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This material format applied to 3D printing gives access to an exhaustive material portfolio already available on the market - thermoplastics, elastomers, but also metals and technical ceramics.

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Additive manufacturing of metal parts using industrial MIM feedstocks

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Resume

The main advantages of additive manufacturing over conventional techniques are the possibility of producing parts with complex geometry, without requiring specific tooling investment, flexibility in terms of design and reduced consumption of raw materials. It also has the advantage of producing small batches of parts, with relatively low costs. Certainly, 3D printing of metals is no longer in its infancy.

However, the processing of metal alloys using additive manufacturing still has major limitations at the technology level due to the high melting points of these materials, the need to perform a subsequent heat treatment to obtain the required structural properties (sintering) of metal alloys.

This article presents a test of the 3D metal printing process, also called Pellet Additive Manufacturing (PAM), using an innovative equipment released by the company Pollen AM.

Additive Manufacturing of Metals by PAM process

With PAM additive manufacturing technology, an object is built by deposition a rod of melted material produced by an extrusion system, through the formation of layers (Figure 1). The PAM process belongs to the FDM family, which is one of the most widespread technologies for plastic 3D printing, which can also be used for metal alloys materials.

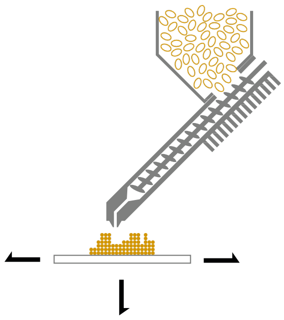


Figure 1- Schematic diagram explaining the PAM additive manufacturing process.

Before the production process, a 3D CAD model is obtained through software, which must be exported to a proper format - the most common is the STL format. In the preparation phase, from the 3D model, the object construction is set up using slicing software that includes all the 3D printing parameters.

The software divides the model into two-dimensional layers (slices) and configures, for example, the selection of the material to be processed, the nozzle diameter, the 3D printing quality, etc.

The production process then integrates three phases: 3D printing, debinding, and sintering[1] (Figure 2). The raw material consists of a mixture of metal powders and thermoplastics. The metal powder is the material from which the final part is to be made. The thermoplastic is a temporary material, which gives the mixture fluidity by heating during the 3D printing process and is removed from the object in the debinding process. In the last step, the object is sintered when subjected to high temperature, a common process in the powder metallurgy industry.

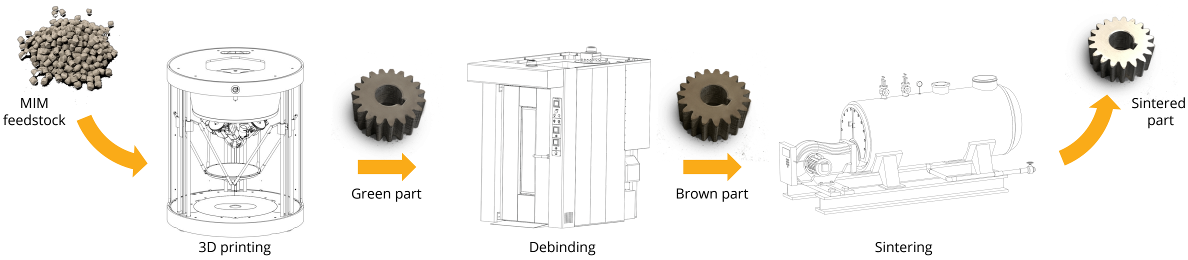


Figure 2 - Production process of metal parts by PAM process.

PAM technology[2](short for Pellet Additive Manufacturing) was developed by Pollen AM, a French company that develops, manufactures, and markets industrial multi-material 3D printers (example in Figure 3). The main characteristic of these 3D printers lies in the fact that they use universal materials in pellet form, those currently used by industry.

This material format applied to 3D printing gives access to an exhaustive material portfolio already available on the market - thermoplastics, elastomers, but also metals and technical ceramics. This specificity makes Pam 3D printers particularly suitable for demanding applications that must meet industry standards.

PAM technology makes it possible to transform certified materials, such as those for skin or food contact, controlled burning for the transport and construction sectors, or for electromagnetic shielding, etc., at an unbeatable cost (granules are 10 to 100 times cheaper than specific materials for 3D printing).

The Pam 3D printer software is also open and allows its users to prepare the 3D print using a set of specific parameters related to the nature of the material to be processed, the parts to be produced and the configuration of the PAM systems - such as nozzle diameter, layer heights, print speeds, process temperatures.

Figure 3 - Pam Series MC 3D Printer from Pollen AM.

Pam 3D printers are equipped with 2 to 4 autonomous and independent extruders. An extruder consists of a hopper (or material cartridges containing the MIM feedstock), a sleeve with an Auger screw, an extrusion die, heating elements, and temperature sensors (Figure 4).

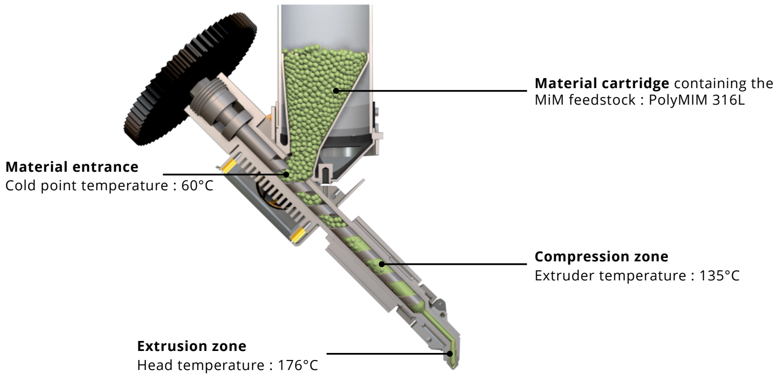
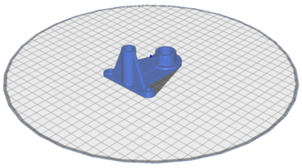


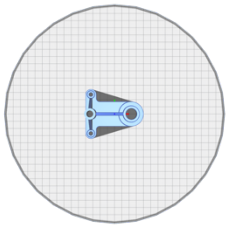
Figure 4 - Pam 3D printer's extrusion melting and deposition system.

Testing the Production Process

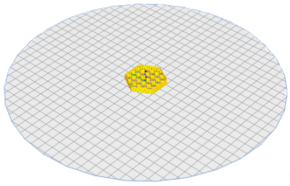
To evaluate the PAM technology, a production procedure was performed on three parts that are shown in Figure 5. The bracket has geometric details related to its mechanical coupling and functionality, and has outside dimensions of 34,9 x 80,5 x 41,9 mm. The hexagon is demonstrator and serves to demonstrate the technology capacity to produce complex parts with specific infill patterns, and has outer dimensions of 26,5 x 30,4 x 3,9 mm. The geometric details present in the parts represent a challenge to test the technology. The tensile specimen will serve to perform some mechanical properties and has outer dimensions of 23,3 x 42 x 4,65 mm.



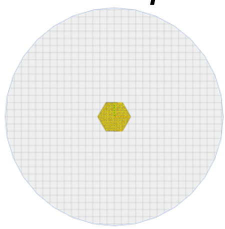
Bracket – Axonometric view



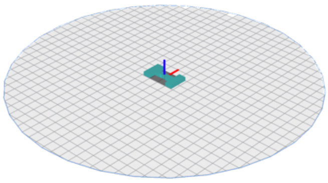
Bracket – Top view



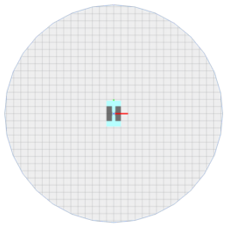
Hexagon – Axonometric view



Hexagon – Top view



Tensile specimen – Axonometric view



Tensile specimen – Top view

Figure 5 - 3D models of the produced parts – Bracket, Hexagon, Tensile specimen.

MIM (Metal Injection Moulding) pellet was used as raw material, with reference PolyMIM 316L - 1.4404[3]. The Pam Series MC printer from Pollen AM was used, with the printing conditions that are presented in Table 1, regarding the extrusion module. The diameter of the extrusion die was 0.4 mm. The build platform was heated to 60 °C, on top of which a 3D printing adhesive was placed to ensure good adhesion of the first build layer.

Figure 6 shows the parts obtained by the 3D printing process, where a good reproduction of shape and geometric details of both parts can be observed. The observed surface quality, which is reflected by the evidence of the construction layers (on the side faces) and the deposited strands (on the top faces) is a characteristic of the process. This process roughness can be adjusted by varying the production parameters, e.g. nozzle diameter and layer height. On the other hand, adjustments of these parameters have an impact on the 3D printing speed. Higher print quality (resolution) is obtained at the expense of production time.

Table 1 – Main 3D Printing parameters.

Temperature	
Feeding Zone	60°C
Compression and fusing zone	135°C
Extrusion zone	176°C
Build plate	60°C

Layer Height	Ø0.4 mm
Nozzle size	0.2 mm

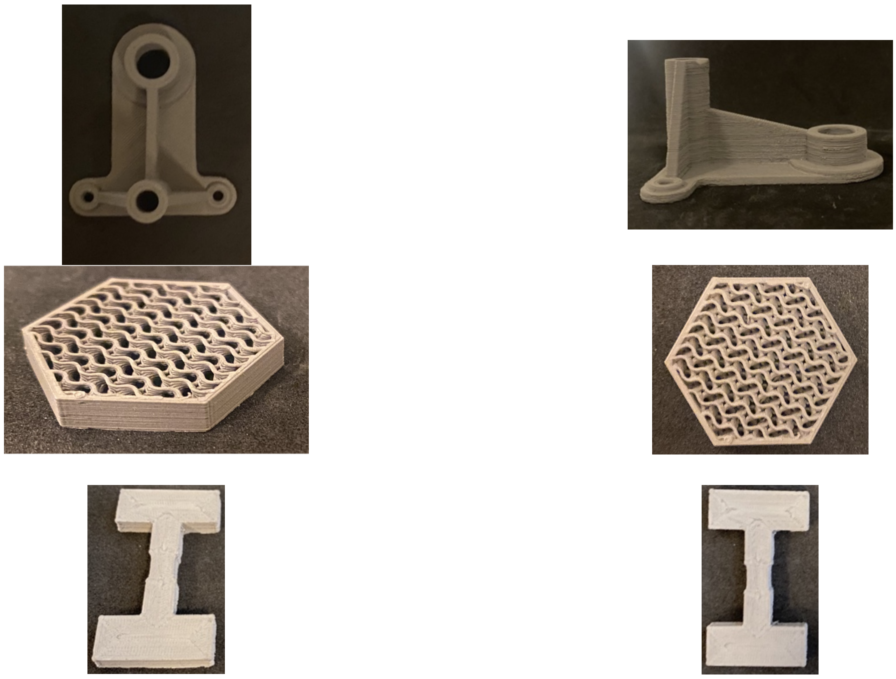


Figure 6 – 3D printed parts (Green parts).

These green parts were subjected to the debinding process for the removal of thermoplastic. In the case of the raw material used, this process is subdivided into two stages: the first stage consists of aqueous debinding - the parts are immersed in the water bath with controlled agitation and temperature; in the second stage - thermal debinding - the parts are placed in an oven, following a predefined heating cycle. In the first step, part of the thermoplastic binder is removed, creating a network of channels with open porosity, which facilitates the thermal degradation of the remaining thermoplastic in the second step. With this two-step process, the goal is to obtain parts free of defects (e.g., warpage, cracks, blisters, etc.), especially in thick-walled parts. Once the debinding process is complete, the "brown parts" are obtained.

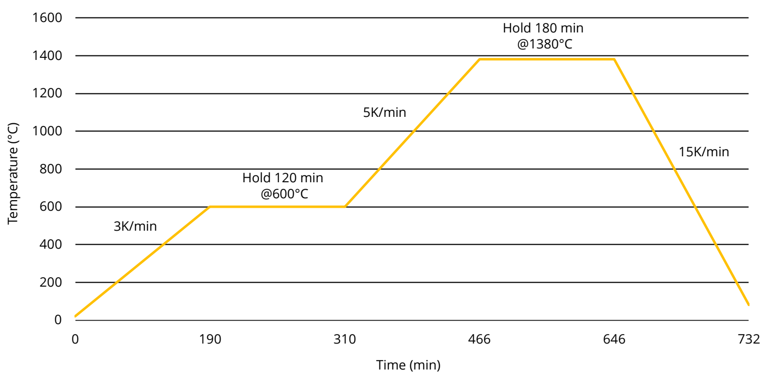


Figure 7 – Sintering cycle.

Then, the parts were sintered at 1380 °C, using the thermal cycle shown in Figure 7. The parts obtained showed good shape retention, no deformations, and no structural defects (Figure 8). An evaluation of the part characteristics was performed based on part shrinkage and density and compared to the specifications of the raw material supplier (Table 2). To calculate the shrinkage of the parts, the green and sintered dimensions were measured.

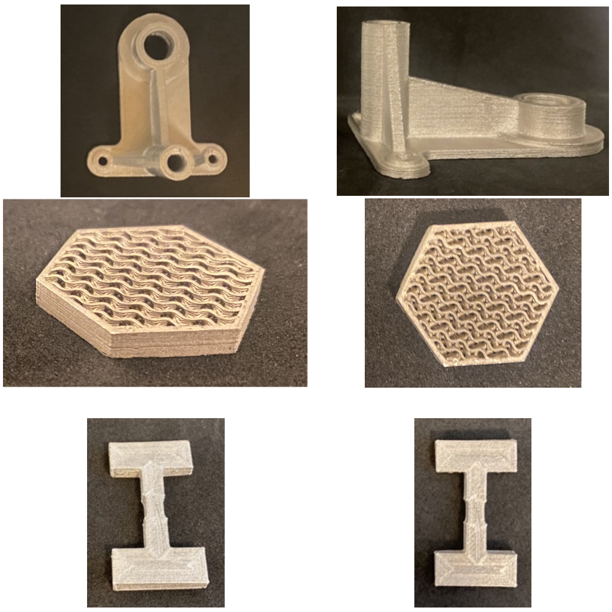


Figure 8 - Sintered parts.

Table 2 – General linear shrinkage.

Bracket		16.48 %
Hexagon		16.69 %
Tensile specimen		16.47 %
Material data sheet		
Minimum	Average	Maximum
16.27 %	16.69 %	17.11 %

Table 3 – Mechanical test results.

	Measured	Material data sheet
Hardness (EN ISO 6507)	148.40 HV	> 120 HV
Density	7.897 g/cm^3	7.90 g/cm^3
Porosity	0.87 %	-
Tensile Strength (EN ISO 6892-1)	565.84 MPa	> 450 MPa

In general, the parts obtained met the specifications of the raw material supplier, both in shrinkage and apparent density.

Conclusion

The PAM technology, for additive manufacturing of metal parts, was tested on two stainless steel 316L parts. The process used a raw material and some process steps common to an existing production technology. Thus, there is already a production chain that facilitates the adoption of this new forming technology.

In the tests performed, parts were obtained with good shape reproducibility, without structural defects and with a degree of densification as expected. Thus, it is considered a technology with potential to be applied in the metal segment. As an additive manufacturing technology, it is indicated to produce parts in small & medium series, with functional and complex geometries, and small dimensions. Some other metal alloys can be 3D printed with Pam Series MC, as in the examples shown in Figure 9, 10 & 11.

Figure 9 - Gear 3D printed in Stainless Steel - 17-4 PH

Figure 10 - Tripod 3D printed in Titanium - Ti6Al4V

Figure 11 - Gear 3D printed in Low alloy steel - 8620

[1] https://www.primante3d.com/mim-like-metallique-04032020/
[2] https://pollen.am/pam_series_mc/
[3] https://www.polymim.com/en/products-applications/polymimr-product-line