The effect of shot peening on corrosion performance of anodized laser powder bed fusion manufactured AlSi10Mg

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Abstract. Anodizing is commonly used on aluminium to improve the surface properties of the product for better corrosion resistance and wear resistance. In this research, the anodizing of laser powder bed fusion (LPBF) manufactured AlSi10Mg parts which were subjected to prior shot peening (SP) were investigated. Anodized specimens were analysed using SEM imaging and the corrosion properties were examined considering the effect of residual stress relief heat treatment and the SP process. The results showed that the SP deteriorates the corrosion performance of the material as such, but together with the subsequent anodizing it resulted to the lowest corrosion current of all investigated structures. As the SP can be used to lower the surface roughness of the LPBF parts and to increase fatigue life as well, the results of this work further encourage the use of SP with anodizing.

1. Introduction
AlSi10Mg is currently the most used aluminium alloy in additive manufacturing (AM) by laser powder bed fusion (LPBF). This material has several advantages including light weight, high strength, and good corrosion resistance [1]. Due to the difference in microstructure and defect structure, the LBPF parts have better corrosion properties compared to cast alloy [2]. Material properties can be further enhanced with suitable post processing methods or surface finishing. In authors’ previous work silver shell-copper core coating could be used to increase the electrical conductivity and improved corrosion resistance [3].

In addition, the rough surface of LPBF manufactured part could be smoothed with the aid of shot peening (SP). Anodizing is commonly used to improve the surface qualities of aluminium parts. Previous studies have focused on the effect of heat treatment [4], and the effect of the characteristic microstructure of the LPBF material [5].

The effect of shot peening on the corrosion properties of LBPF manufactured AlSi10Mg has not been previously studied. The current work addresses this with a microscopical view of the anodized surface together with corrosion resistance measurements.

2. Experimental
2.1. Specimen manufacturing and the material
An SLM 280 HL printer was used for the LPBF manufacturing of the samples. The powder was supplied by Carpenter Additive and had a size range of 20-63 µm with a chemical composition detailed in [3]. The following parameters were used to print all of the samples in 90° orientation: power (P) of 650 W, laser speed (v) of 1850 mm/s, hatch spacing (h) of 0.17 mm, layer thickness (t) of 60 µm and laser spot...
diameter of 0.15 mm, which resulted to an energy density of 34.4 J/mm³. Stress relief heat treatment (T5-HT) was carried out at 300°C for 2 h in a muffle furnace under argon atmosphere.

2.2. Anodizing and shot peening processes
Samples were anodized after the printing and the subsequent HT. The process consisted of several steps and had a rinse after each one. At first, the samples underwent an alkaline prewash for 15 minutes which was followed by activation in nitric acid for 10 min. Sulfuric acid anodizing was completed in 55 min and the process was finished by cold-sealing for 15 min and ageing for 15 min and drying. Shot peening was performed in a shot peening chamber using glass beads in the size of 0.25-0.5 mm and utilizing a shot pressure of 3 bar.

2.3. Characterization
AlSi10Mg alloy and its microstructure and surface features with and without the anodizing were analyzed using a field-emission gun scanning electron microscope (FEG-SEM) (Carl Zeiss Ultra plus). Secondary electron micrographs were captured at an operating voltage of 5 kV.

Corrosion resistance of the structures were evaluated in an Autolab electrochemical system (Autolab VersaSTAT 3 by Princeton Applied Research, USA). All the electrochemical experiments were performed in 3.5% NaCl solution at room temperature using a three-electrode compartment glass cell. Round samples were cut with a 15 mm diameter and worked as electrodes with an exposed area of 10 mm². The potentiodynamic polarization curves were recorded during immersion for 30 min until a stable open circuit potential (OCP) was reached.

3. Results and discussion
3.1. Surface features and microstructure of the LPBF AlSi10Mg
The surface features of the LPBF manufactured AlSi10Mg are presented in Figure 1a). The layer-by-layer formation of the part from bottom to top can be identified from the surface features that appear approximately at the build layer thickness intervals of 60 µm. The surface has a rough appearance due to the partially melted powder particles that are still attached to the surface. In closer inspection the surface has small cracks and pits that are mostly related to the areas between the layers. Cross-section of the AlSi10Mg after the HT is presented in Figure 1b). The microstructure of the material is pseudo-eutectic with primary α-Al phase (areas in size range of 1-2 µm) surrounded by precipitated Si-network.

3.2. Anodized AlSi10Mg
Cross-sectional view of the anodized AlSi10Mg is presented in Figure 2a. A very thin platinum coating was developed over the sample to be able identify the layer thickness of the non-conducting anodized layer. The anodized layer is visible in Figure 2a and has a thickness of 3-4 µm. Figure 2b shows how the anodizing has thoroughly penetrated into the material voids and cracks. Although the surface features have very abrupt changes and discontinuities, the anodizing shows very uniform around each of those.

3.3. Surface features and microstructure of the LPBF AlSi10Mg
The corrosion resistance of the LPBF manufactured AlSi10Mg material in as built, HT and HT + SP conditions were measured and compared to the respective anodized structures. The results (Figure 3 and Table 1) show that heat treatment has a beneficial effect on the corrosion resistance, but the usage of SP reduces it (i corr increases to 50 µA/cm² from 13). Anodizing has a clear positive impact on the corrosion properties on all investigated structures. The lowest corrosion current density was measured with the combination of HT and SP before anodizing. It was determined that the SP closing the surface voids and cracks and removing the balling phenomenon and satellites as shown in [3] is beneficial for the uniformity of the anodized layer improving the corrosion resistance as well. This is due to the decreased surface porosity, which is an important corrosion parameter. Reduced surface roughness reduces the
pitting corrosion as there are fewer and smaller sites for pit initiation, but the residual compressive stresses introduced by SP have detrimental effect but can be suppressed by anodizing.

![Figure 1](image1.jpg)

**Figure 1.** a) Surface features of the laser powder bed fusion manufactured AlSi10Mg and b) cross-section showing the microstructure.

![Figure 2](image2.jpg)

**Figure 2.** a) Anodized layer on laser powder bed fusion manufactured AlSi10Mg smooth area and b) around rough areas.

4. Conclusions
This work investigated the effect of shot peening on the properties of laser powder bed fusion (LPBF) manufactured AlSi10Mg and can be concluded as follows:
- The surface of LPBF is rough due to the partially melted particles.
- Anodized layer was successfully built on all investigated structures and resulted to improved corrosion resistance in all cases.
- The highest corrosion resistance was measured with the combination of heat treatment and SP before the anodizing.
Figure 3. Potentiodynamic polarization curves of additively manufactured AlSi10Mg in different states.

Table 1. Corrosion current density $i_{\text{corr}}$ and corrosion potential $E_{\text{corr}}$ of different states of additively manufactured AlSi10Mg in 3.5% NaCl solution.

| State                  | $E_{\text{corr}}$ (mV$_{\text{SCE}}$) | $i_{\text{corr}}$(µA/cm$^2$) |
|------------------------|--------------------------------------|-------------------------------|
| Built                  | -740                                 | 30                            |
| HT                     | -760                                 | 13                            |
| HT+SP                  | -788                                 | 50                            |
| Anodizing              | -778                                 | 10                            |
| HT + Anodizing         | -772                                 | 4                             |
| HT + SP + Anodizing    | -685                                 | 3                             |

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