# Physical Properties and Microstructure Study of Stainless Steel 316L Alloy Fabricated by Selective Laser Melting

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**Abstract.** Selective Laser Melting (SLM) demonstrates the 21st century's manufacturing infrastructure in which powdered raw material is melted by a high energy focused laser, and built up layer-by-layer until it forms three-dimensional metal parts. SLM process involves a variation of process parameters which affects the final material properties. 316L stainless steel compacts through the manipulation of building orientation and powder layer thickness parameters were manufactured by SLM. The effect of the manipulated parameters on the relative density and dimensional accuracy of the 316L stainless steel compacts, which were in the as-build condition, were experimented and analysed. The relationship between the microstructures and the physical properties of fabricated 316L stainless steel compacts was investigated in this study. The results revealed that 90° building orientation has higher relative density and dimensional accuracy than 0° building orientation. Building orientation was found to give more significant effect in terms of dimensional accuracy, and relative density of SLM compacts compare to build layer thickness. Nevertheless, the existence of large number and sizes of pores greatly influences the low performances of the density.

## INTRODUCTION

Selective Laser Melting (SLM) is one of the known additive manufacturing technology that utilises high energy focused laser to melt powdered raw material using a built up layer-by-layer techniques to form three-dimensional metal parts [1]. Nevertheless, SLM true strength is the ability to allow manufacturing of bespoke part with complex geometries matching the properties of parts conventionally manufactured in series, for example, cast and cut [2]. Despite this, to maximise the full potential of SLM, its particular issues need to be well understood.

Poor physical properties and residual porosity of the SLM manufactured parts prevent their usage for the application that requires high strength and fatigue resistance. Just like conventionally fabricated parts, properties of SLM parts do not rely only on microstructure but also on typically porous defects and their morphology, which are controlled by initial processing parameters [3]. For this reason, most of the present-day studies have shown interest to understand how processing parameters affect microstructural evolution in SLM.

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Due to the excellent corrosion resistance and properties exhibits by 316L stainless steel, this material has been chosen to be conducted by significant numbers of researches on SLM process [3-6]. Excellent physical properties such as dimensional accuracy and built part's densification with 100 % relative density in practice are the challenges for SLM process. In previous work, Yasa *et al.*, (2011) has studied the effect of laser re-melting on the density of the built by SLM parts and managed to nearly reached 100 % of densification [7]. Another research was done by Cherry *et al.*, (2015) has introduced a semi-empirical formula of energy power density to improve the density of 316L stainless steel components[8]. Layer thickness was designed as parts of the formula. Several studies were done to assess the effect of building direction on the mechanical properties of 316L stainless steel fabricated by SLM [9, 10].

This paper discusses the effect of building orientations and powder layer thickness of SLM process on the physical properties and microstructure of the SLM fabricated stainless steel 316L compacts using SLM, in the as-built condition. The dimensional accuracy, compact density and microstructure of the compacts are systematically discussed.

## EXPERIMENTAL

The metallic parts fabrication has been carried out using SLM machine SLM®125 HL (SLM Solutions, Germany). The 125 HL used an IPG-Faser laser with a power of 200 W. Stainless steel 316L powder utilised in this work was nitrogen gas-atomised powder with nominal chemical composition (wt.%) of 16–18 % Cr, 10.3 % Ni, 2.2 % Mo, 0.01 % C, 0.69 % Si, 0.99 % Mn, 0.02 % P, 0.005 % S and Fe balance.

Four sets of compacts were fabricated by SLM in the current study. The compacts were designed in the form of flat dog-bone shape with the dimension shown in Figure 1. The processing parameters are as listed in Table 1. Scanning speed and laser power were kept constant at 800 mm/s and 200 W, respectively. The manipulated parameters in this study are building orientation of 0° and 90°, and layer thickness of 30 and 50 µm.

The dimensional accuracy was measured on the as-built compacts at four main points which was the thickness of the compact, the largest width of the compact, width at the gauge and length of the compact. Digital Vernier calliper with 0.01 sensitivity, was employed. The compacts' density was discovered by the Archimedes method using Precisa Gravimentrics equipment. In this method, the compacts' density was calculated according to the Archimedes Principle. A compact's weight was measured in both distilled water and air. The compact's density was gained when the distilled water's density was given. The microstructures were observed under MEIJI-MT 7100 optical microscope (OM) at 5x and 10x magnification.

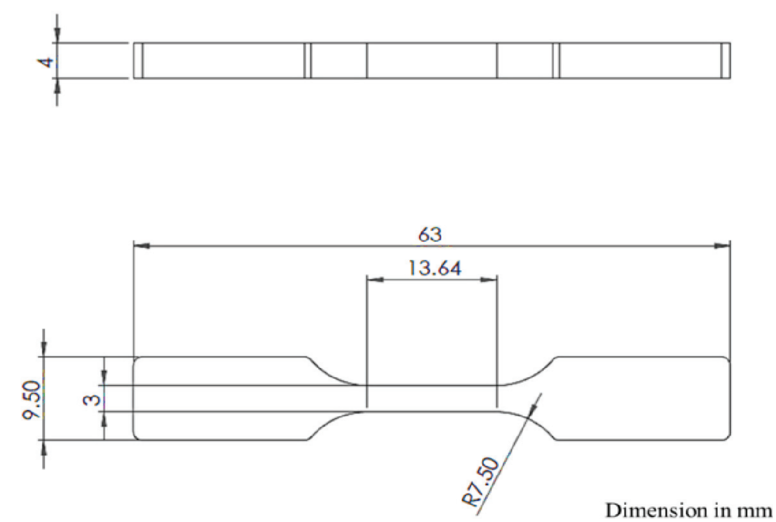



**FIGURE 1.** Shape and dimension of tensile test compact.

**TABLE 1.** SLM parameters for the SS316L compacts fabrication

| Compacts | Laser Power (W) | Scanning Speed (mm/s) | Building Orientation (°) | Layer Thickness (µm) |
|---|---|---|---|---|
| S01 | 200 | 800 | 0 | 30 |
| S02 | 200 | 800 | 90 | 30 |
| S03 | 200 | 800 | 0 | 50 |
| S04 | 200 | 800 | 90 | 50 |

## RESULTS AND DISCUSSION

### Dimensional Accuracy

Figure 2(a) reveals that 90° building orientation compacts have higher dimensional accuracy compare to 0° building orientation with 6.6 % differences. Meanwhile, 30 µm compacts show higher dimensional accuracy than 50 µm with only 0.5 % differences. The highest dimensional accuracy compact condition is 30 µm with 90° building orientation, while the lowest dimensional accuracy compact condition is 50 µm with 0° building orientation. From the result, it can be shown that the building layer thickness does not give significant effect on the dimensional accuracy of the compact as compared to building layer thickness. Despite this, all compact conditions can be said to be above 90 % of dimensional accuracy.

The low dimensional accuracy of compacts can be related to the existence of remaining support at the bottom of compacts as illustrated in Figure 2(b). This was probably due to the poor quality of surface finish done at the lower part of the compacts during the post-process of removing compacts from the substrate. The remaining support, cause an addition in the measurement value of compact's dimension. 0° building orientation compacts have a larger area of remaining support compare to 90° building orientation, thus, highly affect the value of the measurement.

The deformation of 0° building orientation compacts, as discussed, greatly influences the compact dimensional accuracy. The degree deformation as shown in Figure 2(c) indicates the changes in the actual dimension of the 0° building orientation compacts.

### Relative Density

The trend in Figure 3 demonstrates that the 90° building orientation compacts have a higher relative density as compared to the 0° building orientation with 0.25 % differences. Meanwhile, the 50 µm layer thickness compacts have a higher relative density as compared to the 30 µm layer thickness with 0.05 % differences. Compact condition that shows the highest relative density is 30 µm layer thickness with 90° building orientation compacts with the value of 99.2 % relative density. While the lowest relative density is 98.8 % relative density as shown by 50 µm layer thickness with 0° building orientation compacts.

Sun *et al.*, (2016) mentioned in their paper that it is very challenging to reach SLM compact with a theoritical density of 100 % in practice [5]. This is due to the possibilities of the existence of internal pores that were trapped within powders [11]. Nevertheless, SLM is capable to fabricate a high density parts. This is supported by the result of the relative density gained in this study of between 99.2 % and 98.8 % which indicate a high relative density of SLM compacts.

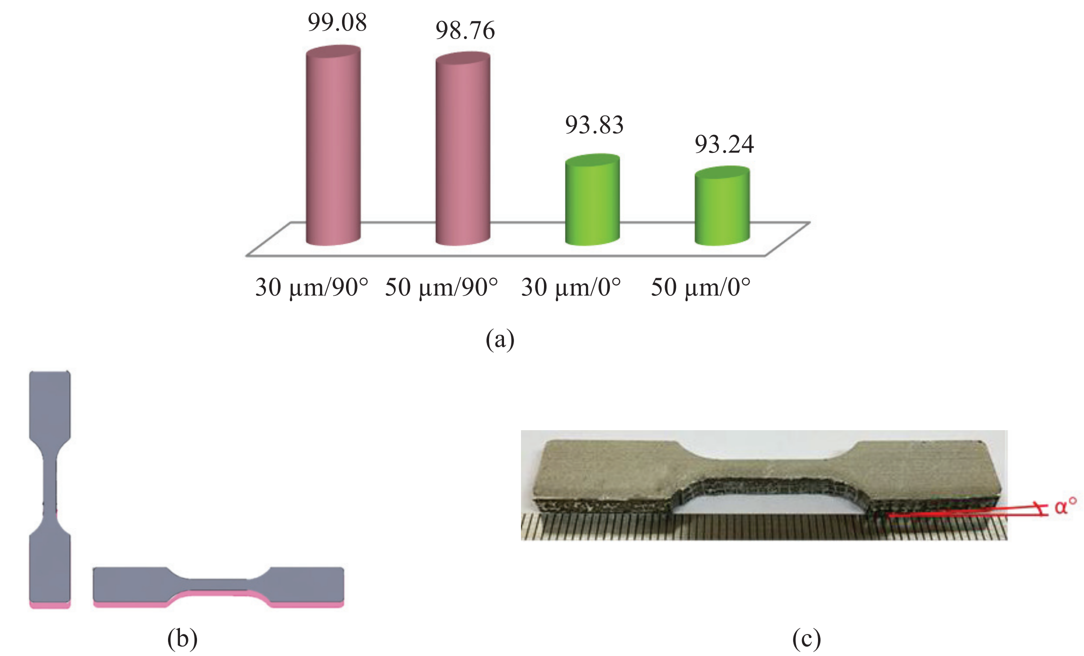



**FIGURE 2.** (a) Dimensional accuracy (%) for different condition of compacts; (b) Schematic diagrams showing the remaining support (pink area) at the bottom of compacts (left) for 90° building orientation, and (right) for 0° building orientations; and (c) As-built compacts of 0° building orientation showing deformations occurred at the bottom surface of the compact.

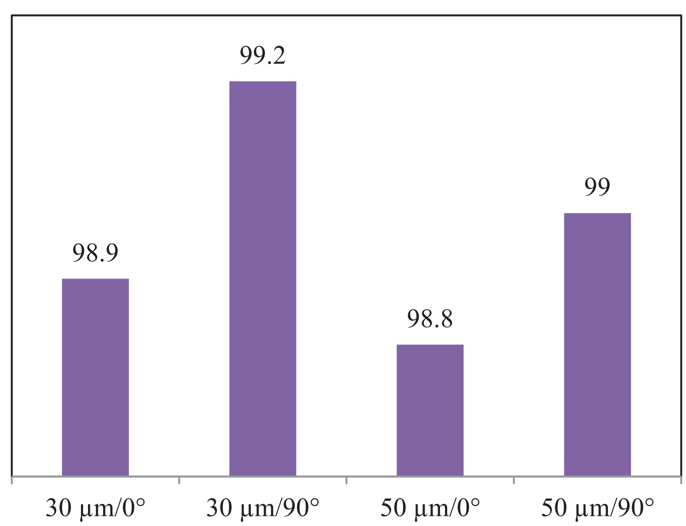
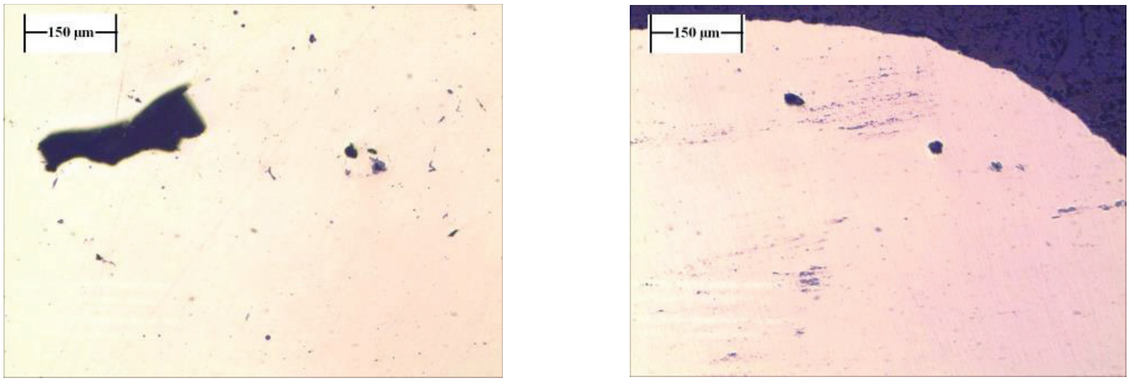



**FIGURE 3.** Average relative density (%) of SLM compacts under different building orientations and powder layer thickness.

## Microstructure

Figure 4 shows the inherent pores existed in the compact for 50 µm layer thickness with 0° building orientation condition, and 30 µm layer thickness with 90° building orientation condition, respectively. The finding provides evidence for limitation of the compact to reach 100 % fully dense. Figure 4(a) shows a larger size of pores as compared to Figure 4(b). The large size of pores causes the 50 µm layer thickness and 0º building orientation compact condition to have the lowest density. This is in line with the finding by Sun *et al.,* (2016) that the lowest density was due to the inherent pores trapped in the compacts [1].




(a) (b)

**FIGURE 4.** Optical micrographs of pores of (a) as-build SLM processed 316L stainless steel powder with 50 µm layer thickness and 0º building orientation, while b) is for 30 µm layer thickness and 90º building orientation.

## CONCLUSIONS

The results reveal that 90° building orientation has higher dimensional accuracy than 0° building orientation. The low dimensional accuracy of the compact is due to large area of remaining support causing an additional measurement value of compact dimension and deformation. The same trend can be seen for relative density, where 90° building orientation shows higher relative density than 0° building orientation. Building orientation was found to give more significant effect in terms of dimensional accuracy and relative density of SLM compacts as compared to build layer thickness. The presence of large size of pores will significantly reduce the compact properties.

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