (W) | Scanning velocity (mm/s) |
|------------------------------|-----------------|--------------------------|
| 0.1/0.3/0.5/0.8/1/2          | 200, 250, 300   | 600, 1000, 1400, 1800, 2200, 2600, 3000 |

The line energy density (LED) was determined by equation (1):

$$\text{LED} = \frac{P}{V}$$

where $P$, $V$ represent the laser power and scanning velocity, respectively.

2.3. Characterization
The surface morphology was observed by VK-X200K laser confocal microscope (LCM) manufactured by Keyence Co., Ltd, Japan. The line roughness and peak height were measured by VK4 business data.
analysis software and the measuring schematic is shown in figure 2.

**Figure 2.** The measuring schematic of the line roughness and peak height.

3. Results and Discussions

3.1. Top Surface Topography

The top surface morphology of different thickness wall samples fabricated by different LED is shown in figure 3. From figure 3, it can be seen that the surface morphology is extremely uneven and the melting track is irregular and intermittent with the LED of 0.0909 J/mm. This is caused by a reason that there is no sufficient energy to form complete molten pool for the low energy input. As the LED increases, the melting track become more uniform and stable due to the enough energy input. However, if the LED increases too much, the surface morphology will transform to non-uniform and irregular, as shown in figures 3d, 3h, 3i, 3p, 3t and 3x.

**Figure 3.** Top surface morphology of different thickness wall samples with different LED: (a)-(d) 0.1 mm; (e)-(h) 0.3 mm; (i)-(l) 0.5 mm; (m)-(p) 0.8 mm; (q)-(t) 1mm; (u)-(x) 2 mm.
Figure 4 illustrates the track evolution in different LED. When the LED is too low, there is no sufficient input laser energy to melt the powder and form a regular track which leads to an uneven top surface, as shown in figure 4a. We can also find that there are a lot of balling derived from splash of molten pool and powder sticky, resulting in a worse top surface. As the LED increases to a suitable level, the track becomes regular and the flat top surface is obtained for the enough input laser energy which makes the molten pool flow sufficiently, as shown in figure 4b. It also can be seen that there are a few balling which due to the heat conduction, viscosity change and surface tension of the molten pool that enables the nearby powders to attach [10]. When the LED is too high, the molten pool will agitate violently on account of high energy input that introduces a non-uniform top surface and there are a mass of balling from splash of droplets on top surface, which has been shown in figure 4c. These diagrams and reasons explain the various phenomenon in figure 3 well.

![Schematic of track evolution in different LED](image)

**Figure 4.** Schematic of track evolution in different LED: (a) low LED; (b) suitable LED; (c) high LED.

### 3.2. Line Roughness and Peak Height

Figure 5 shows that Ra and Rz in function of the LED in different wall thickness. It is apparently observed that Ra and Rz first decrease then increase and reach equilibrium ultimately with the LED increase in fabricating sample of wall thickness of 0.1 mm. The maximum value of Ra is 18.25 μm with the LED 0.3333 J/mm and the minimum value of Ra is 10.5 μm with the LED 0.1389 J/mm of wall thickness of 0.1 mm as shown in figure 5a. Figure 5b indicates that first decrease then increase in Ra/Rz as the LED adds and the turning point is 0.20 J/mm of wall thickness of 0.3 mm. The peak height is as high as 179.28 μm with the LED of 0.0909 J/mm while the Rz is 68.8 μm with the LED of 0.20 J/mm. The trend of top surface of wall thickness of 0.5mm has been shown in figure 5c. It is obviously seen that the Ra and Rz show a decline at the LED range of 0.0909 J/mm-0.20 J/mm then suggest they are prone to increasing at the LED range of 0.20 J/mm-0.3333 J/mm. Figure 5d shows that the line roughness and the peak height change in the LED and we can find that there is a sign of decreasing first then increasing and the turning point has come to the LED 0.25 J/mm. Figure 5e
shows that the Ra and Rz in function of the LED of wall thickness of 1 mm. We discover that the Ra and Rz decrease in a high speed when the LED locates in 0.0909 J/mm - 0.1785 J/mm, then the falling velocity tends to be gentle as the LED to the 0.25 J/mm. Finally, the Ra and Rz transform to rise. Figure 5f shows that 2 mm thick sample's line roughness and peak height vary in different LED. Obviously, the Ra and Rz first decline then add with the LED increases and we obtained the minimum Ra/Rz of 8.79 μm/61.43 μm in the LED 0.3 J/mm.

![Fig 5](image)

Figure 5. Ra and Rz in function of LED in different wall thickness: (a) 0.1 mm; (b) 0.3 mm; (c) 0.5 mm; (d) 0.8 mm; (e) 1 mm; (f) 2 mm.

4. Conclusions

The effect of line energy density on surface quality of different wall thickness of AlSi10Mg sample deposited via SLM was investigated and the conclusions are as follow:

1) As the line energy density increases, the top surface morphology of different wall thickness sample turns from poor to good then to poor.

2) Line roughness Ra and peak height Rz decrease firstly and then increase with the LED increases of distinct wall thickness.

3) As the wall thickness of sample increases from 0.1 mm to 2 mm, the optimal LED at which the lowest surface roughness and peak height are obtained is also gradually increased from 0.1389 J/mm to 0.30 J/mm.
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References
[1] Zhang B L and Attar H 2016 selective laser melting of titanium alloys and titanium matrix composites for biomedical applications: A review (4) 463-475
[2] Leon A and Aghion E 2017 Materials characterization effect of surface roughness on corrosion fatigue performance of AlSi10Mg alloy produced by selective laser melting (SLM) Mater. Charact. 131 188-194
[3] Maamoun A H, Xue Y F, Elbestawi M A and Veldhuis S C 2018 Effect of SLM process parameters on the quality of Al Alloy parts; Part I: powder characterization, density, surface roughness, and dimensional accuracy
[4] Kempen K, et al. 2015 Processing AlSi10Mg by selective laser melting: parameter optimisation and material characterisation 0836
[5] Dai D and Gu D 2015 Tailoring surface quality through mass and momentum transfer modeling using a volume of fluid method in selective laser melting of TiC/AlSi10Mg powder Int. J. Mach. Tools Manuf. 88 95-107
[6] Kqeel and Shamsudin S 2017 Benchmarking of dimensional accuracy and surface roughness for AlSi10Mg part by selective laser melting (SLM) AIP Conf. Proc. 1831
[7] Weißmann V et al. 2018 Effects of build orientation on surface morphology and bone cell activity of additively manufactured Ti6Al4V specimens Materials (Basel) 11 (6)
[8] Mohammadi M and Asgari H 2018 Achieving low surface roughness AlSi10Mg_200C parts using direct metal laser sintering Addit. Manuf. 20 23-32
[9] Józwik J, Ostrowski D, Milczarczyk R and Krołczyk G M 2018 Analysis of relation between the 3D printer laser beam power and the surface morphology properties in Ti-6Al-4V titanium alloy parts J. Brazilian Soc. Mech. Sci. Eng. 40 (4)
[10] Monroy K, Delgado J, Sereno L, Ciurana J and Hendrichs N J 2015 Geometrical feature analysis of Co-Cr-Mo single tracks after selective laser melting processing Rapid Prototyp. J. 21 (3) 287-300