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<th>Effects of re-melting strategies on densification behavior and mechanical properties of selective laser melted AlSi10Mg parts</th>
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<td>Author(s)</td>
<td>Yu, Wenhui; Sing, Swee Leong; Tian, Xuelei; Chua, Chee Kai</td>
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ABSTRACT: Effects of re-melting strategy on densities and mechanical properties of AlSi10Mg samples fabricated by selective laser melting (SLM) were investigated. Strategies of same and opposite re-melting routines based on the alternative stripe scanning routine were performed. The densification behaviors of the SLM manufactured AlSi10Mg samples with different strategies were characterized by a solid densitometer. Tensile strength and elongation were also measured and compared with the samples produced with simple stripe strategy. The results show that re-melting strategies result in insignificant increase in the densification and slight decrease in ultimate tensile strength of the SLM components. However, great increase in elongation is obtained by re-melting. Furthermore, the same or opposite directional re-melting scanning witnesses no significant difference in results.

KEYWORDS: Additive manufacturing; Selective laser melting; Re-melting strategy; Densification; Mechanical properties.

INTRODUCTION

Selective laser melting (SLM), a powder bed fusion technique in which a laser beam is used to selectively melt powder materials by layer, has emerged as a promising additive manufacturing (AM) technology since late 20th century (Olakanmi et al., 2015; Yap et al., 2015). Due to the layer-by-layer addition of materials, the technology allows large number of geometrical degrees of freedom and thus fabrication of parts with complex shapes and features, which are difficult to produce using conventional manufacturing techniques (Chua & Leong, 2017). Moreover, the parts can be fabricated directly from three-dimensional (3D) computer aided design (CAD) file data without manufacturing molds (Fatemi et al., 2017; Louvis et al., 2011; Sing et al.,
The rapid solidification rate (~10^6 °C/s) in the processing enables fine grains and promising mechanical properties (Long et al., 2018; Thijs et al., 2013). The above advantages resulted in more and more applications and investigations.

Despite SLM process providing many advantages compared with conventional machining, challenges such as porosity, densification and low surface quality is still of concern (Leon & Aghion, 2017). Various solutions have been applied, among which re-melting strategy has been investigated only briefly (Yasa et al., 2011). Re-melting means that the same sliced layer is scanned again before recoating a new layer of powder (Xie et al., 2005; Yasa et al., 2011). It was reported that the effect of re-melting strategy on densification depends much on the first scanning strategy and nanoparticles distribution can be redistributed with re-melting in TiC/316L composite (AlMangour et al., 2017). Other investigation also revealed that the effect of re-melting on densification depends on the processing parameters (Yasa et al., 2011). However, re-melting in aluminum alloys was seldom performed. AlSi10Mg alloy finds numerous structural applications in automobile and aerospace industries due to its high strength and low weight. Minor additions of Mg enable precipitation of Mg2Si and thus hardenability by natural or artificial ageing (Brandl et al., 2012; Lam et al., 2015; Read et al., 2015). The alloy also stands out in a wide range of aluminum alloys for feasible processing in SLM due to its near eutectic composition and small range of solidification temperature (Martin et al., 2017). This paper seeks to investigate the influence of re-melting strategies on density and mechanical properties of AlSi10Mg alloy with different laser re-melting routines.

**EXPERIMENTAL PROCEDURE**

The commercial AlSi10Mg powder (TLS Technik GmbH & Co. Spezialpulver KG, Germany) is spherical in shape with size range between 20 and 63 μm. The SEM image of the powder is presented in Figure 1. Fabrication of all specimens was carried out on a SLM 280HL machine (SLM Solutions Group AG, Germany), which is equipped with two Yb: YAG lasers with maximum power of 400 W. The laser beam profile follows the Gaussian distribution and has a wavelength of 1.064 μm. The aluminum substrate plate was preheated to 200 °C to reduce the thermal gradients and thermal stresses experienced by the specimens during the SLM process. All processing occurred in an argon environment with less than 0.1% oxygen to prevent oxidation and degradation of the material during the process. The process parameters are shown in Table 1. As to the scanning strategies, bi-directional stripe scanning as shown in Figure 2(a) was used. Re-melting strategies with the same or opposite direction routines were employed, indicated with orange arrows in Figure 2 (b) and (c).

Relative density was measured using Archimedes’ Principle with a density kit (Model XS 204, Mettler Toledo). The theoretical density of AlSi10Mg is 2.68 g/cm³. Tensile test (Instron Static Tester Series 5569) was conducted with loading rate of 1 mm/min. Tensile test loading direction was perpendicular to the building direction. Each group was tested with 5 specimens. The characteristic fracture surface morphologies of the SLM-fabricated AlSi10Mg parts were characterized using a JEOL JSM-7600F field emission scanning electron microscope (FESEM) in secondary electron mode at 15 kV.
Figure 1. SEM image of AlSi10Mg powder particles.

Table 1. SLM processing parameters.

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<tr>
<th>Processing parameters</th>
<th>Laser power (W)</th>
<th>Scanning speed (mm/s)</th>
<th>Hatch spacing (μm)</th>
<th>Layer thickness (μm)</th>
<th>Re-melting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A</td>
<td>350</td>
<td>1150</td>
<td>170</td>
<td>50</td>
<td>No</td>
</tr>
<tr>
<td>Sample B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Same direction</td>
</tr>
<tr>
<td>Sample C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Opposite direction</td>
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Figure 2. Overview of the scanning strategy used for the different samples. All samples are scanned with bi-directional vectors. (a) Sample A is scanned without re-melting; (b) Sample B is scanned with same directional re-melting routine; (c) Sample C is scanned with opposite directional re-melting routine. The blue arrows represent the first scanning vectors and the orange ones stand for the re-melting vectors.

RESULTS AND DISCUSSION

Densification

To quantify the comparison between parts with different re-melting strategies, the density was measured. The relative density of the samples is thereafter calculated and presented in Figure 3. It does increase with both re-melting routines, though the increase (0.09% and 0.06%) is insignificant. Compared with the significant increase in former research (AlMangour et al., 2017;
Yasa & Kruth, 2011), the processing parameters of first stripe routine has already been set to achieve almost full density, limiting the improvement that can be achieved by re-melting. Opposite routine to the first scanning stripes show little difference with the same directional re-melting strategy, both witnessing no much effect to density under these parameters.

Figure 3. Relative density of the samples without and with different re-melting strategies.

**Mechanical properties**

Figure 4 shows the ultimate tensile strength (UTS) and elongation (EI) of the three groups of samples. The UTS of the SLM fabricated parts with no re-melting is 377 MPa and it drops to 368 and 365 MPa for sample B and C, respectively. Compared with the high pressure die casting parts, of which the UTS is around 330-350 MPa (Read et al., 2015), the strength of SLM parts are higher. The decrease in tensile strength caused by re-melting is approximately 2%. Re-melting strategies with same or opposite directional scanning show similar results. In contrast, the EI of the alloys increases from 5.3 % for sample A to 8.3 % and 8.2 % for sample B and C, respectively. The ~ 57 % increase in ductility means that re-melting may not improve the tensile strength but incur other advantages such as increase in density and ductility. Therefore, the performance of the alloys would be improved accordingly for specific applications that require high ductility.

Figure 5 shows the fracture surfaces of the AlSi10Mg alloys with different scanning strategies. Fracture of sample A without re-melting is less flat with bigger pores (indicated by arrows and assumed to be crack initiation). Sample B and C exhibit smaller pores, however, micro cracks are also observed. In high magnification micrographs, a typical brittle failure with regular cleavage planes can be seen in all 3 samples, which is consistent with the low ductility shown in Figure 4. Despite the improvement in ductility, there are no dimples observed in sample B and C. In this case, post process heat treatment may still be needed.
Figure 4. UTS and EI of the samples without and with different re-melting strategies.

Figure 5. SEM images of fracture surfaces. (a, d) Sample A, (b, e) Sample B, (c, f) Sample C.

CONCLUSIONS

In the present study, laser re-melting is employed in SLM processing. The results show that the influence of re-melting under this parameter setting (except scanning strategy), which is assumed to be able to achieve full density, on densification is insignificant. Re-melting strategy decreases the tensile strength of the parts by ~ 2%, while it increases the ductility of the parts greatly by 57 %. Therefore, the comprehensive performance of the alloys would be improved accordingly. However, the fracture surface indicates brittle fracture even for the re-melting samples. Same and opposite directional re-melting routine shows little difference in results.

ACKNOWLEDGMENTS

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REFERENCES


