Journal of Materials Processing Technology 231 (2016) 326–335

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Evaluation of corrosion resistance of Al–10Si–Mg alloy obtained by means of Direct Metal Laser Sintering

Marina Cabrini[a,**], Sergio Lorenzi[a], Tommaso Pastore[a], Simone Pellegrini[a,*], Diego Manfredi[b], Paolo Fino[c], Sara Biamino[c], Claudio Badini[c]

[a] University of Bergamo, Department of Engineering and Applied Science, Viale Marconi 5, 24044 Dalmine (BG), Italy
[b] Center for Space Human Robotics @Polito, Istituto Italiano di Tecnologia, Turin, Italy
[c] Polytechnic of Turin, Department of Applied Science and Technologies, Turin, Italy

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form 3 December 2015
Accepted 31 December 2015
Available online 8 January 2016

Keywords:
Aluminium silicon magnesium alloy
Direct Metal Laser Sintering (DMLS)
Additive manufacturing (AM)
Corrosion
Surface finishing

ABSTRACT

Direct Metal Laser Sintering (DMLS) is a powder-bed based Additive Manufacturing (AM) technique, which allows fully dense near net-shape parts to be obtained thanks to a powerful laser source able to melt and consolidate the powders layer by layer. Many types of metals are available for DMLS, and aluminium alloys play a major part in applications in different fields, from aerospace to automotive and robotics, due to their high strength-to-weight ratio. In previous years the DMLS technique has been refined with the final aim of producing complex shape components with these alloys. In this study the corrosion behaviour of an aluminium alloy processed through DMLS was studied using Potentiodynamic (PD) tests and Electrochemical Impedance Spectroscopy (EIS) tests. All the tests were executed on Al–10Si–Mg alloy in aerated diluted Harrison solution on surfaces obtained sectioning samples along different orientations with respect to the building direction. The effect of different surface finishing – shot peening and mechanical polishing – was also evaluated.

The results highlighted preferential dissolution of α-Al at the border of the laser scan tracks and a slight variation with plane orientation. Moreover, the modification of the surface by shot peening or polishing increases pitting potential and reduces corrosion rate.

Nomenclature

E_{cor}	Corrosion potential (V vs SCE)
E_{pit}	Pitting potential (V vs SCE)
I	Current density (μA/cm^2)
$\|Z\|$	Module (Ω cm^2)

1. Introduction

The characteristic properties of aluminium, such as high strength and stiffness to weight ratio, good formability, good corrosion resistance, and recycling potential make it an ideal candidate to replace heavier materials (steel or copper) in the transport industry. The use of aluminium reduces the weight leading to more fuel-efficient vehicles, lower energy consumption and less air pollution (Miller et al., 2000). Moreover, there is a strong interest in new near-net-shape manufacturing technologies that produce metal components close to the final size and shape, thus requiring only a minimum amount of finishing process. In comparison with traditional processes, Additive Manufacturing (AM) technologies offer significant benefits, such as near-net-shape capabilities, superior design and geometrical flexibility, reduced tooling and fixturing, shorter cycle time for design and manufacturing, as well as material, energy and cost efficiency. In particular Direct Metal Laser Sintering (DMLS), the trade name of EOS GmbH to indicate the Selective Laser Melting (SLM) process, is an AM technology for the fabrication of dense metallic parts directly from computer-aided design data by melting together different layers of powdered metal with

Abbreviations: AM, Additive Manufacturing; DMLS, Direct Metal Laser Sintering; SLM, Selective Laser Melting; PD, potentiodynamic; EIS, Electrochemical Impedance Spectroscopy; SEM, scanning electron microscope; AR, as received; SP, shot peened; P, polished with emery paper and 0.1 μm alumina; SCE, Standard Calomel Reference Electrode; HAZ, heat affected zone.

* Corresponding author.
** Corresponding author. Fax: +39 35 2052077.
E-mail addresses: marina.cabrini@unibg.it (M. Cabrini), simone.pellegrini@unibg.it (S. Pellegrini).

http://dx.doi.org/10.1016/j.jmatprotec.2015.12.033

an high power laser source (Manfredi et al., 2013a,b). The components produced are near-net-shape and fit for end-user products. The use of DMLS provides design and manufacturing freedom without the restrictions of traditional forming or machining processes, with the added benefit of lighter components.

On the other hand, DMLS produces a large amount of residual stresses, due to the high thermal gradients inherently present in the process, which if not relieved, could lead to component distortion and dimensional inaccuracy (Shiomi et al., 2004). Merceis and Kruth, 2006 pointed out the possibility of having cracks or disconnection of parts from the base plate and suggested heating the substrate plate. Additionally, in DMLS, the temperature distribution in the powder bed and consolidated layers changes quickly with time and space. The temperature of the powder particles is elevated rapidly under the action of absorbed energy, causing a molten pool, when the temperature exceeds the melting temperature, and heat affected zones in the surrounding loose powder (Zaeh and Branner, 2010). Moreover, despite progress in material flexibility and mechanical performances, relatively poor surface finish still presents a major limitation in the DMLS process the laser welding process causes a general surface roughness due to partially molten powder and droplets on the surface of the part, which may affect its mechanical, chemical and functional properties (Sun et al., 2014).

In previous studies, Manfredi et al., 2013a,b demonstrated that Al–10Si–Mg alloy specimens obtained by means of DMLS have higher hardness and yield strength than conventional casted specimens in a similar alloy (A360), due to the very fine microstructure and fine distribution of the silicon phase promoted by the extremely rapid cooling and solidification, as also reported by Thijs et al., 2013. Furthermore, Manfredi et al., 2013a,b reported a probable presence of Mg_2Si intermetallic at a nanometric scale, as previously observed by Olakanmi, 2013. Read et al., 2015 also observed the increase in the tensile strength of AlSi10Mg compared to die cast A360, in both building directions.

To the best knowledge of the authors, there is a lack of data showing the corrosion behaviour of DMLS aluminium alloys. However, the effect of DMLS can be hypothesized because it produces different microstructures with respect to traditional processes. The role of second phases on the corrosion behaviour of aluminium is generally recognised (Szklarska-Smialowska, 1999). The intermetallics containing Cu and Fe are cathodic with respect to the matrix and promote dissolution of the matrix, while the intermetallics rich in Mg are anodic with respect to the matrix and dissolve preferentially (Wei et al., 1998). Coarse intermetallic Al–Si–Mg-containing particles are strongly reactive in 1 M NaCl solution and seem to be nucleation sites for pits and consequently for intergranular corrosion (Guillaumin and Mankowski, 2000). The effect of second phases was also analysed in different alloys by means of Kelvin microprobe by Fratila-Apachitei et al., 2006 on AlSi(Cu) alloy and Andreatta et al., 2003 on 7xxx alloy. Büchler et al., 2000 characterized the effect of inclusions using fluorescence microscopy on traditional alloys.

However, the aim of this work is to begin recovering this gap thus starting to experimentally investigate the corrosion behaviour DMLS aluminium alloys with particular attention to understand the role of the surface finishing and the anisotropy of DMLS microstructure. In particular in this paper we report the study of Al–10Si–Mg alloy produced by DMLS in Harrison solution which is commonly used for evaluating the corrosion resistance of aluminium alloys (Battocchi et al., 2006). Potentiodynamic (PD) tests and Electrochemical Impedance Spectroscopy (EIS) were performed in aerated diluted Harrison's solution, adopting different surface finishing, both on surfaces parallel and perpendicular to the orientation of building plane, in order to analyse the effect of different textures.

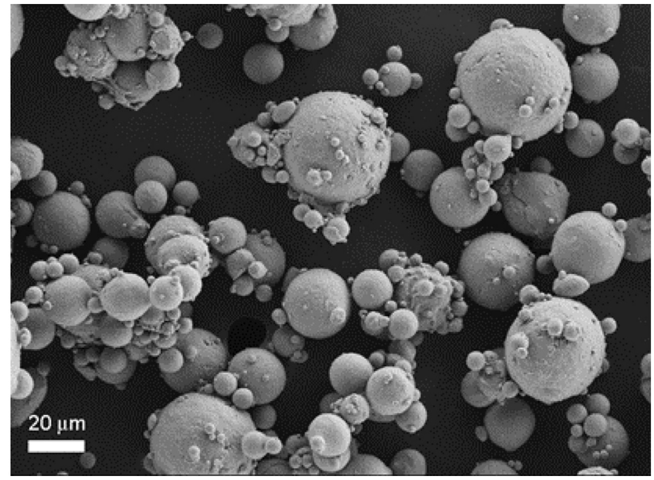

Fig. 1. SEM image of the AlSi10Mg powders employed in this study.

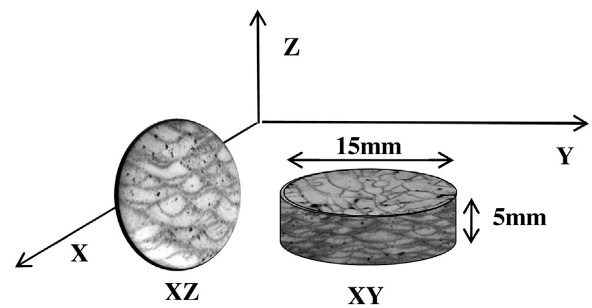

Fig. 2. schematic representation of the directions of the production of test specimens.

2. Experimental

2.1. Material and specimens

The tests were carried out on specimens obtained by DMLS using a gas atomized Al–10Si–Mg powder produced by EOS (Germany). The alloy composition is reported in Table 1.

This alloy is commonly used in casting due to its near Al–Si eutectic composition and low melting temperature, around 570 °C (Davis, 1998; Fulcher et al., 2014). As shown in the scanning electron microscope (SEM) images of Fig. 1, the particles have a regular spherical shape, with a diameter ranging from 0.5 to 40 μm, and a mean size of 25 μm.

Specimens to be analysed are disks of 15 mm diameter and 5 mm height. They were fabricated using an EOSINT M270 Xtended machine along different geometric orientations compared to the building platform (*xy*-plane) and the building direction (*z*-axis). The specimens with the base circular face on *xy*-plane were named XY; the specimens with the base face perpendicular to the *xy*-plane were called XZ (Fig. 2).

In this machine, a powerful ytterbium fibre laser system in an argon atmosphere is used to melt powders with a continuous power up to 200 W. The detail of the DMLS process, together with the choice of the process parameters to obtain a part with the highest density and the best surface finishing for the Al–10Si–Mg alloy,

Table 1
chemical composition of the Al Si10Mg powder.

Elements	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
%wt	10.08	0.16	0.001	0.002	0.35	0.002	0.01	bulk