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Criteria selection for a comparative study of functional performance of Fused Deposition Modelling and Vacuum Casting processes

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A B S T R A C T

Additive Manufacturing Technologies is one of the enabling technologies within the industry 4.0. However, there are other more traditional manufacturing processes to develop polymer parts and can compete in efficiency and effectiveness as is the Vacuum Casting.

In this paper, this technology is compared with one of the most used Additive Manufacturing technologies for polymeric parts such as Fused Deposition Modelling (FDM). In this way a comparative will be established between the two processes, based on the functional performance of products obtained with both processes, based on the most important parameters in each one.

To achieve this end, the process will be analysed, as well as the problems inherent to them and the most common defectology in the parts obtained. The functional integrity of the pieces will be quantified according to the surface characteristics (surface roughness) as well as the mechanical characteristics (tensile strength).

With the data obtained, it is possible to establish a possible alternative, with a traditional process to additive manufacturing processes for a certain range of parts with certain characteristics.

1. Introduction

The market demand for products with increasingly complex geometries, in short series and customized products, increases every day in different areas. This leads to technical and economic difficulties in conventional manufacturing processes [1,2].

Rapid Manufacturing Technologies (RP) respond to these need because they are able to create products with complex and customized geometries, even assembled, difficult to manufacture by other manufacturing technologies by a quick and economic way, in a single step. An example of these technologies is the Additive Manufacturing (AM) that is also one of the most important manufacturing technology within the Industry 4.0 [3–6].

There are many processes of additive manufacturing, also with different types of materials (polymeric, ceramic and metallic). However, the polymeric technologies are the most developed in recent times. Specifically, Fused Deposition Modelling (FDM) is one of the main processes of polymeric additive manufacturing that meets all these requirements and its use extends to different industrial fields. Though, it is still a technique with limitations. Among them, the surface quality and geometric tolerances, as well as the reduction in the functionality of the pieces in comparison with other technologies. Nevertheless, it is a technology that advances every day and that is increasingly incorporated into all sectors of the industry [5].

On the other hand, Vacuum Casting (VC) is a process similar to conventional injection and casting methods. This process also represents an alternative for the customization of pieces in limited series, around 20 units. It is a process that starts from a standard model of the desired piece, to create duplicates with the use of silicone moulds, achieving reproductions with very tight tolerances [7–10]. One of the applications of these combined technologies is the RP parts used as masters to make production tooling, for example to produce silicon moulds for production by Vacuum Casting. As with AM techniques, different materials can be used as ceramics, polyurethane resins and even low-melting metals [11]. In addition, there are different mould manufacturing techniques associated with the material used, most of them Hard and Soft Tooling. The latter refer to disposable moulds, traditionally associated with craft processes. As a result, there are few studies referred to its industrial implantation [9]. However, its industrial application would allow to establish niches of competition with other polymeric processes.

Both technologies allow to create short series of parts with the desired properties, reducing costs and production times significantly. This makes it possible to have physical elements available 24–48 h. This

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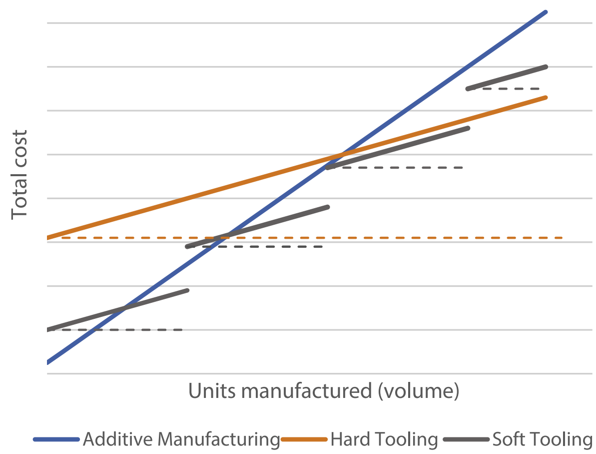

Fig. 1. Comparison of AM with plastic injection, depending on the volume and total cost.

significant savings in time and cost allows testing the market and acceptance of the product with minimal investment.

In spite of this, due to the fact that they are relatively modern techniques or that are in continuous evolution, there are no data on the overall performance of these processes, especially in the case of Vacuum Casting. The few existing data refer to this performance as a balance of several factors, among which the economy, the environment, the energetic and the functional stand out. The latter covers the fulfilment of the geometrical and physicochemical design requirements, being the most relevant for its impact on the applicability of the final product [12].

But all these factors are separately studied, and there is no comparative beyond the purely economic. According to this, FDM stands out for personalized products and VC stands out for repetitive products (Fig. 1).

However, the use of Soft Tooling allows high customization of VC parts and the inclusion of multi-head equipment allows the improvement of productivity in FDM, therefore the choice of both processes should be made not by purely economic criteria, but there is no real comparative on functional aspects related to these processes.

So that, in this paper, a comparison between the functional performances of specimens obtained through Fused Deposition Modelling and Vacuum Casting technologies under different working conditions is proposed. Thus, it is possible to define criteria selection of one of these processes and the most appropriate parameters according to their application in certain production lines that offer common objectives with quite dissimilar solutions.

To define this performance, variables related to surface quality, geometry, dimensional and basic mechanical properties, such as tensile strength, have been considered. In this way, the necessary quality standards can be met to cover the needs of the customer.

2. Materials and methods

This study intends to cover the geometrical characterization of the specimens as well as the tensile behaviour of them obtained by Fuse Deposition Modelling and Vacuum Casting.

For the manufacture of these specimens, the most commonly used materials will be used in each of the technologies, PLA (Polylactic Acid) in FDM and WWAS epoxy resin in Vacuum Casting, Table 1.

To comply with current standards related to polymeric assays the design of standardized tensile specimens for Additive Manufacturing has been carried out [13,14] for FDM process and standardized tensile specimens for plastic injection [15] for Vacuum Casting process. After that they were manufactured under different working conditions. In this way it is possible to compare the influence of the conditions and the technology itself on the result obtained.

Table 1
Properties of PLA and WWAS materials, supplied by their respective manufacturers.

Propertie	PLA	WWAS epoxy resin
Density [g/cc]	1.24	1.08
Tensile Strength [MPa]	50	66
Elongation at Break [%]	9	8
Hardness	85 Shore D	95 Shore A

The machine used to manufacture the test specimens via FDM is CubeX, a 3DSystems equipment. It has been identified in previous studies that working temperature is one of the most influential factors in the final result, defined as the temperature at which the nozzle is in the course of the filament deposition [16–20]. For this reason, it is proposed to make the specimens with three different temperatures 180, 190 and 200 °C, keeping constant the other manufacturing parameters, like 0.25 mm layer height, 0.5 mm nozzle diameter and 30 mm/s printing speed. The specimens were manufactured taking into account the most favourable traction direction, namely with the fibre in the tensile direction. In addition, the filler used was 100% rectilinear.

On the other hand, in Vacuum Casting, the first step is the mould manufacturing. A special pattern is used for the vacuum mould casting process. It is either a match-plate or a cope and drag pattern with tiny holes (air vents) to enable a vacuum suction. In this case the equipment used was 5/01 ULC Renishaw. Due to the nature of the technology itself, it is observed that both the variation of the relative vacuum pressure and the configuration of the moulds are factors of great relevance in the final result. Therefore, it is proposed to make two configurations of moulds varying the number of air vents of each of them, so-called M2 and M4 respectively. Furthermore, it is intended to make the pieces by varying the conditions of vacuum pressure relative to atmospheric pressure, at 0 bar or atmospheric pressure, and in vacuum conditions, at −0.5 bar and at -1 bar pressure. Likewise, to make the samples of both processes closer together, the model that was used to manufacture the VC mould was made by a polymeric additive manufacturing process.

It is possible to know all parameters used in the Table 2. The different specimens obtained for this study is show in Fig. 2.

Before carrying out the mechanical tests and due to the repercussion that these may have on the final result, a morphological and geometric characterization of the test pieces have been carried out. In this way, the main process deficiencies were characterized using Stereoscopic Optical Microscopy techniques. In this form, the most characteristic surface defects were analysed.

Also, thus the level of porosity has been measured with the density of the respective materials and a volume meter, by difference in volume and density of each material.

In addition, the dimensional deviations and the surface finish were characterized using Optical Measures 3D Techniques, concretely Tesa Visio 300 was used.

For this, the global dimensional deviations identified in comparison with the theoretical measure of the virtual model were quantified, where deviation ranges were obtained for the different working conditions in both technologies.

Table 2
Parameters used to manufacture the different specimens.

Fused Deposition Modelling	Vacuum Casting	
Nozzle temperature	2 air vents mould (M2)	2 air vents mould (M4)
180 °C	−1 bar	−1 bar
190 °C	−0.5 bar	−0.5 bar
200 °C	0 bar	0 bar