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Effect of heat treatment on corrosion resistance of DMLS AlSi10Mg alloy

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ABSTRACT

The paper deals with the effect of heat treatments on corrosion resistance of an AlSi10Mg alloy obtained by means of Direct Metal Laser Sintering. The tests were performed on as-processed alloy and after different post-heat treatment, covering stress relieving, annealing at high temperature and water quenching.

Potentiodynamic and electrochemical impedance spectroscopy tests were carried out in aerated Harrison solution. The results show localized corrosion and selective penetrating attack at the border of melt pools on untreated or only stress relieved specimens. The selective attack was not observed after high temperature annealing. Modification of EIS plot evidenced galvanic coupling with silicon coarse particles that extensively precipitate during high temperature annealing. The morphology of precipitates is described in order to evidence their relevance in terms of rising selective penetrating attack and galvanic coupling.

1. Introduction

Direct Metal Laser Sintering (DMLS) is an additive manufacturing technology for fabrication of semi-finished parts directly from computer-aided design modelling, through melting and consolidation, layer upon layer, of a metallic powder with a laser source. In comparison to conventional technologies like die-casting, it offers several benefits such as constructing previously impossible geometries thus opening new ways to design; significantly reducing material waste by using only the material necessary; reducing time to market; moving to mass customization [1].

The objects fabricated with this technology have specific features. They have rough surfaces and can contain porosities [2]. Furthermore, the local fusion of overlapped layers of metallic powder creates small "melt pools" that rapidly solidify with a characteristic fine microstructure, which increases the mechanical properties [3,4], but may have adverse effect on corrosion behaviour. A decrease in corrosion resistance of Al-Si alloys produced by DMLS was already evidenced in previous works [5,6]. The process produces preferential path for insurgence of selective attacks along the border of melt pool and promotes growth of a passive film less protective than in air formed one. The localized attacks were ascribed to variations of microstructure and chemical composition in the thermal altered zone, inside the melt pool. Although the microstructure is too fine for SEM-EDS analysis, it was hypothesized that thermal cycle due to the laser scans leaves a different alloying element distribution between the border and the centre of the melt pools.

The DMLS process leaves high residual thermal stresses in metal structure. In order to reduce them and avoid distortion of the object, stress relieving is usually adopted [7]. More pronounced modifications in microstructures of alloys produced by DMLS can be achieved by annealing at higher temperature, as shown by Aboulkhair et al. on AlSi10Mg [8], Prashanth et al on Al-12Si alloy [9], and Pan Ma et al. on Al-20Si alloy [10]. However, some works were published on the microstructure of Al-Si-Mg cast alloys [11,12].

Heat treatments at high temperature can promote the coalescence of second phases and change their distribution [13]. In addition, the presence of intermetallics containing impurity of iron and copper, which promote selective attacks, can be favoured.

The paper deals with the effect of heat treatments on corrosion resistance of an AlSi10Mg alloy obtained by means of DMLS. It

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

Si	Fe	Cu	Mn	Mg	Zn	Ti
10.1	0.16	0.001	0.002	0.35	0.002	0.01

investigates the effectiveness of microstructure modifications by high temperature heat treatment for restoring the intrinsic corrosion resistance of the alloy.

The corrosion resistance is evaluated in aerated Harrison solution at room temperature by means of potentiodynamic tests and Electrochemical Impedance Spectroscopy (EIS). The tests were executed both on as produced surface and after polishing in order to assess the effect of the film formed during fabrication process.

2. Experimental

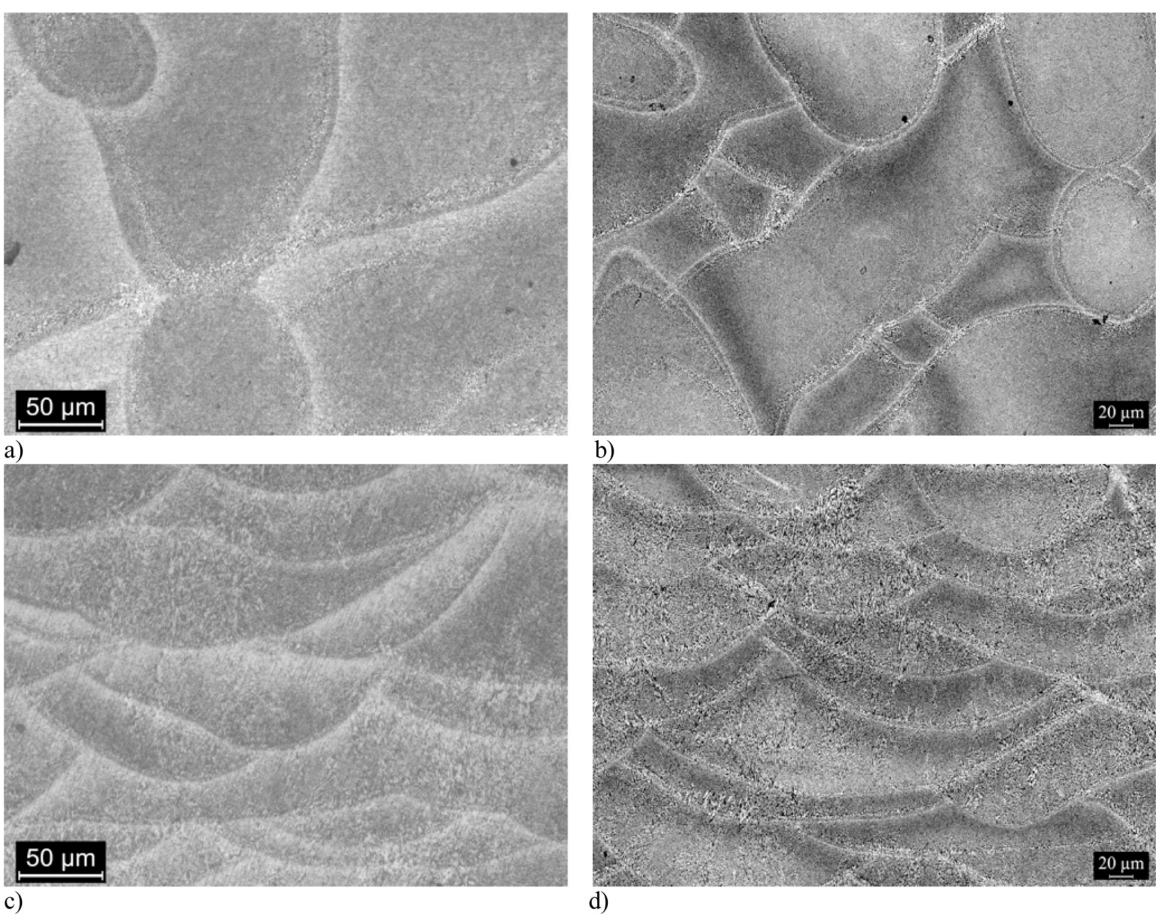
The tests were carried out on specimens obtained by DMLS using a gas atomized AlSi10Mg powder produced by EOS (Germany). Table 1 reports the chemical composition of the alloy. Near eutectic Al-Si alloy is commonly used in casting due to its low melting temperature, around 843 K. Further details about powder composition, grading and other specifications are reported in previous works [7,14]. The particles have quite regular spherical shape, ranging from 0.5 to 40 μm, with a mean size of 25 μm.

During DMLS process, the laser beam intensity was adjusted in order to achieve partial melting between adjacent powder layers to grant a good jointing. The direction of scanning was rotated by 67° between consecutive layers in order to achieve the best densification [14]. The scan speed, laser power and hatching distance were optimized in order to minimize porosities, as previously reported [7]. The role of scan strategy to reduce the porosity of specimens was also underlined by Aboulkhair et al. [15], Read et al. [16], and Louvis et al [17].

Disk specimens with 15 mm diameter and 5 mm height were used. They were produced by considering the base circular face parallel to the building platform. The specimens as obtained by DMLS process without any further heat treatment are called untreated (UT).

The relieving of residual stresses was performed in furnace at 573 K for 2 h on specimen still placed on the building platform. Such specimens were named SR (Stress Relieved).

In order to achieve more pronounced modifications of microstructure and homogeneous distribution of alloying elements, a solution annealing treatment at 823 K for 4 hours



a) b) c) d)

Fig. 1. Optical images of microstructures of untreated (left) and SR (right) specimen, along building plane (upper) and building direction (lower).