Drying strategies to reduce the formation of hydrogen porosity in Al alloys

Laura Cordova, Ton Bor, Mónica Campos and Tiedo Tinga

May 8, 2019

DRYING STRATEGIES TO REDUCE THE FORMATION OF HYDROGEN POROSITY IN AL ALLOYS PRODUCED BY ADDITIVE MANUFACTURING

L. Cordova [1*], T. C. Bor [1], M. Campos [2], and T. Tinga [1]

[1] University of Twente, Enschede, The Netherlands
[2] University Carlos III of Madrid, Leganés, Spain
* Corresponding author: l.cordovagonzalez@utwente.nl

Introduction

Laser powder bed fusion (L-PBF) is an additive manufacturing (AM) technology using a high-power laser to selectively melt metal powders for building complex parts. Coping with contamination in the powder is usually a challenge for this technology. Gases entrapped in the material in contact with the laser create a plasma of impurities that can lead to porosity. This contamination is usually coming from moisture, organics and adsorbed gases from the atmosphere (i.e. oxygen and nitrogen). In this work, two drying strategies to reduce the formation of porosity will be investigated.

Experimental method

AlSi10Mg powder provided by LPW Technology was processed to produce test cubes using a SLM Solutions machine. The test cubes produced were 6×6×6 mm. The L-PBF process was conducted under an argon atmosphere with quality 5.0. The build platform on which the cubes were built was kept at 150°C. The relative density of each of the cubes was determined by Archimedes principle. A digital microscope (Keyence VHX-5000) was used to study the microstructure and porosity of the cubes after conventional metallographic preparation and etching using a Keller's reagent for 20s to reveal the microstructure.

Fig. 1. Test cubes produced by L-PBF.

The size and shape parameters of the pores were obtained with the help of the VHX analyzer using Equations (1) and (2) [1, 2]. The resulting pore shape (f_{shape}, inverse of aspect ratio) and circularity ($f_{circular}$) values provide an idea of type of porosity present in the specimens. The closer f_{shape} and $f_{circular}$ values are to 1, the more spherical the pore is. The pore size and number of pores were obtained by measuring and counting the pores from five images randomly taken with the same magnification (300×).

$$f_{shape} = \frac{minD}{maxD};\ \{f_s \in \mathbb{Q} \mid 0 < f_s < 1\} \quad (1)$$

$$f_{circular} = \frac{4\pi A}{P^2};\ \{f_c \in \mathbb{Q} \mid 0 < f_c < 1\} \quad (2)$$

(*minD* is minimum pore diameter, *maxD* maximum pore diameter, *A* is area and *P* is perimeter of pore. The diameters are obtained as ferret diameters)

This study presents two strategies to dry the metal powder prior to the build job. The first strategy consists of drying the metal powder outside the SLM Solutions machine under vacuum for 18h at 70°C to avoid powder contamination. The second strategy applies the strategy of drying the powder in the AM by scanning it with 90W laser power prior to the melting process. Samples were printed with either both strategies applied, one of them or none, giving four different conditions. During the L-PBF process the laser power was set to either 350 W (low) or 380 W (high).

Results and discussion

After the external drying the as-received powder showed a considerable mass loss of 0.05%, probably due to moisture reduction. The density measurements of the cubes built after different drying strategies do not show significant differences. The density values are approximately 96% (2.6 g/cm^3) for all AlSi10Mg cubes. There are hardly any differences visible between the externally and internally dried specimens, see Figure 2. The average pore size does not seem smaller after drying, which agrees with the density measurements, but the pore shape becomes more spherical for the externally dried samples B1-B4 as observed from the f_{shape} and $f_{circular}$ indices (Table 1). The cubes presented mostly metallurgical pores, which are formed from entrapped gases within the melt pools while using a high energy density to melt the powders. These pores mostly have a spherical shape and are usually small in size (< 100μm) [3]. Weingarten, *et al.* [4] investigated the internal and external drying strategies with different scanning speeds. Their study concluded that external drying (in air) resulted in a reduction of the hydrogen porosity, which seems contradictory to our results. However, in their work also lack of fusion pores were present indicating a relatively low energy density during the manufacturing process different from the research described here. In this study the external drying was carried out in vacuum which is different from air drying. In addition, the internal drying here does not seem to be effective when using a high energy density.

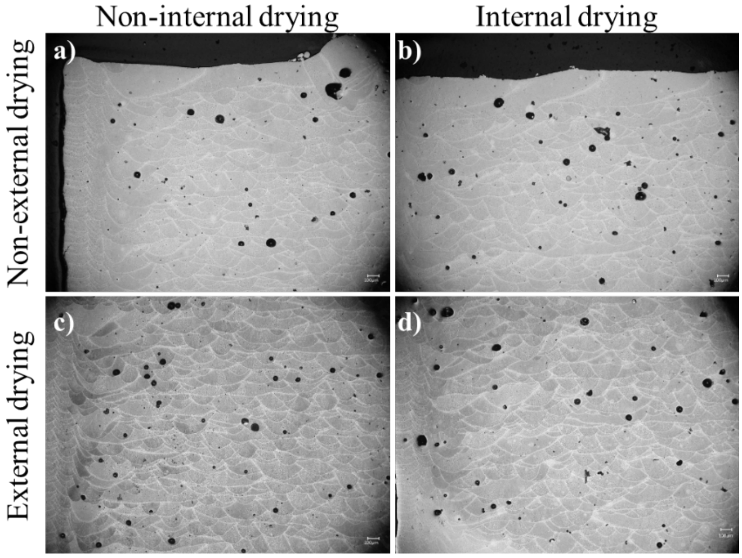

Fig. 2. Etched blocks of AlSi10Mg in the following drying conditions: (a) non-external and non-internal, i.e. no drying, (b) non-external and internal, (c) external and non-internal and, (d) external and internal drying, i.e. both drying strategies.

Table 1 *Shape and circularity indices and pore size of cubes built with external and internal drying strategies. Two different laser powers were used: 350W (low) and 380W (high).*

Sample	External drying	Internal drying	Laser power	f_{shape} (AR^{-1})	$f_{circular}$	Average pore size (μm)	Max. pore size (μm)
A1	N	N	Low	0.78	0.76	56.6	170
A2	N	N	High	0.77	0.74	56.9	162
A3	N	Y	Low	0.78	0.73	58.4	177
A4	N	Y	High	0.78	0.76	56.2	178
B1	Y	N	Low	0.86	0.88	57.9	159
B2	Y	N	High	0.84	0.88	53.8	230
B3	Y	Y	Low	0.83	0.89	53.9	130
B4	Y	Y	High	0.85	0.88	59.1	127

To conclude, two drying strategies to reduce the formation of hydrogen porosity in L-PBF cubes were investigated. In all cases the same density was achieved and no significant changes in pore dimensions were observed. External drying showed a tendency to improve the pore shape towards a more spherical shape. Metallurgical pore formation can be affected during the process by different parameters, such as the time between the melting and the solidification and the melt pool temperature. When the melting pool temperature is high, the viscosity of the molten metal decreases and the hydrogen molecules are more easily dissolved forming bubbles almost perfectly spherical.

References

[1] L. Cordova, M. Campos, T. Tinga, Revealing the Effects of Powder Reuse for Selective Laser Melting by Powder Characterization, JOM, (2019) 1062-1072.

[2] T. Marcu Puscas, M. Signorini, A. Molinari, G. Straffelini, Image analysis investigation of the effect of the process variables on the porosity of sintered chromium steels, Materials Characterization, 50 (2003) 1-10.

[3] N.T. Aboulkhair, N.M. Everitt, I. Ashcroft, C. Tuck, Reducing porosity in AlSi10Mg parts processed by selective laser melting, Additive Manufacturing, 1-4 (2014) 77-86.

[4] C. Weingarten, D. Buchbinder, N. Pirch, W. Meiners, K. Wissenbach, R. Poprawe, Formation and reduction of hydrogen porosity during selective laser melting of AlSi10Mg, Journal of Materials Processing Technology, 221 (2015) 112-120.