

**LARGE-DIMENSION METAL PARTS PRODUCED THROUGH LASER POWDER BED FUSION**

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**Abstract**

Laser Powder Bed Fusion (LPBF) is an Additive Manufacturing technology in which a defined metal powder thickness is selectively melted with a laser, according to the geometry of the part being produced. The layer-by-layer approach allows manufacturing functional complex shaped components, with high structural integrity at low cost. This technique has been proven to produce near net-shape parts up to 99 % relative density and has viable economic benefits. However, the typical build envelope for this type of machines is of 300x350x250 mm, thus the manufacturing of large-dimension parts is unachievable.

The goal of this project was to develop a customized LPBF machine with a build envelope of 1020 mm x 1020 mm x 520 mm that is able to produce high quality parts. Through fine-tuning of the processing parameters, the machine has produced samples with 316L stainless steel which exhibit relative densities above 99 %. Besides the samples, the machine has also successfully built large-dimension parts. The results obtained are a positive indicator towards the ultimate goal of zero-defect manufacturing.

**Keywords:** Additive manufacturing, LPBF, density, large-dimension parts, 316L SS

**1. INTRODUCTION**

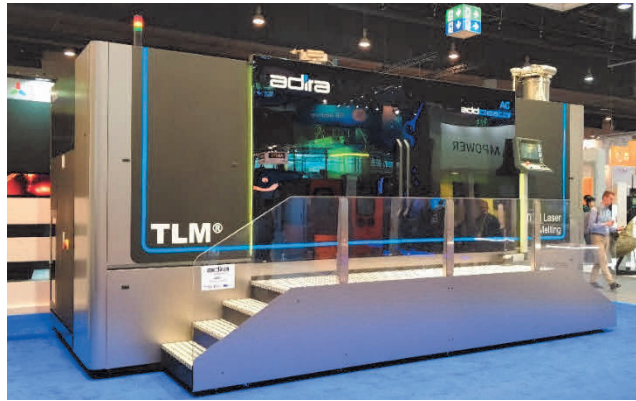
Additive Manufacturing (AM) comprises different types of technologies which allow the production of parts from different materials, such as metals, polymers or ceramics, but all are based on the same layer-by-layer building principle that allows parts to have very complex geometries which would be very hard, if not impossible, to obtain through Subtractive Manufacturing (SM) technologies. One of the technologies available for metal AM is Laser Powder Bed Fusion (LPBF), in which a bed of powder metal is selectively melted with a laser, according to the geometry of the layer of the part being produced.

LPBF, being powder-based, produces parts with lower density than parts produced by SM from bulk material, due to pores that appear within the part [1]. Nonetheless, with the correct parameter settings, LPBF machines are able to produce parts with relative densities above 99 % [2]. Under optimal conditions, LPBF parts may even present tensile strength greater to SM obtained parts [3]. One limitation of all AM technologies is the build volume [4]. In the case of LPBF, the typical build volume is approximately 300x350x250 mm, though some manufacturers present larger build volumes.

The goal of the presented work was to evaluate the performance of a large-dimension customized LPBF machine. The machine has a build volume of up to 1020x1020x520 mm, and has produced samples in 316L stainless steel with relative densities above 99 %, as well as a large-dimension part (530x150x25mm) with an average relative density of 98.94 %. Additionally, even though its properties are still being determined, the machine has also successfully built a part with overall dimensions of 940 mm x 245 mm x 88 mm.

## 2. EQUIPMENT

The machine used for the experiments was the Adira Add Creator 100 (AC100), shown in **Figure 1**, developed by manufacturer Adira, alongside Instituto Superior Técnico, NOVA School of Science and Technology, INEGI and MCG as part of the SLM-XL project. The Add Creator's specifications are depicted in **Table 1**.

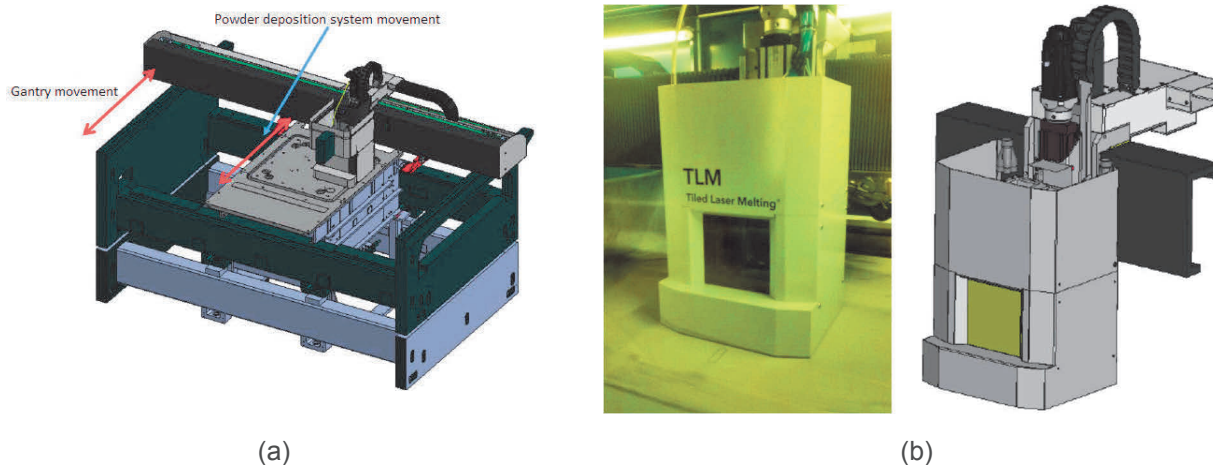


**Figure 1** Adira Add Creator 100 large-dimension LPBF machine

**Table 1** Add Creator 100 specifications

<b>Laser</b>	400 W fibre laser
<b>Minimum layer thickness</b>	25 $\mu\text{m}$
<b>Maximum scan speed</b>	9 m/s
<b>Laser beam diameter</b>	60 - 600 $\mu\text{m}$
<b>Build volume</b>	1020 mm x 1020 mm x 520 mm

The Add Creator has a closed frame structure, with a mobile platform on which the powder bed sits, as well as a mobile processing chamber. The powder cycle is fully automated, and, due to structural constrictions, the powder deposition system moves in the same direction as the gantry that holds the processing chamber, as it can be seen in **Figure 2 (a)**. The machine is prepared to operate with an Argon or Nitrogen protective atmosphere.



**Figure 2** (a) AC100 drawing with gantry and powder deposition system movement;  
(b) Tiled Laser Melting<sup>®</sup> mobile processing chamber

The key feature that enables the production of large-dimension parts is the Tiled Laser Melting<sup>®</sup> (TLM) technology, which consists of a mobile processing chamber, shown in **Figure 2(b)**. The mobile processing chamber splits the working area into „tiles“ of 250x250 mm that are sequentially processed, thus reducing the volume of controlled atmosphere that needs to be maintained. The modular nature of this technology also allows the expansion of the working area to larger dimensions.

### 3. SAMPLES

#### 3.1. Samples production

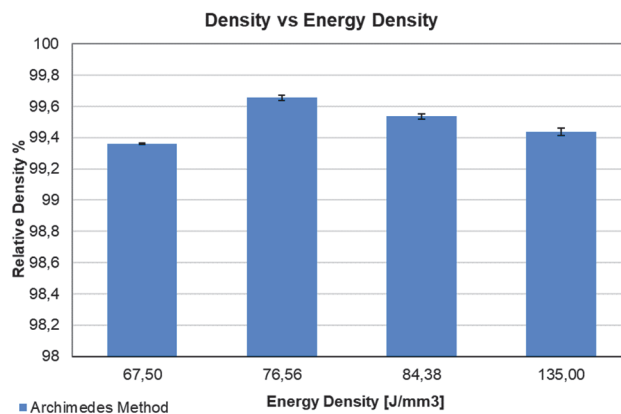
In order to evaluate the performance of the machine, cubic 10 mm edge samples were produced. The material chosen was the 316L stainless steel powder, by LPW Technologies, with a particle size distribution of  $D_{90}=46\ \mu\text{m}$ , and the chemical composition described in **Table 2**. Considering that the processing parameters play a very important role in determining the properties of the manufactured parts [2], the specimens were produced with the different combinations of parameters described in **Table 3**.

**Table 2** - Chemical composition of the AISI 316 L powder (wt.%). (LPW Technology, 2018)

Weight Percent								
AISI 316L	C	Cr	Ni	Mo	Cu	Mn	Others	Fe
	0.03	18.00	13.00	2.50	0.50	2.00	<1	Balance

**Table 3** - Sample parameters

Sample type	Power - Hatch (W)	Power - Contour (W)	Scan speed - Hatch (mm/s)	Scan speed - Contour (mm/s)	Hatch spacing ( $\mu\text{m}$ )	Scan strategy	Vector size (mm)	Energy Density - Hatch ( $\text{J}/\text{mm}^3$ )
1	270	200	800	600	0.10	Stripes	10	67.50
2	270	200	800	600	0.05	Stripes	10	135.00
3	270	200	800	600	0.10	Stripes	15	67.50
4	270	200	800	600	0.10	Chess	1	67.50
5	270	200	800	600	0.10	Chess	5	67.50
6	270	200	800	600	0.05	Stripes	15	135.00
7	270	200	800	600	0.08	Stripes	15	84.38
8	245	245	800	600	0.08	Stripes	15	75.56



**Figure 3** Relative density for samples produced at different energy densities

### 3.2. Samples density

The density of the produced samples was measured through the Archimedes method. As it can be seen in **Figure 3**, optimal density was obtained for an energy density of 76.56 J/mm<sup>3</sup> with a relative density of 99.655 %, considering a reference value of 7.965 g/mm<sup>3</sup>. Also, a non-linear pattern may be observed in density variation with energy density increase. These results are similar to Cherry's [5] findings. Low energy densities increase the probability of unmolten areas within the layers. An increase in energy density improves melting and the flow of the molten material, thus filling the pores and increasing density. Nonetheless, if energy density values are too high, part density decreases due to vaporization of low melting point elements. For instance, traces of oxygen and carbon may react due to the high temperatures of the process, resulting in the formation of CO and CO<sub>2</sub> gases which can remain entrapped and form pores.

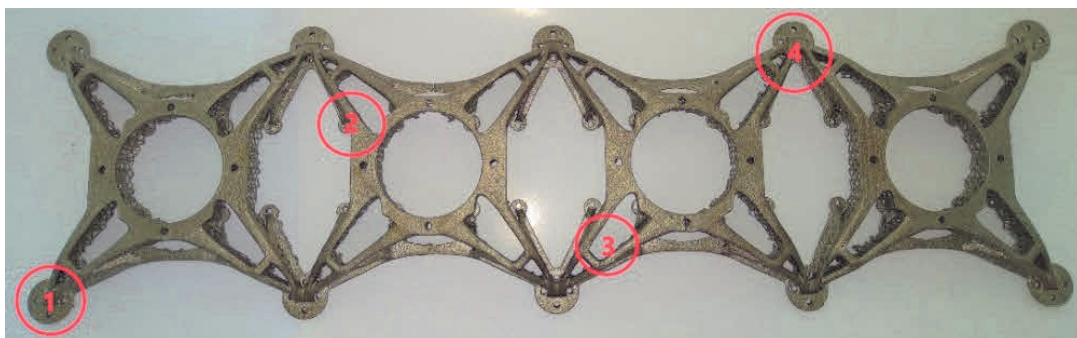
## 4. LARGE-DIMENSION PARTS

For the proof of concept for large-dimension LPBF metal parts, the part shown in **Figure 4** was produced. It has overall dimensions of 530 mm x 150 mm x 25 mm and was manufactured within the previously determined optimal energy density range.



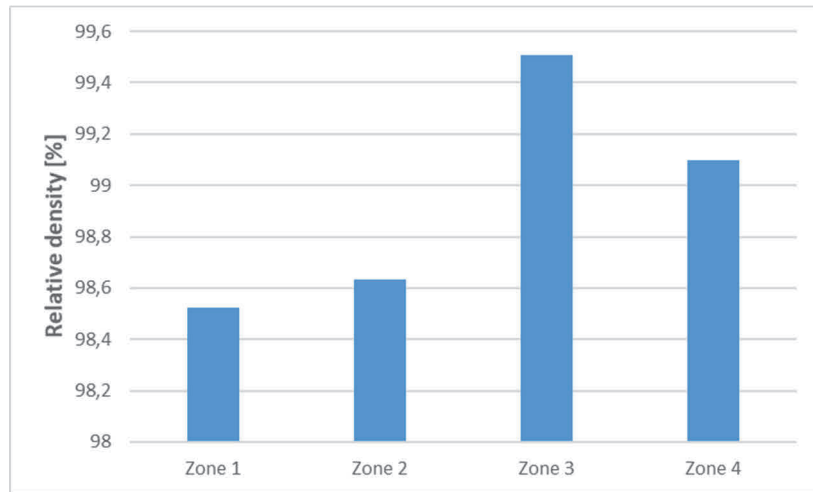
**Figure 4** - Large-dimension part produced in the AC100 machine. Overall dimensions: 530x150x25mm

The part has a lattice structure that optimizes its strength to weight ratio and is only possible to obtain through AM. Several samples were taken from the areas shown in **Figure 5** in order to obtain the density in multiple points of the part.



**Figure 5** Areas where samples were extracted for density analysis

The density of the different points analysed is shown in **Figure 6**. The best value was obtained in zone 3, with a relative density of 99.507 %, and the worst value was obtained at zone 1 with a relative density of 98.522 %.



**Figure 6** Relative density at different points of the part

Additionally, even though the analyses of its properties are still being conducted, the part show in **Figure 7** has been produced. It is currently the largest LPBF produced part in the world, it was also produced in 316L stainless steel, and it has overall dimensions of 940 mm x 245 mm x 88 mm.



**Figure 7** Largest LPBF produced part in the world (at present time).  
Overall dimensions: 940 mm x 245 mm x 88 mm

## 5. CONCLUSION

The analysis performed on the samples produced on the customized LPBF machine show relative densities above 99 %. The best results were obtained for energy density of 76.56 J/mm<sup>3</sup> with a relative density of 99.655 %.

The manufactured large-dimension part, with a geometry only achievable through additive manufacturing, also shows promising results, presenting an average relative density of 98.94 %. The largest LPBF produced part is also a strong statement regarding the feasibility of large-dimension LPBF parts. Further studies on the influence of the processing parameters are being conducted to optimize the density of the manufactured parts. Nonetheless, the results are a positive indicator towards the ultimate goal of zero-defect manufacturing.

## ACKNOWLEDGEMENTS

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