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# Dimensional Accuracy and Surface Roughness Analysis for AlSi10Mg Produced by Selective Laser Melting (SLM)

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**Abstract.** Selective Laser Melting (SLM) is an Additive Manufacturing (AM) technique that built 3D part in a layer-by-layer method by melting the top surface layer of a powder bed with a high intensity laser according to sliced 3D CAD data. AlSi10Mg alloy is a traditional cast alloy that is broadly used for die-casting process and used in automotive industry due its good mechanical properties. This paper seeks to investigate the requirement SLM in rapid tooling application. The feasibility study is done by examining the surface roughness and dimensional accuracy as compared to the benchmark part produced through the SLM process with constant parameters. The benchmark produced by SLM shows the potential of SLM in a manufacturing application particularly in moulds.

## 1 Introduction

Selective Laser Melting (SLM) is a layer-wise material addition technique that allows generating complex 3D parts by selectively consolidating successive layers of powder material on top of each other, using thermal energy supplied by a focused and computer controlled laser beam [1-4]. The competitive advantages of SLM are geometrical freedom, mass customisation and material flexibility [5].

Aluminium-Silicon alloys are characterised by sound castability, great weld ability and excellent corrosion resistance. Due to their attractive combination of mechanical properties, high heat conductivity and low weight, the Al-Si alloys found a large number of applications in automotive, aerospace and domestic industries [2]. SLM allows parts to be built additively to form near net shape components rather than by removing waste material. Traditional manufacturing techniques have a relatively high set-up cost (e.g. for creating a mould) while SLM has a high cost per part mostly because it is time-intensive and it is advisable if only very few parts are to be produced. Much of the part from SLM technologies is on lightweight fabrication that applied for aerospace. This technology is able to manufacture multifaceted shapes where traditional manufacturing constraints, such

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as tooling and physical access to surfaces for machining and restrict the design of components [6].

Additive Manufacturing (AM) also results in reduction of emission and very low wastage because it able to recycle the powder waste through the processes itself. Lots of energy and resources are consumed to produce tools like dies and moulds [7]. Besides, AM techniques provide almost unchallenged freedom for design without the need for part-specific tooling [8].

To employ SLM into a manufacturing technique, the laser melted parts have to comply the strict material requirements regarding mechanical and chemical properties and the process must guarantee the high accuracy and appropriate surface roughness [9]. In this study, benchmark product was produced by SLM with constant parameters. The process requirements for rapid tooling application was characterised and the feasibility study also done by examining the surface roughness and dimensional accuracy. The benchmark produced by SLM shows the potential of SLM in a manufacturing application particularly in moulds.

## 2 Methodology

AlSi10Mg is a typical casting alloy with virtuous casting properties and is typically used for cast parts with thin walls and complex geometry and it provides good strength, hardness and dynamic properties and is therefore also used for parts subject to high loads [10].

SLM is an AM process used a laser beam which selectively melts and fuses accumulating layers of powder to build solid metal parts [11]. SLM equipment technology provides a laser system, a set of optical laser beam focusing, a powder feeding system (loader and roller or coater) and a control centre as shown in Figure 1. The SLM is a cyclical process which consists of three steps which repeated until the end of the construction process. First, a recoater applies an even coating of metal powder in layer thicknesses of 20 µm to 100 µm. Then, the exposure will solidify the powder with a laser beam. The absorption of the laser radiation causes the metal powder to heat up above the melting temperature of the metal. This causes the blending of the exposed areas of the current layer and the solidified areas of the layer beneath it through metallurgic melting.

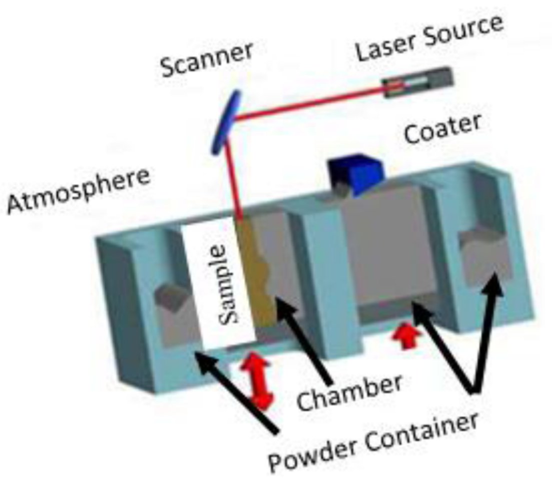



**Fig. 1.** SLM equipments [11]

The AlSi10Mg in a powder form was sieved into 63 microns, while the loose density of 7.68 g/cm$^3$ and chemical composition as shown in Table 1 supplied from the LPW Technology Limited UK. For this study, the default SLM parameters shown in Table 2 were used to produce a benchmark sample.

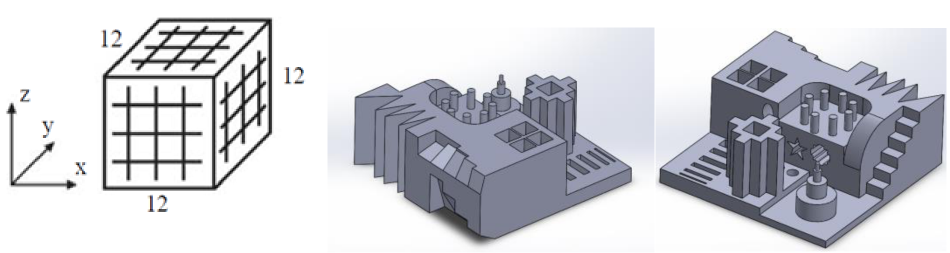
**Table 1.** Chemical composition of the investigated AlSi10Mg alloy (wt. %).

| Si | Fe | Mn | Mg | Ni | Zn | Pb | Sn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| 9.92 | 0.14 | 0.00 | 0.29 | 0.00 | 0.001. | 0.00 | 0.00 | 0.01 | Balance |

Since, the good surface roughness could be an important requirement in rapid tooling, a roughness analysis has been performed. The surface roughness depends on many factors: material, powder particle size, layer thickness, laser and scan parameters, scan strategy and surface post-treatment [12]. The roughness of top and two side surfaces (Figure 4) were measured along different directions as shown in Figure 2 (a). Figure 2 (b) shows a benchmark model consisting of different features such as stairs, cylinders, circumferential surface, rectangular cuts and etc. was developed to test the influence of sloping angle, dimensional analysis, measurement accuracy and the difference between top and bottom surfaces (Figure 4). The sloping angle of this benchmark top plane are ranging from 0º to 90º and bottom planes are ranging from 30º to 90º. On the other hand, the sloping angle for the horizontal holes changes continuously. All surface roughness tests were investigated by using roughness measuring meter and mean $R_a$ and $R_z$ values were calculated with a cut-off length of 2.5 mm, according to the DIN 4768 standard [12].

**Table 2.** SLM parameters for producing benchmark for dimensional accuracy and surface roughness.

| Sample Number | SLM Parameter | Setting Values |
|---|---|---|
| 1 | Laser Power | 350 watt |
| 2 | Scanning Speed | 1650 mm/s |
| 3 | Hatch Distance | 0.13 mm |
| 4 | Layer Thickness | 30 Micron |
| 5 | Laser Beam Spot | 80 Micron |
| 6 | Laser Beam Offset | 0.025 mm |




(a) (b)

**Fig. 2.** (a) Indication of surface roughness measurements on blocks; (b) Benchmark model with different features and sloping angles for top and bottom planes

The benchmark model as shown in Figure (2b) was characterised to investigate the process accuracy (in x, y, and z directions), accuracy of measurement for cylinders, stairs, rectangular cuts and other angle features. The presence of 2 mm thin wall is to indicate the warpage due to thermal stresses. Otherwise the features as Table 3 was developed to evaluate the feasible precision and resolution of the process.

**Table 3.** Developed features on the benchmark models

| Features | Range (mm) |
|---|---|
| Small holes | 0.5 – 3 (diameter) |
| Small slots | 0.5 – 3 (thickness) |
| Small Cylinders | 1 – 5 (diameter) |
| Thin walls | 0.5 – 3 (thickness) |

All geometrical features of benchmarks produced were measured three times by tactile probes on a Numerical Control 3D coordinate measurement machine (CMM) as shown in Figure 3.

**Fig. 3.** Numerical control 3-D coordinate measuring machine (CMM)

## 3 Results and Discussion

The breakthrough of SLM as a Rapid Manufacturing technique will depend on the reliability, performance and economical aspects like production time and cost [13]. These factors cannot be characterised in general, but some were investigated in this paper for the mould application. The results of the roughness analysis on the benchmark model as shown in Figure 2(b) are presented in Table 4.

The building orientation of side surface and top surface are difference where the top surface is built in x-y direction while side surface was built in x-z direction (Figure 4). This difference should give a difference value for surface roughness, however both top and side surfaces not present significant differences regarding measurement direction.

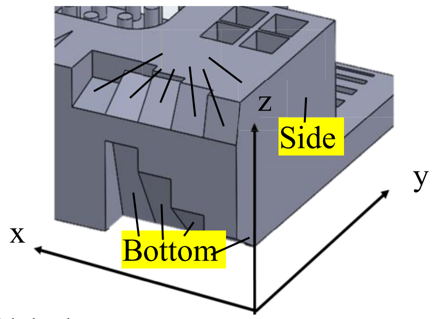



**Fig. 4.** Orientation of benchmark fabrication.

In spite of a lower powder particle size, the AlSi10Mg samples showed higher roughness in $R_z$ value (Table 4), it is because of physical properties of the material where the melt pools are more stable for Silicon.

In order to have appropriate reading of average surface roughness the measurements were taken at angles, curves and other features at the top and bottom (Figure 4) of the benchmark while on the straight face of the side of it (Figure 4), as shown in Table 4.

**Table 4.** Average surface roughness for top, down and side of the benchmark

| No | Average | SLM AlSi10Mg | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Top | | | Bottom | | | Side |
| | | 45° | 60° | 75° | 45° | 60° | 75° | |
| 1 | Ra (μm) | 3.35 | 2.28 | 3.43 | 9.20 | 8.32 | 7.19 | 2.29 |
| 2 | Rz (μm) | 15.05 | 12.16 | 15.63 | 42.16 | 43.61 | 34.96 | 11.45 |

The surface roughness depends on many factors such as material, powder particle size, layer thickness, laser and scan parameters, scan strategy and surface post-treatment [14]. The surface roughness of a sloping plane depend on the sloping angle because of the stair effect due to the layer wise production. In addition, roughness of top surfaces differ strongly from the roughness of bottom surfaces. So the values of roughness in this work are varied by varying the angles of the benchmark because of the layer thickness and the particle size of the AlSi10Mg.

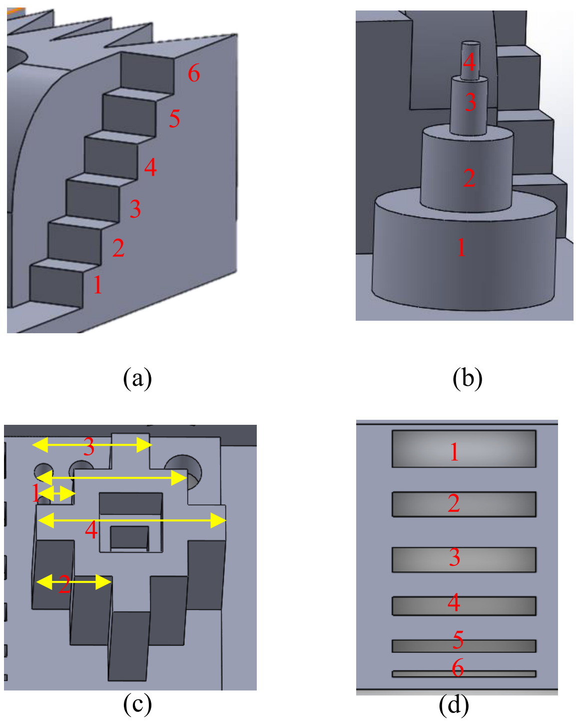



**Fig. 5 (a) to (d).** Benchmark of different parts for dimensional analysis

The dimensional accuracy analysis of SLM benchmark model was shows in Table 5 to Table 8. Figure 5 (a) to 5 (d) indicate the different shape feature of benchmark such 90º edge (stair) (Figure 4a), cylinders (Figure 5b), reactangular (Figure 5c) and variate rectangular slot (Figure 5d).

Mean value and maximum deviations between measured and designed dimensions are stated absolutely (mm) and relative to the nominal dimension (percentage). All small features of the benchmark shown on Figure 5 (a) to (d), were built successfully. The highest deviation percentage is obviously shown in table 5(b) with 11.66%. However, others value are show the value between 0.10% to 3.30%. While the negative value for deviation are indicate the actual sample is expand over the designed dimension and contrary with that, the positive value of deviation show the part was shrinkage. The dimensional accuracy for this study is possible to accept for mould fabrication due and this trend is valuable for mould designer to predict the mould design.

**Table 5.** Dimension measurements of stairs as shown in Figure 5(a)

| Stairs No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Designed Dimensions(mm) | 3.000 | 6.000 | 9.000 | 12.000 | 15.000 | 18.000 |
| Reading 1 | 3.044 | 5.986 | 9.018 | 12.083 | 15.104 | 18.127 |
| Reading 2 | 3.011 | 5.996 | 9.042 | 12.085 | 15.126 | 18.184 |
| Reading 3 | 3.038 | 5.996 | 9.026 | 12.063 | 15.091 | 18.194 |
| Mean Value | 3.031 | 5.992 | 9.028 | 12.077 | 15.107 | 18.168 |
| Deviation (%) | -1.470 | 0.240 | -0.190 | -0.690 | -0.690 | -0.710 |

**Table 6.** Dimension measurements of cylinders as shown in Figure 5(b)

| Cylinder No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Designed Dimensions in mm | 10 | 5 | 1.5 | 0.5 |
| Reading 1 | 9.854 | 4.898 | 1.460 | 0.432 |
| Reading 2 | 9.862 | 4.892 | 1.460 | 0.451 |
| Reading 3 | 9.871 | 4.897 | 1.470 | 0.442 |
| Mean Value | 9.862 | 4.896 | 1.460 | 0.442 |
| Deviation (%) | 1.380 | 2.080 | 2.530 | 11.660 |

**Table 7.** Dimension measurements of the rectangular slot with different relating position as shown in Figure 5(c)

| **Designed Dimensions (mm)** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Reading 1 | 2.989 | 5.945 | 8.887 | 11.865 | 14.876 |
| Reading 2 | 2.997 | 5.976 | 8.879 | 11.880 | 14.866 |
| Reading 3 | 2.990 | 5.974 | 8.876 | 11.878 | 14.883 |
| Mean value | 2.992 | 5.965 | 8.881 | 11.874 | 14.875 |
| Deviation (%) | 0.270 | 0.920 | 1.320 | 1.050 | 0.830 |

**Table 8.** Dimension measurements of variable rectangular slots as shown in Figure 5(d)

| Rectangular Slot Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Designed Dimensions in mm | 3 | 2 | 2 | 1.5 | 1 | 0.5 | 8 |
| Reading 1 | 2.998 | 2.028 | 1.994 | 1.499 | 1.056 | 0.426 | 8.005 |
| Reading 2 | 2.963 | 2.037 | 1.996 | 1.497 | 1.032 | 0.394 | 7.994 |
| Reading 3 | 3.002 | 2.021 | 1.998 | 1.493 | 1.010 | 0.409 | 7.974 |
| Mean Value | 2.988 | 2.029 | 1.996 | 1.496 | 1.033 | 0.410 | 7.991 |
| Deviation (%) | 0.400 | -1.450 | 0.200 | 0.250 | -3.300 | 18.000 | 0.113 |

## 4 Conclusion

AlSi10Mg has been characterised with rapid manufacturing technique by SLM technology. After analysis of the roughness and dimensional accuracy, it can be concluded that the values of roughness on the bottom are higher than the top and side of the benchmark because of the starting of the SLM process the thermal conductivity influence on the layers of the features of the benchmark.

For the mould manufacturing from AlSi10Mg by SLM process, there are many positive and negative variations in the measured values and designed values of the benchmark, nevertheless the range of the deviation is acceptable.

Lastly SLM can produce even a complex shape of geometry, which proved that SLM enables an efficient production of mould manufacturing and complex parts with strong economic, good surface, dimensional accuracy and potential.

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