THE AlSi9Cu3 ALLOY PROCESSED BY THE SELECTIVE LASER MELTING TECHNOLOGY

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Abstract

The AlSi9Cu3 alloy, conventionally produced by High-Pressure Die Casting (HPDC), is extensively used in the automotive industry for its high specific strength, good heat and electric conductivity. There is currently an effort to produce this alloy using selective laser melting technology (SLM) due to design possibilities such as producing geometrically complex and lightweight products. However, the performance of SLM parts is highly dependent on its process parameters. The main aim of this research is to optimize the SLM process parameters of the AlSi9Cu3 alloy to achieve high mechanical performance. The tested process parameters were laser speed and hatch distance in the range of 1200-1500 $mm \cdot s^{-1}$ and 120-170 μm, respectively. The process parameters selection was performed based on a low porosity level. According to our study, the suitable combination of process parameters is laser power of 350 W, layer thickness of 50 μm, scanning speed of 1400 $mm \cdot s^{-1}$ and hatch distance of 120 μm. Mechanical properties of SLM samples were compared with cast alloy according to the European Standard (EN 1706:2010). In this paper, the AlSi9Cu3 alloy produced by the SLM process outperformed the mechanical performance of the conventionally cast alloy in 0.2% proof stress (271 ± 1.7 MPa compared to 160 MPa), ultimate tensile strength (494 ± 2.6 MPa compared to 220 MPa), and elongation at break (5.6 ± 0.2 % compared to 1.5 %).

Keywords: AlSi9Cu3 alloy, selective laser melting, porosity, mechanical properties

1. INTRODUCTION

Additive manufacturing (AM) techniques, also known as 3D printing, enable the production of three-dimensional components from the CAD model [1]. The principle of AM techniques is adding layer by layer which allows the fabrication of geometrically complex and lightweight structures [2,3]. Selective laser melting (SLM) is one of the promising AM techniques for the fabrication of metallic components. The most common powder materials used in SLM include steel [4], nickel-based [5], titanium-based [6], and aluminum-based alloys. [7-9]

Aluminum alloys are a widely used material in the automotive and aerospace industries for their high specific strength, good corrosion resistance, excelling electric and thermal conductivity [10]. AlSi9Cu3 alloy indented for the automotive industry is conventionally prepared by high-pressure die casting (HPDC) [11]. Casting technology has certain limitations and the SLM process may prevent some defects typical for casting technology. Additionally, SLM induces an extremely fine microstructure which positively affects mechanical properties [12,13]. However, the properties of components manufactured by SLM technologies are highly dependent on the process parameters used, especially laser power (Lp), scanning speed (Ss), hatch distance (Hd) and layer thickness (Lt). [14,15]

Optimization of process parameters is crucial to achieving fully dense parts and high mechanical properties. The goal of this work is to find optimal process parameters for the fabrication of the AlSi9Cu3 alloy by SLM technology. The optimal combination of process parameters was selected based on the low porosity level of the samples and the quality of manufactured samples was verified by tensile testing.

2. MATERIAL AND EXPERIMENTAL PROCEDURE

Gas atomized AlSi9Cu3 alloy (Sandvik Osprey Ltd.) has the chemical composition listed in **Table 1**, as determined by EDS Oxford. **Figure 1a)** shows the particle size distribution evaluated by laser particle analyzer LA-960, Horiba. The mean resp. the median size of powder particles was 42.3 resp. 39.8 µm. The shape of particles is rather of irregular character **(Figure 1b**).

Table 1 Chemical composition of used AlSi9Cu3 alloy powder determined by EDS analyses

Element	**Al**	**Si**	**Cu**	**Fe**
Average (wt%)	85.0	11.2	3.1	0.7

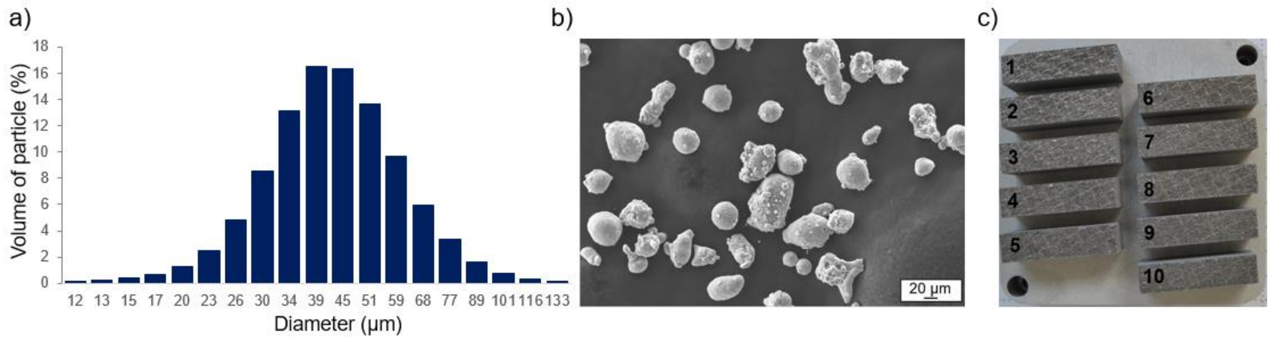

Figure 1 a) Particle size distribution of AlSi9Cu3 alloy powder, b) Morphology of AlSi9Cu3 alloy powder particles c) Blocks samples manufactured by SLM process for porosity test

Firstly, ten samples were produced with the dimensions of 10×14×40 mm (W × H × L). The samples were manufactured by SLM 280HL machine equipped with 400 W ytterbium fibre laser horizontally, as shown in **Figure 1c)**. Process parameters were kept the same (Lp = 350 W and Lt = 50 µm), except for the hatch distance and scanning speed, as summarized in **Table 2**. Average relative density was determined on metallographic samples (the microstructures were documented by Axio Observer Z1 microscope) from 3 perpendicular areas measuring 8×8 mm by image analysis (ImageJ software). Based on the porosity results, a suitable combination of the process parameters was used for the subsequent production of the billets intended for the tensile test. Bulk tensile test bars were prepared from the SLM billets (10×14×80 mm) according to DIN 50125 FORM B (dimensions of the gauge length Ø 6×30 mm). The tensile test was performed using the Zwick Z250 testing machine and fractographic analyses on broken samples were performed using scanning electron microscope Tescan Mira.

Table 2 The process parameter of AlSi9Cu3 alloy produced by SLM process

		Scanning speed (mm·s⁻¹)			
		1200	**1300**	**1400**	**1500**
Hatch distance (µm)	**120**	-	Sample 1	Sample 2	Sample 3
	150	Sample 4	Sample 5	Sample 6	Sample 7
	170	Sample 8	Sample 9	Sample 10	-

3. RESULTS

3.1. Porosity testing

The porosity measurement results are presented in **Table 3**. No significant differences in porosity were found, and the porosity of all samples was less than 1.5 %. The lowest porosity was obtained in sample 2 (1.18 %) and the highest in sample 1 (1.48%). **Figure 2** shows a schematic view of observed planes. **Figure 3** shows the polished samples with porosity assessments in two planes, perpendicular to the building-up direction i.e., XY-plane (**Figure 3a**), and the other one parallel to the building-up direction i.e., YZ-plane (**Figure 3b**). Based on the low level of porosity results, the process parameters used for the preparation of samples 2, 5, 7 and 9 can be considered suitable for the following fabrication. Another important aspect is the size and shape of the pores, spherical pores are being considered more favorable compared to irregular pores. For further analyses, the process parameters of sample 2 were selected for its lowest porosity. However, the porosity results of sample 2 differed in the planes perpendicular (XY-plane) and parallel (YZ-plane) to the building direction about of 0.46 %. Directional dependence of porosity was observed in samples 7 and 9 as well. For this reason, the process parameters of sample 5, which showed both low porosity level and lower directional dependence (differing by 0.11 %), were also selected for the following analysis.

Table 3 The porosity results of AlSi9Cu3 alloy produced by the SLM process

	Porosity (%)			Average porosity	Relative density
	XY-plane	XZ-plane	YZ-plane	(%)	(%)
Sample 1	1.35	1.42	1.66	1.48	98.52
Sample 2	0.98	1.12	1.44	1.18	98.82
Sample 3	1.35	1.38	1.42	1.38	98.62
Sample 4	1.00	1.82	1.37	1.40	98.60
Sample 5	1.20	1.31	1.21	1.24	98.76
Sample 6	1.50	1.24	1.19	1.31	98.69
Sample 7	1.20	1.44	1.18	1.27	98.73
Sample 8	1.45	1.44	1.23	1.37	98.43
Sample 9	1.40	1.10	1.20	1.23	98.77
Sample 10	1.20	1.65	1.49	1.45	98.55

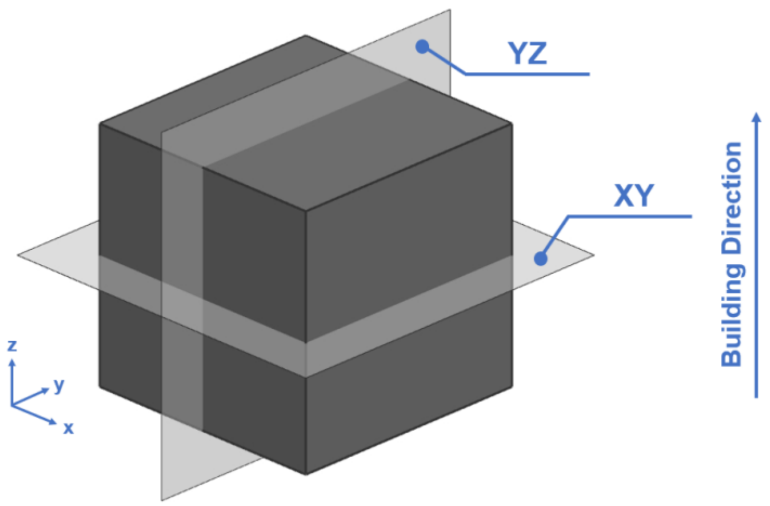

Figure 2 Schema showing the observation planes

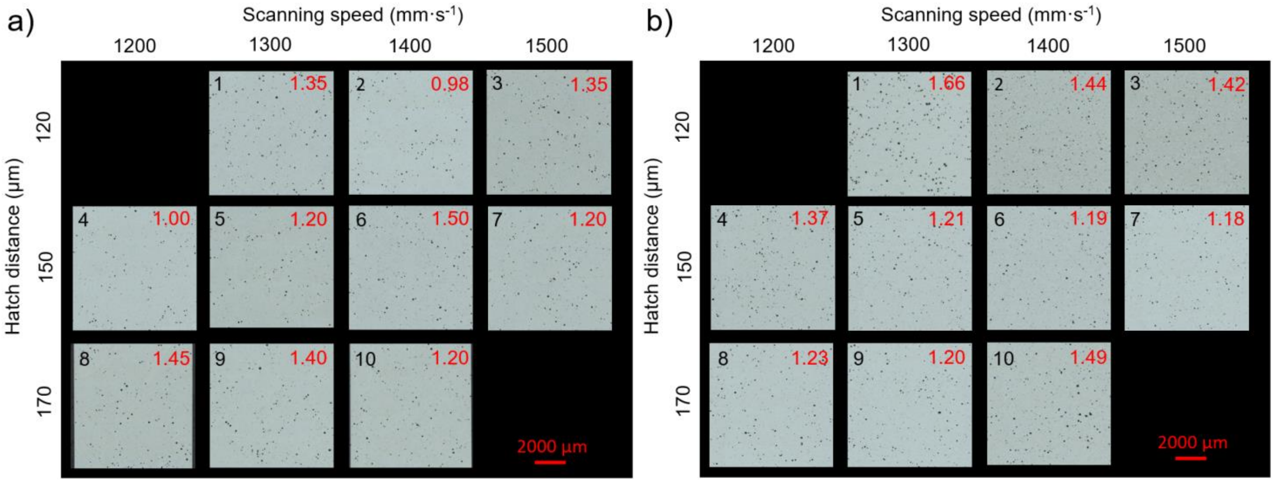

Figure 3 Image of polished specimens a) XY-plane b) YZ-plane, sample number (top left of images), porosity (top right of images)

3.2. Tensile testing

The tensile test was performed for the evaluation of basic mechanical properties. Based on the porosity results, the process parameters of the sample 2 (Lp = 350 W, Ss = 1400 mm·s⁻¹, Hd = 120 µm and Lt = 50 µm) and sample 5 (Lp = 350 W, Ss = 1300 mm·s⁻¹, Hd = 150 µm and Lt = 50 µm) were selected to produce samples for tensile test. The values of mechanical properties are summarized in **Table 4**. The resulting value is the average of three measurements.

Table 4 The mechanical properties of AlSi9Cu3 alloy produced by SLM Technology

	$R_{p0.2}$ (MPa)	*UTS* (MPa)	$A_{5.65}$ (%)	*Z* (%)
Sample 2	271 ± 1.7	494 ± 2.6	5.6 ± 0.2	7.4 ± 0.4
Sample 5	275 ± 0.8	488 ± 2.9	5.0 ± 0.2	5.3 ± 0.9

3.3. Fractographic analyses

A fractographic analysis was performed on the broken samples 2 and 5 after the tensile test. The fracture surface of the sample is illustrated in **Figure 4**. Gas porosity was found on the fracture surface, as shown in **Figure 4 a)** and **c)**. The damage mechanism was of ductile character with very fine dimples in both cases, as shown in **Figure 4 b)** and **d)**.

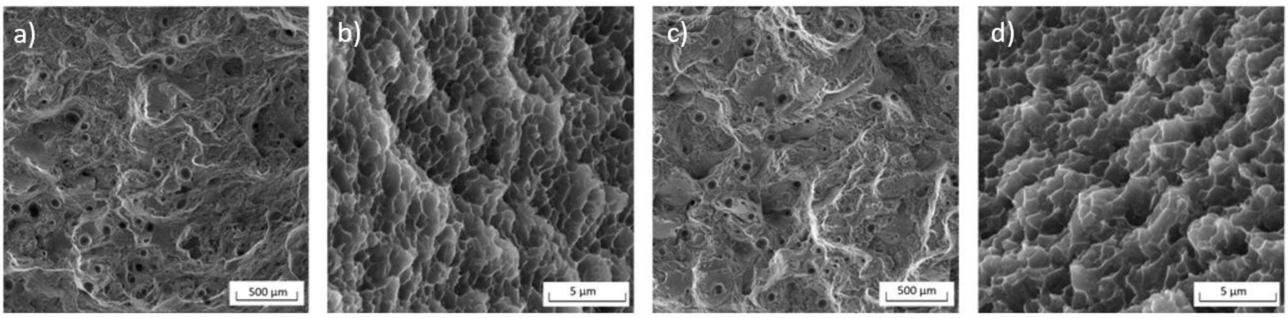

Figure 4 Fracture surfaces of SLM AlSi9Cu3 alloy a) and b) Sample 2, c) and d) Sample 5

4. DISCUSSION

The influence of process parameters on the porosity was investigated. Despite the wide range of process parameter values, the porosity of individual samples was similar. In this work, the spherical pores have been observed particularly. The spherical pores appeared in material as a consequence of entrapped gasses, which might be oxides or evaporated powder. [11,13]

Figure 5 shows a comparison of the mechanical tensile properties obtained in this work with the values available from the literature. The mechanical performance of SLM samples is higher compared to the cast ones [16]. The reason may be the finer microstructure of SLM parts without the presence of unfavorable acicular morphology of eutectic silicon. An absence of the acicular eutectic silicon has a favorable effect on the resulting strength and elongation. [10]

Due to the trade-off between strengths and deformation characteristics, sample 2 has slightly higher mechanical performance than sample 5. The SLM process parameters used in the present work lead to higher mechanical properties compared to [12] (Lp = 400 W, Ss = 1300 mm·s^{-1}, Hd = 120 μm, and Lt = 50 μm). It may be caused by the distinct value of laser power which has a significant influence on porosity and thus mechanical performance. On the other side, the mechanical performance (*UTS*, *A*) of [10] (Lp = 350 W, Ss = 1200 mm·s^{-1}, Hd = 120 μm and Lt = 50 μm) is comparable with Sample 2 (Lp = 350 W, Ss = 1300 mm·s^{-1}, Hd = 120 μm and Lt = 50 μm). As expected, the process parameters are the same except for scanning speed. In this case, the higher Ss of Sample 2 leads to the higher $R_{p0.02}$.

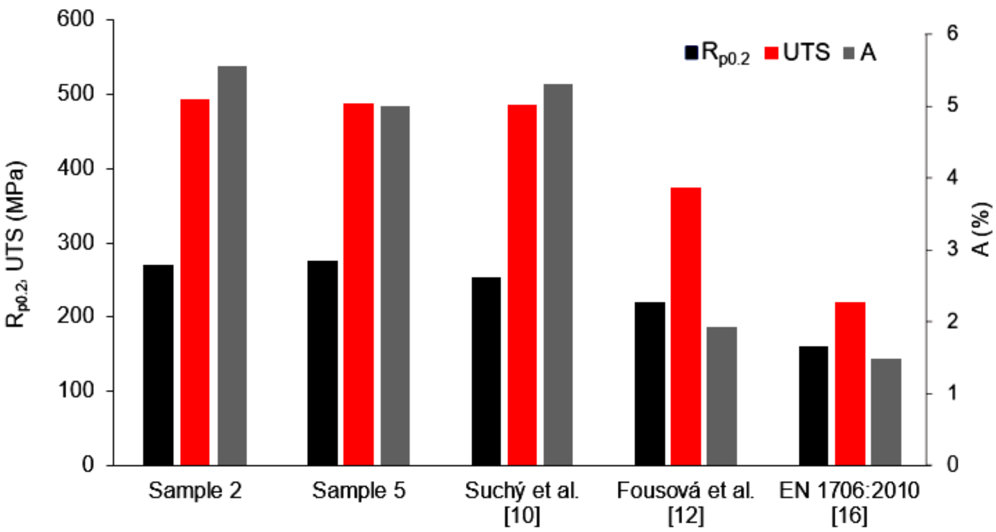

Figure 5 Comparison of mechanical properties of AlSi9Cu3 alloy from the tensile test with results in the literature

5. CONCLUSIONS

The lowest porosity of 1.18% was achieved with process parameters of Lp = 350 W, Ss = 1300 mm·s^{-1}, Hd = 120 μm and Lt = 50 μm. The mechanical performance evaluated by the tensile test of samples prepared by the SLM process overcome the cast state alloy in 0.2% proof stress (271 ± 1.7 MPa compared to 160 MPa), ultimate tensile strength (494 ± 2.6 MPa compared to 220 MPa), and elongation at break (5.6 ± 0.2 % compared to 1.5 %).

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