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Evaluación de procesos de acabado para componentes DMLS

Evaluation of Finishing Processes for DMLS Components

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Resumen – En la actualidad, parece claro que las técnicas asociadas a la denominada Fabricación Aditiva (FA), son extremadamente útiles para la fabricación de componentes con formas complejas, especialmente en el entorno de la Industria 4.0. No obstante, muchas de las técnicas agrupadas bajo esta denominación, tienen todavía un amplio margen de mejora, principalmente cuando se trata de materiales metálicos. Aspectos como el acabado superficial, partículas sin fundir o variaciones dimensionales centran los esfuerzos de la industria para mejorar las técnicas y los procesos de conformado, ya que están directamente relacionados con el tiempo de post-procesado y, consecuentemente, con el coste de producción. En el presente trabajo se presenta un completo trabajo de investigación y análisis sobre el acabado superficial de piezas fabricadas mediante la técnica DMLS (Direct Metal Laser Sintering o Sinterizado Directo de Metal por Láser), comparando los resultados de las diferentes técnicas de post-procesado tanto en calidad de acabado como en coste.

Palabras clave – DMLS, Industria 4.0, FA (Fabricación Aditiva), post-procesado, acabado superficial.

Abstract – Nowadays, it is quite clear that additive manufacturing (AM) technologies are extremely useful for manufacturing various and complicated shapes. However, most of the different techniques that are grouped under AM denomination, have still some important aspects to be improved, such as surface excessive roughness, unmelted particles or dimensional variations. As it is very well known within this sector, this is one of the key aspects to optimize when using additive manufacturing, since it is directly related to post-processing time and cost. In this work, a deep experimental analysis on DMLS manufactured parts surface finishing is presented, comparing the results of different post-processing techniques both in finishing quality and cost.

Keywords – DMLS, 4.0 Industry, AM (Additive Manufacturing), post-processing, surface finishing

1. INTRODUCTION

One of the most characteristic qualities of AM is the possibility of making complex internal cavities inside the mechanical parts, which can have many advantages within the industry. However, the surface finishing that can be achieved with these technologies, and especially when using DMLS (Direct Metal Laser Sintering or "Sinterizado Directo de Metal por Láser" in spanish), most of the times does not meet the technical requirements that are requested, and therefore, it is necessary to perform a postprocessing [1].

DMLS is still an extremely important AM technique since it is not only one of the most versatile and promising ones, but also is one of those that provides a better compromise between economic, social and sustainability aspects, even if this later one (sustainability) it performs worsen than, for example, AFSD (Additive Friction Stir Deposition) [2] Thus, the main objective of the present work is to find which are the best processes to reduce surface roughness in channels and internal cavities made in parts manufactured by DMLS technology.

Before starting to manufacture a metal part by additive manufacturing (AM), some important aspects must be considered to ensure that the parts are manufactured in an optimized manner. The main ones are the following:

- Identification of the areas that are going to require postprocessing works
- Identification of the areas where most critical tolerances will be located
- Types of support structures that will be needed, and where they should be located for the manufacturing process.
- When using DMLS manufacturing, a series of anchors on the construction platform will be necessary, to reduce the deformation caused by thermal stresses during the process. In the following Fig. 1 an example is shown.

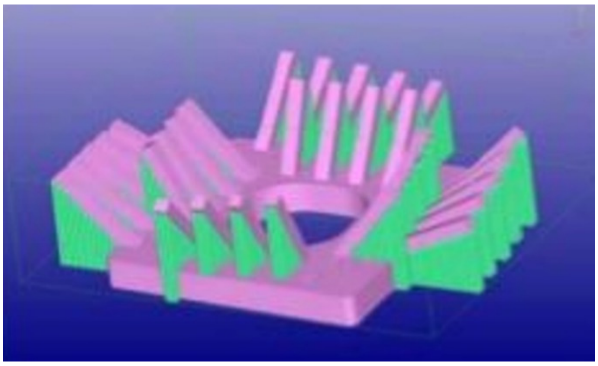

Fig. 1. CAD representation of anchors and supporting structures for a particular part to be manufactured using DMLS. Picture courtesy of Idonial [3].

Most of the post-processing process, will depend on the above-mentioned aspects, since the normal operations after manufacturing are support structures' elimination, dust elimination, thermal treatments, and surface finishing. And these are critical aspects, since all of them represent important cost, both on operators and equipment costs [4,5]. The more those aspects could be diminished, the easier for DMLS to become a technology fully incorporated to industrial processes, [6,7]. DMLS, while being one of the most used AM technologies within industry, is not the only one that needs further investigation and research, as there are still some important related issues that hinder its broad applicability [8]. Besides, the finishing process is one of the most important aspect for the total cost of the postprocessing phase, since it is extremely intensive in labour, but there are also other important challenges like structural and weight optimization, or the process definition and organization. Some good examples of this are [9], for structural optimization when manufacturing using Sequential Element Rejection and Admission (SERA), or [10], for safety related parts manufactured with laser direct energy deposition (L-DED).

Post-processing through shot blasting is one of the most used methods to improve surface finishing when using DMLS, so some interesting research works like [11] delve into other interesting ways of decreasing the cost of post-processing phase through the optimization of the main shot blasting working parameters, namely blasting pressure, grit size and time. In fact, the integration of metal AM techniques within industrial supply chains is still lower than estimated just a few years ago, and that is why its impact on supply chains must be properly simulated before its final implementation, in order to achieve real optimization of industrial processes [12].

However, and especially for DMLS manufactured parts, finishing quality is not only important for post-processing cost, but it is also a key factor for those parts subjected to dynamic and alternating loads, since there is an strong relationship between the finishing and the useful service life of the mechanical parts, as highlighted by [13,14].

The main objective of this work is, therefore, to carry out a comparative and systematic analysis of three of the surface finishing techniques for DMLS parts that could be used in industrial processes for medium manufacturing volumes, in order to help decision making for the definition of manufacturing processes, considering that the post-processing phase, and especially the finishing phase, is conclusive for the final manufacturing cost.

2. EXPERIMENTAL WORK METHODOLOGY

When defining the methodology for this work, some key aspects were stated from the beginning. Those were the following:

- The part to be used for the experiments (layout, manufacturing process parameters, etc), should be complicate enough and include as much elements as possible to enable important and broad conclusions over different internal shapes.
- Among all the finishing existing techniques, only those that could eventually be used in an industrial process (low to mid-size series production) would be investigated.

2.1. Test Part Definition

The usual procedure to manufacture a part using AM, and more precisely DMLS technique, the whole process is integrated by the following phases: CAD design, STL file creation, SW fine adjustments, layers' parameters definition, slicer file creation, and finally, the printing process. Given the objectives of the present work, and the subsequent tests to be performed, a specific design was defined. This design had to include several interior channels of different sizes and shapes, with enough structural strength, and such that it meets the requirement of being able to obtain parts of homogeneous characteristics to guarantee the representativeness of the results. Therefore, the final design was defined as a parallelepiped part, with different diameters, shapes and section changes, attached in Fig. 2.

The decided placement of the part on the 3D printer machine, and the printer itself are shown in Fig. 3. It was manufactured with this inclination to avoid the need for support structures inside the part, by ensuring that all the surfaces were at more than 45º. Support structure is shown in red, above the main platform which is marked in green. Total printing time on the EOS 280 machine that was used, was around 115 minutes per manufactured part, and a total of eight parts were manufactured for the research work.

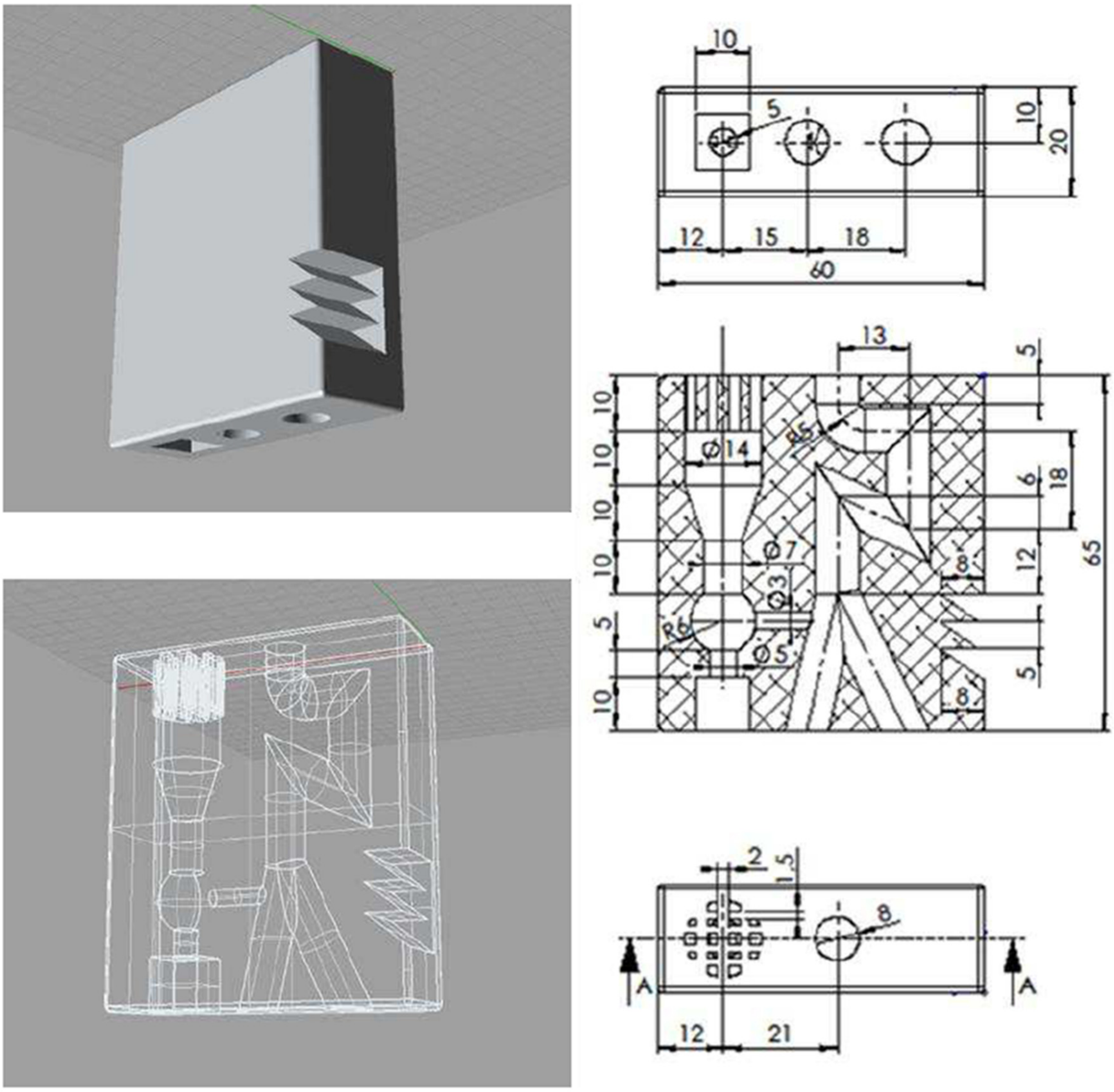

Fig. 2. Engineering definition of the test part used for the research work. Pictures courtesy of Idonial [3].

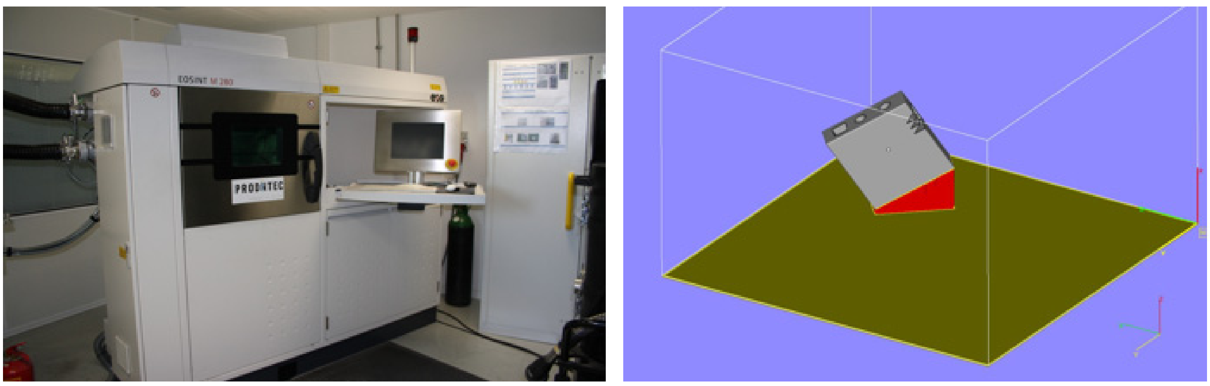

Fig. 3. EOS M 280 printer that was used for the research. The part was specifically placed onto the base plate to maxim-ize the results of the research, through the orientation of the internal holes and channels. Pictures courtesy of Idonial [3].

2.2. Finishing techniques

In this section, all the polishing processes that have been applied to the test parts for their evaluation are presented. As mentioned before, just the processes that are expected to be incorporated to industrial process in the near future have been analyzed. Those are the following:

- **Electropolishing**: A chemical pickling with acid base was applied for a certain time, and temperature was found to be a critical parameter to be controlled. Although the liquid flows easily through all the internal ducts, regardless of the geometry, in Figure 4a it can be visually seen that the roughness has not changed significantly when compared with the original piece.
- **Vibration finishing**: The process was carried on with non-abrasive porcelain particles. As it can be seen in Figure 4b, nearly no important roughness decrease was found mainly due to both the process characteristics (more effective for external surfaces), and the particles' definition parameters. Just a few millimetres of polished surface can be found at the entrance of the different channels.
- **Abrasive Flow Machining (AFM):** The process that was carried out in this case was a one-way type one, with silicon carbide-based abrasive, applied for 25 minutes, and only to the main path of the testing piece (shown in Figure 4c) to save process time. However, similar results could have been obtained with similar processing times in all the other ducts. While the roughness improvement from the original part seems to be much higher than with the former techniques, the polishing has not been homogeneous throughout the entire channel.

2.3. Experimental procedure

A total of eight pieces were manufactured on the same printing machine and maintaining the same conditions (batch of material used, room conditions, temperature, etc.). For each type of finishing technique to be evaluated, two parts were used, and the remaining two pieces were used as reference elements.

Once each pair of test pieces were treated with the different finishing procedures that have been analyzed, each of the two pieces treated with the same technique was measured in three different areas of the main interior channel (entrance, central area and exit), in a total of seven different places indicated in Figure 6, which correspond to three measurements in the entry area, one longitudinal measurement in the central area, and three in the exit area. At each of these points each measurement is repeated twice, and each component, out of the two that are used for each finishing process, is considered as a different replication, to assure the calculation of data dispersion is as low as possible, as so that the results obtained are sufficiently precise, reliable and consistent to draw conclusions.

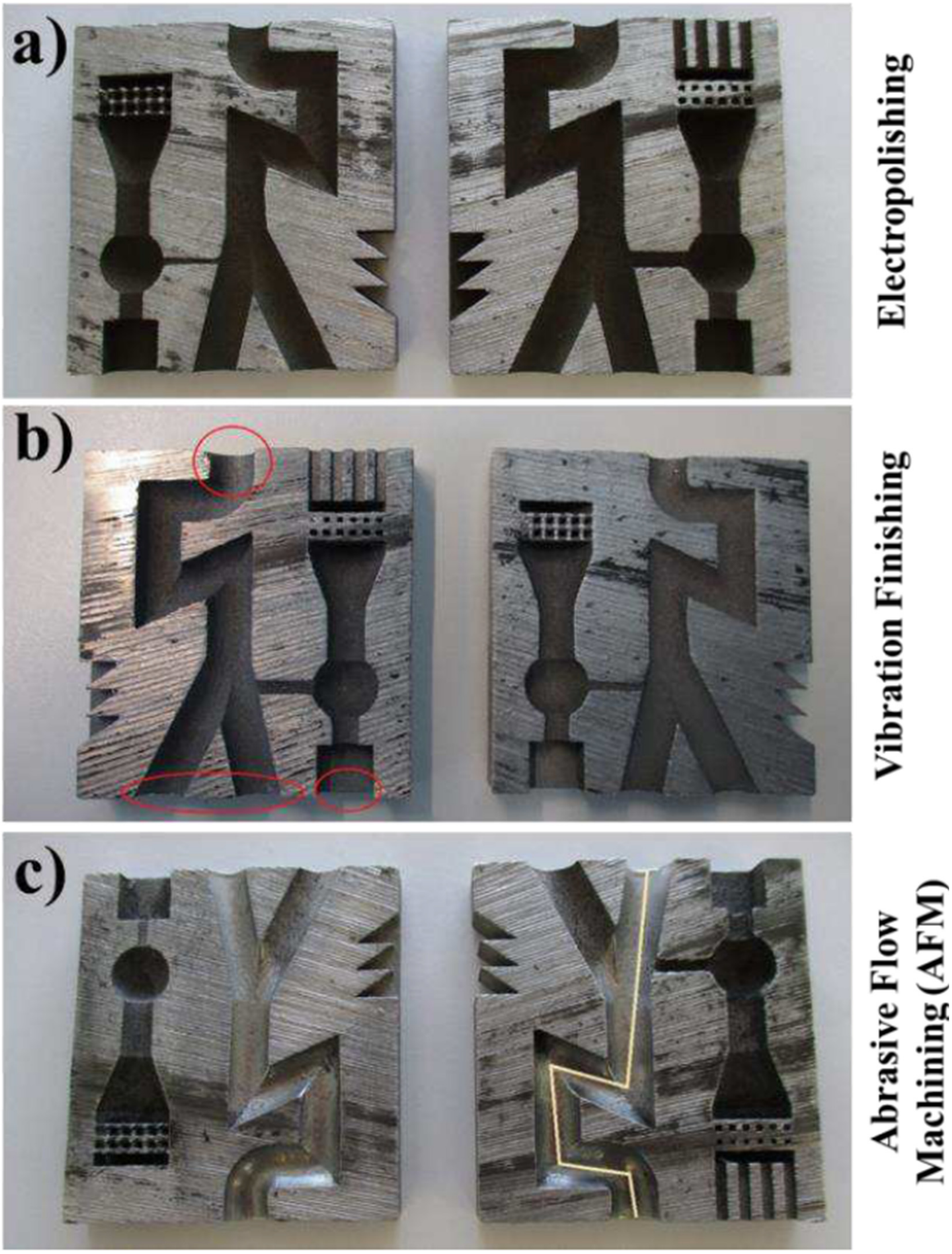

Fig. 4. Finishing results of the tested parts, using the three different processes that were used during the research. Pictures courtesy of Idonial.

3. RESULTS AND MEASUREMENTS

Once the testing units were treated with the different finishing alternatives, the next step was to measure the roughness in a systematize way, and compare the values with the ones of the original non-treated pieces. The equipment to be used for this work was an opto-electronic white light profilometer, Solarius Viking, which is part of the metrology laboratory of the "Idonial Foundation". This equipment (Figure 5) allows three-dimensional scanning of micro geometries, measuring profiles and analyzing them using SolarMap © software.

When selecting the most appropriate method to quantify the roughness of the analyzed parts, mainly optical and palpation-based (also known as contact methods) were evaluated. The optical method was finally selected since it is able to provide extremely high resolution for non-transparent or highly absorbent materials, and medium roughness surfaces, like it is the case of the analyzed parts. Beyond these factors, it is also to be considered that optical methods are normally more sensitive to external conditions, so the whole process was performed under ISO 25178 standards, and consequently, the measuring room was carefully controlled continuously.

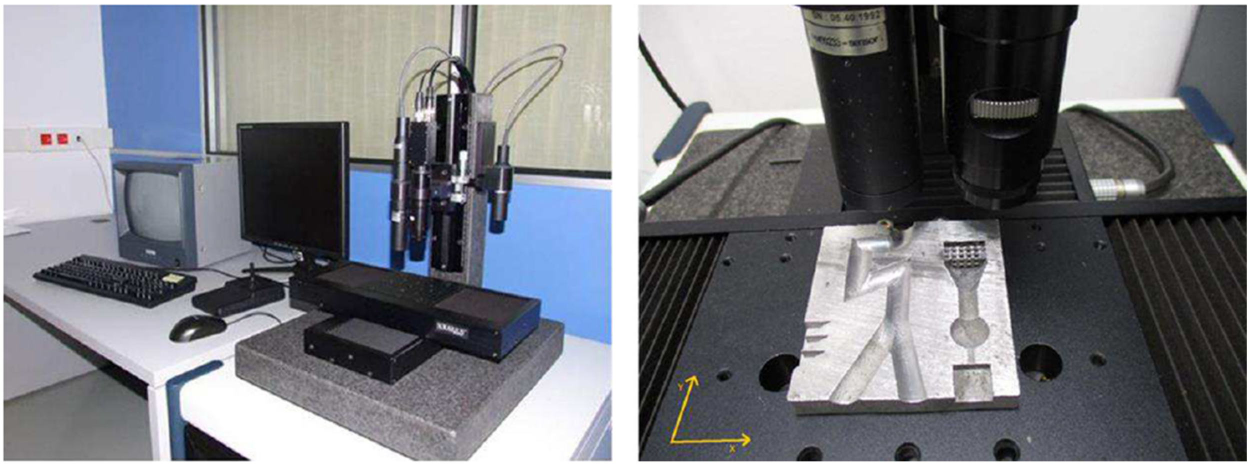

Fig. 5. Solarius Viking roughness measurement equipment and positioning of the testing part for measuring. Pictures courtesy of Idonial [3].

In order to have comparable results among all polishing methods, same "measurements' areas" have been defined for all the treated parts. As it can be seen at Figure 6, two at the ends (A and C) of a channel, with three measurements on the x-axis each, 1 mm apart from the external edge, and a third in the central zone of the channel (B) with a measurement on the y-axis. About the reasons why these areas have been selected, it must be said that, all of them are part of the central channel (the only one that has been treated with AFM, and, in addition, in these areas it is where apparently the best results have been obtained with all the techniques.

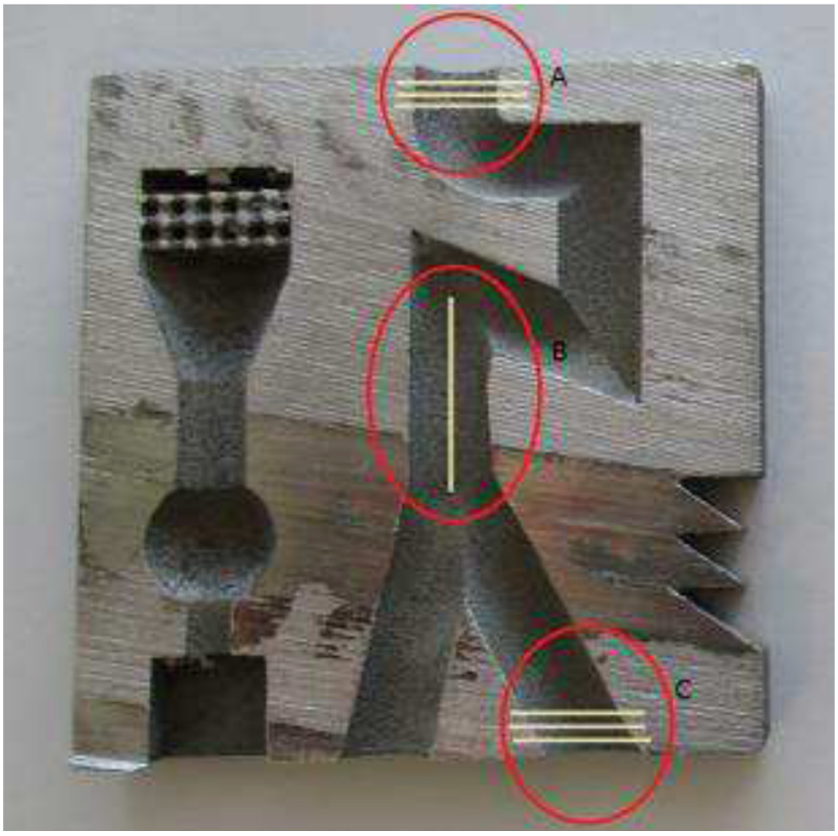

Fig. 6. Selected measuring areas for all the testing parts. Pictures courtesy of Idonial.

Aiming to guarantee the results, it is important to define the correct sensor type and its distance from the measured part. Besides, it is also imperative to control the light intensity and temperature of the room. To minimize uncertainties in the results, no filter was applied to any measurement. However, all the results were processed in order to avoid the "edge effect" not considering the readings of those limit parts (Figure 7).

At all the measurement areas, the arithmetic mean of the 7 measurements of each case and its corresponding standard deviation is performed. In case of any triggered value with respect to the others, it is removed from the calculations (shown in red), since it is supposed to be caused by some error. Table 1 summarizes the obtained results.

As it can be observed, and in line with the visual assessments, the Vibration Finishing method has not achieved any type of polishing inside the testing part, since it presents a roughness result very similar to that of the non-treated part. The case of AFM polishing has clearly been the most effective method, both in the Ra obtained, which is much smaller than in the other cases, and visually, which offered the brightest surface.

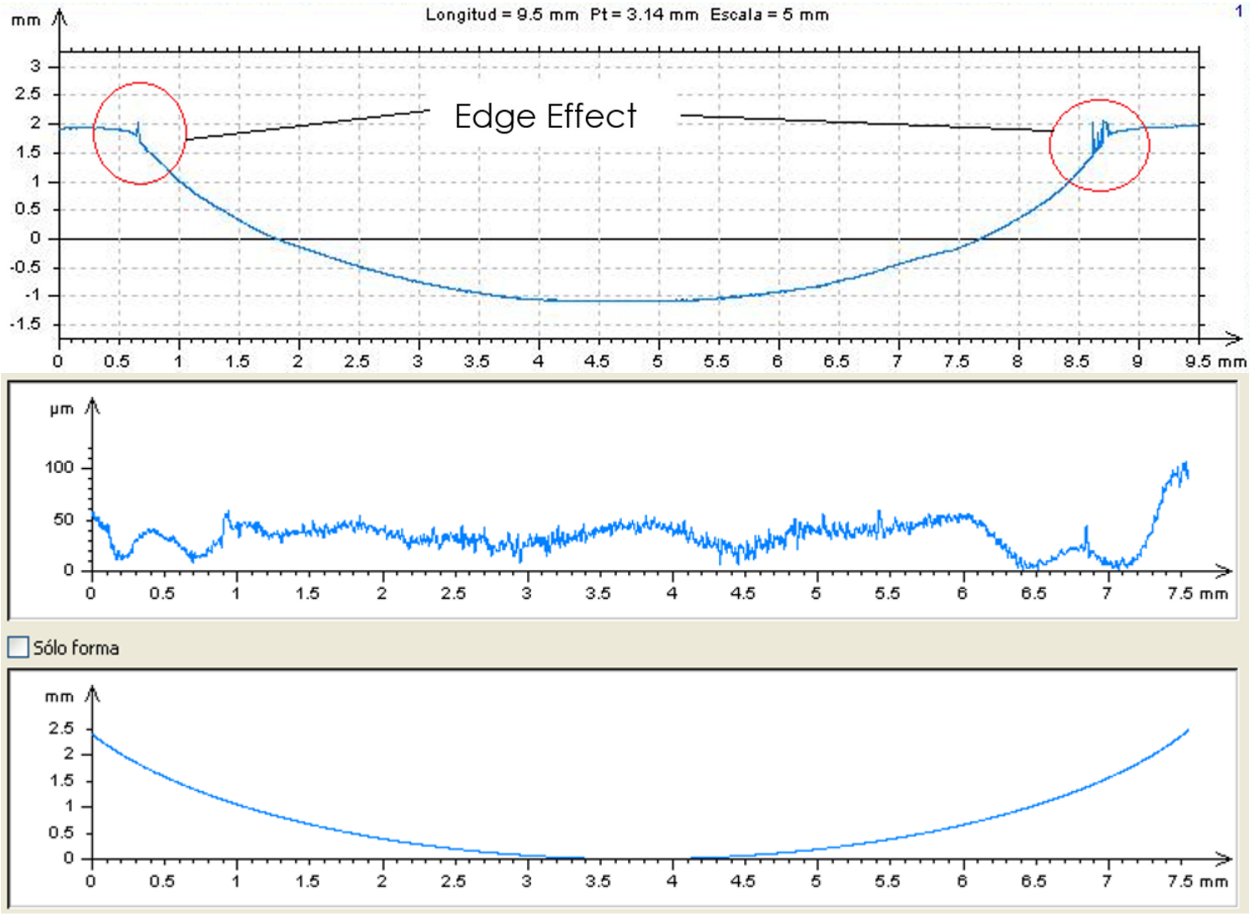

Fig. 7. “Edge effect” elimination from the measurement area (top) and decoupling of the geometric profile and that of the surface roughness (mid and bottom). Pictures courtesy of Idonial [3].

Table 1. Roughness measures of all the finishing tests. Values in red have not been considered for the calculations All the measures are expressed in µm, and the column names indicate, from left to right, the values for the reference part (so non treated), and for the three analyzed processes.

	Without Finishing	Electro-polishing	Vibration Finishing	AFM
“A” Area	20	9,72	18,9	3,07
	28,2	13,8	17,2	2,83
	18,2	21,1	17,2	3,58
“B” Area	15,2	9,42	14,6	2,99
“C” Area	16,9	7,76	19,6	3,15
	14,6	9,85	19,1	3,68
	16	12,4	17,6	3,3
Average	16,8 µm	10,5 µm	17,7 µm	3,2 µm
Std. Dev.	2,01	2,20	1,69	0,31

4. CONCLUSIONS

From the research work that has been presented in this paper, about the efficacity and efficiency of the three different finishing processes that have been tested for DMLS manufactured parts, namely Electropolishing, Vibration finishing, and Abrasive Flow Machining (AFM); some important conclusions can be obtained from the results:

- **Electropolishing** reduces the overall roughness of the surface just by a few microns, so its application in DMLS parts is not effective due to the high starting values. However, its main advantage is its independence from the channels' geometry, being a good method for micro-roughness application.
- The effectiveness of the **Vibration finishing** method is related to the sizes and shapes of the interior cavities, since the particles must be able to access internally to polish the interior walls. In the analyzed case, this method was not effective, since the dimensions were too small.
- **AFM** is the method that has shown a better capability to treat this kind of internal surfaces. However, it is the most expensive and also the one with the longest processing time. It is also a process that depends on the geometry of the channels, since in those areas where backwater points are created, polishing is minor or even null. The amount of material removed during the process is also considerable, so it must be considered when defining the final shape and measures of the treated parts.

The three finishing techniques that have been analyzed and compared are some of the most used and those on which there is a greater consensus about their applicability and automation within industrial applications.

Any improvement in AM parts' surface finishing, and specially in internal ones, would immediately mean an important post-processing cost decrease, that could reach up to 45-55 % in some specific parts like pitot tube probes, internal parts of biological or chemical reactors, etc. This is the main reason why it is extremely interesting to continue with research works like the one that has been presented, since there are many industrial applications where this improvement will enable the use of DMLS and other techniques while maintaining the required profitability.

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