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# PROCESS PARAMETERS INFLUENCE ON ECONOMIC EFFICIENCY OF 3D PRINTING

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***Abstract:*** Once with the need to limit the plastics consumption, researchers and large industries have begun to look for solutions that are as environmentally friendly as possible, so the market for biodegradable polymers has registered an economic advance. However, due to the considerably higher manufacturing costs of biopolymers based on renewable resources but also to the constraints related to productivity, the economic efficiency it has become a very important aspect to follow. For this purpose the present study develop a framework related to the influence of the process parameters on the economic efficiency, such as the manufacturing time, the material consumption both in case of part and part support using Fused Deposition Modeling (FDM) technology. Analyzing the economic factors obtained after printing according an experimental plan, by varying the input parameters (sample orientation, layer thickness, and printing speed), it was highlighted that the material consumption and the printing time are closely and significantly influenced by input parameters especially by the sample orientation on the printing bed.

**Key words**: economic efficiency, 3D printing technology, printing parameters

## 1. INTRODUCTION

The additive manufacturing (AM), also known as three-dimensional (3D) printing, is a manufacturing process that has been used in production on the last 30 years. The term additive is referring to the construction of a piece through the addition of consecutive layers of material on a build plate (bed), [1]. The additive manufacturing technology is used in a variety of industries, such as aerospace, medicine, education, prototyping, food industry, art and not least hobbies. The Fused Deposition Modeling (FDM) is a 3D printing technology along with Stereolithography (SLA), Digital Light Processing (DLP), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Electronic Beam Melting (EBM) and Laminated Object Manufacturing (LOM, Fused Deposition Modeling (FDM) compared with other AM processes is relatively cheaper and easier to set up with lower consumable and maintenance cost, [2].

The authors decide to use the FDM technology because it allows for printing a wide range of materials and the final product have good structural properties that are very close to the real product. This technology is characterized by: dimensional accuracy and shape, technical indicators such as tensile strength, bending and impact respectively economic indicators such as printing time, amount of material used etc. [3, 4].

The first limitation of FDM 3D printing technology is that the printed piece does not have a long-term durability compared to an object made with traditional injection molding. Using injection molding, the object is created as one single part, while with FDM the object is created through multiple thin layers. With this technique, there are multiple areas for the appearance of weaknesses. Another limitation is its disability to produce at a fine resolution. Due to the layering method, there will be many rigid edges on the workpiece surface that, to make it smooth requires additional finishing methods, such as grinding. When produced in larger quantities, these variants usually would not pass the quality control, [5]. Other disadvantage is that the FDM is not efficient with resources when it comes to mass production. Even if are running concurrently multiple 3D printers, the time required the large output is enormous and also we can take into consideration that the piece needs additional time for surface finishing.

According to some authors, in the case of 3D printing, there are several process parameters that influence the final part strength, quality, cost and production time including material and support selection, part design, layer thickness, print design – wall thickness, infill pattern and print conditions uniformity of extruder and/or build-bed temperature, [6-10]. During the production design process, quality, cost and manufacturing time must be taken into account in order to have a sustainable future production [11].

## 2. MATERIALS AND METHODS

In order to establish the economic efficiency of the printed part using FDM technology it is important to discuss the material used during the process. The materials proposed for this study were produced by various companies: PLA (polylactic acid), Impact PLA Grey, HD PLA Green - Raise3D (Headquarters, USA), Extrudr BDP Pearl, Extrudr BDP Flax - Extrudr (Lauterach, Austria) and Fiber Wood - Fiberlogy (Brzezie, Polonia), [12 – 15].

In order to obtain the specific tensile test samples it was used a Raise 3D Pro2 Plus 3D equipment produced by Raise3D, USA, the samples having the following dimensions according to SR EN ISO 527-2 and ASTM D638, [16]: total length ≥150 [mm]; length of the narrow parallel part 60±0.5 [mm]; reference length ≥60 [mm]; thickness 4 [mm]; width at the extremities 20±0.2 [mm]; width of the narrow part 10±0.2 [mm] and radius ≥0°. The diameter of the printed threads was 1.75mm. The infill degree was 100% for all the printed samples.

Ideamaker Raise3D is a partitioning software that, starting from 3D models in STL format, creates files with the print head trajectories and transforms them into G-Code files. It also allows the simulation of the printing process displaying the economic factors necessary to achieve a sample, printed with or without support construction, depending on the complexity and inclination angles of the proposed model. In this case, the model being a simple one, bone-type sample, it was not necessary to use a complex support, this having small dimensions depending on the orientation of the sample on the printing bed.

- *on edge orientation* (2 supports - rectangular shape, with rounded corners): length – 31 [mm]; width – 15 [mm]; thickness – 1.82; infilling degree – 3 layers 10%, 2 layers 70%; radius ≥ 5.5°;
- *flat orientation*: length – 161[mm]; width – 31 [mm]; thickness -1.82 [mm]; length of the narrow parallel part 50 [mm]; width of the narrow part 21 [mm]; width at the extremities 20 [mm], radius ≥ 5.5°; infilling degree – 3 layers 10%, 2 layers 70%;

To create a general idea about the economic efficiency, the authors decided to set as targets the determination of both the necessary material quantity and the necessary printing time to produce a sample. First, it was necessary to determine the printing time for part building. Therefore, starting from the input parameters: part orientation, layer thickness and deposition speed the effective processing time and the material quantity were obtained.

## 3. RESULTS AND DISCUSSION

Table 1 is a summative one of all obtained results for the considered economic factors, manufacturing time and material consumption. Are presented the eight experiments for each biodegradable material taking into account also the printing parameters. As expected, the orientation of the sample has a significant influence on the material consumption and also of time. Thus:

- for the *flat orientation* of the samples the material consumption is approximately 20% higher than in the case of edge orientation, the difference resulting from the amount of material needed to make the support. To perform a flat-oriented sample, the resulting amount of material, according to the software, is divided as follows: 73.6% of consumption for the actual sample and the difference of 26.4% for the support. For the placement on the edge of the sample, the consumption, the percentage distribution is 94.8% for the sample and only 5.2% for the support;
- the printing time difference is visible and is also significantly influenced by the input parameter, the *sample orientation* on the printing bed. A longer printing time would not be necessary to make the sample oriented on edge, but due to the numerous pauses made by the printing head in order to reposition itself during the supports construction, increase significantly the total execution time;
- another printing parameter that has a significant influence on economic factors is the *printing speed*. It is observed, in the case of all printed materials that when the printing speed is high, (80mm/s), the orientation of the sample is flat and the layer thickness is high (0.2mm), situation corresponding to the experiment number 7, the shortest printing time is obtained but with the disadvantage of larger material consumption;
- following the *printing times*, it is observed that the lowest values are recorded, comparing all the experiments, by the PLA material. This is most likely due to its structure which behaves differently at the heating time. The PLA material is a synthetic, biodegradable polyester that most likely has better rheological characteristics than the other study materials, thus explaining its better printing behavior and the shorter printing time.

Table 1. Economic factors for the printed biodegradable materials

| | Exp. No. | Sample orientation | Layer thickness [mm] | Printing Speed [mm/min] | Printing time [s] | Material quantity [m] |
|---|---|---|---|---|---|---|
| **PLA** | 1 | flat | 0.1 | 40 | 5019 | 5.98 |
| | 2 | on edge | 0.1 | 40 | 6234 | 4.63 |
| | 3 | flat | 0.1 | 80 | 4239 | 5.98 |
| | 4 | on edge | 0.1 | 80 | 5588 | 4.64 |
| | 5 | flat | 0.2 | 40 | 3196 | 6.08 |
| | 6 | on edge | 0.2 | 40 | 3162 | 4.37 |
| | **7** | **flat** | **0.2** | **80** | **2898** | **6.08** |
| | 8 | on edge | 0.2 | 80 | 2956 | 4.37 |
| **HD PLA Green** | 1 | flat | 0.1 | 40 | 5036 | 5.97 |
| | 2 | on edge | 0.1 | 40 | 6916 | 4.65 |
| | 3 | flat | 0.1 | 80 | 4924 | 5.97 |
| | 4 | on edge | 0.1 | 80 | 6590 | 4.65 |
| | 5 | flat | 0.2 | 40 | 3192 | 6.07 |
| | 6 | on edge | 0.2 | 40 | 3615 | 4.65 |
| | **7** | **flat** | **0.2** | 80 | **3134** | **6.08** |
| | 8 | on edge | 0.2 | 80 | 3451 | 4.65 |
| **Impact PLA Grey** | 1 | flat | 0.1 | 40 | 5037 | 5.98 |
| | 2 | on edge | 0.1 | 40 | 6916 | 4.65 |
| | 3 | flat | 0.1 | 80 | 4835 | 5.98 |
| | 4 | on edge | 0.1 | 80 | 6360 | 4.65 |
| | 5 | flat | 0.2 | 40 | 3222 | 6.07 |
| | 6 | on edge | 0.2 | 40 | 3615 | 4.65 |
| | **7** | **flat** | **0.2** | 80 | **3077** | **6.08** |
| | 8 | on edge | 0.2 | 80 | 3390 | 4.65 |
| **Fiber wood** | 1 | flat | 0.1 | 40 | 5039 | 5.98 |
| | 2 | edge | 0.1 | 40 | 6900 | 4.65 |
| | 3 | flat | 0.1 | 80 | 4737 | 5.98 |
| | 4 | edge | 0.1 | 80 | 6611 | 4.65 |
| | 5 | flat | 0.2 | 40 | 3195 | 6.07 |
| | 6 | edge | 0.2 | 40 | 3615 | 4.65 |
| | **7** | **flat** | **0.2** | **80** | **3036** | **6.08** |
| | 8 | edge | 0.2 | 80 | 3515 | 4.65 |
| **Extruder BDP Flax** | 1 | flat | 0.1 | 40 | 5039 | 5.9 |
| | 2 | edge | 0.1 | 40 | 6916 | 4.65 |
| | 3 | flat | 0.1 | 80 | 4739 | 5.9 |
| | 4 | edge | 0.1 | 80 | 6611 | 4.65 |
| | 5 | flat | 0.2 | 40 | 3178 | 6.08 |
| | 6 | edge | 0.2 | 40 | 3615 | 4.65 |
| | **7** | **flat** | **0.2** | **80** | **3016** | **6.08** |
| | 8 | edge | 0.2 | 80 | 3515 | 4.65 |
| **Extruder BDP Pearl** | 1 | flat | 0.1 | 40 | 5040 | 5.98m |
| | 2 | edge | 0.1 | 40 | 6900 | 4.65m |
| | 3 | flat | 0.1 | 80 | 3618 | 5.98m |
| | 4 | edge | 0.1 | 80 | 6720 | 4.65m |
| | 5 | flat | 0.2 | 40 | 3195 | 6.08m |
| | 6 | edge | 0.2 | 40 | 3632 | 4.65m |
| | **7** | **flat** | **0.2** | **80** | **3036** | **6.08m** |
| | 8 | edge | 0.2 | 80 | 3515 | 4.65m |

A comparison in terms of printing time of all analyzed materials is shown in Figure 1. It can be seen that the shortest printing time is for experiment 7, flat orientation of the sample, in the case of all studied materials. The longest printing time was obtained for the parts printed in experiment number 2, whose printing parameters were: on edge orientation, 0.1mm layer thickness, 40mm/min deposition speed.

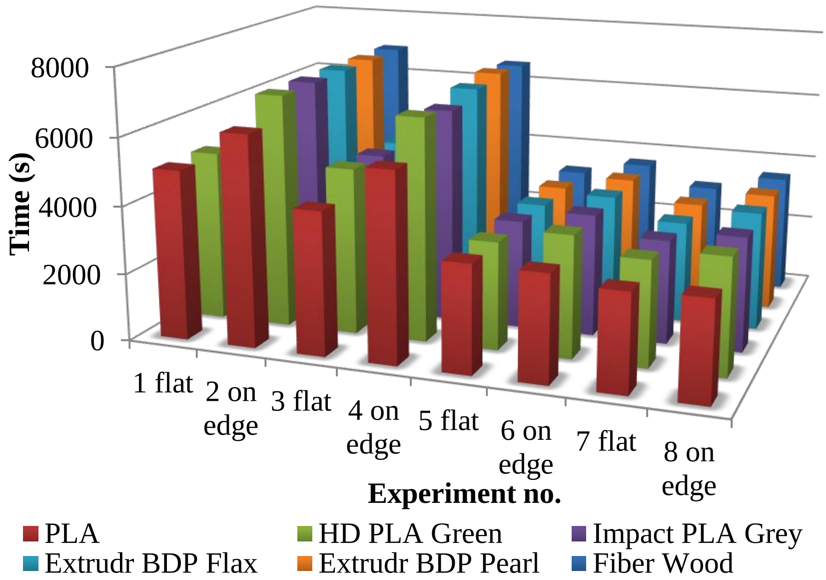


Fig. 1. Printing time required to realize a sample

The economic indicator, *the amount of material consumed to print a sample*, shows the lowest values in the case of even experiments, with the orientation of the samples on the edge. The amount of material (Figure 2) needed to print a sample oriented on edge about 4.6m and for flat orientation about 6m, the effect of this difference being discussed and justified above.

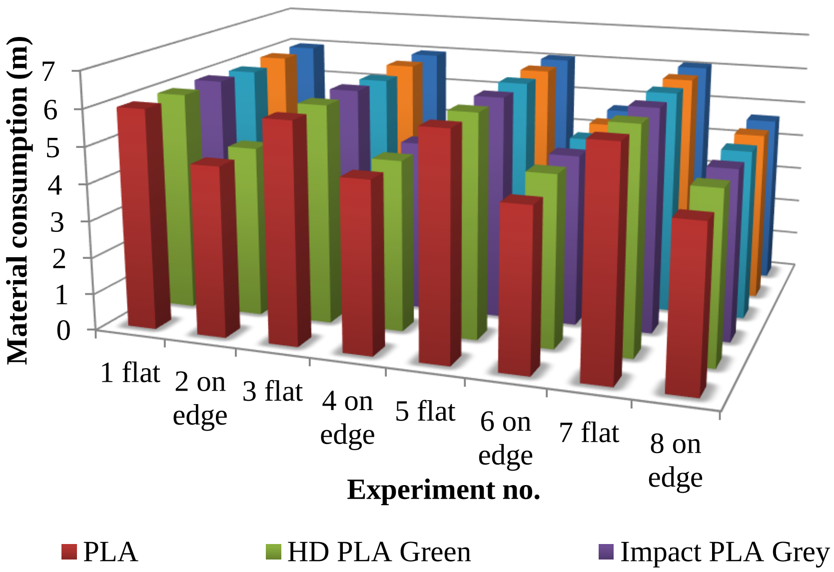


Fig. 2. The amount of material needed to print a sample

The input parameter - *layer thickness* has a huge impact on the 3D printed objects quality. It must not exceed the diameter of the nozzle. The thinner the layer, the higher the accuracy and fin detailed 3D printed objects will be obtained. A thin layer thickness is preferable to be applied only to print small objects, due to the fact that the printing time will increase significantly. But, sometimes is better to set a high layer thickness than the nozzle because the layers will be more connected and the printing time will be much shorter. Also, this objects printed with a high layer thickness tend to be more durable and don't crack.

Another input parameter take into account is the *deposition speed*. Reducing the layer deposition speed can significantly increase the quality of 3D FDM printing. In this way, the extruder will have more time to do a

better job, especially on the corners and edges. Also, the filament will stick better and will have more time to cool, which should prevent it from spilling.
Another parameter that significantly influences the economic factors and the parts performances from biodegradable materials is the *infill degree*. With the decrease of the infilling degree, the economic factors will have to gain, but the mechanical performances will decrease in direct proportion. In this situation, it is up to the designer who depending on the customer's requirements will choose a high-performance product for applications that involve mechanical stresses or a lower-performance product that can be used successfully for example on aesthetic models. Due to the fact that the present paper aimed at obtaining parts with high mechanical characteristics, it was opted for infilling degree 100%.
During the sample printing process, can be observed that if *printing temperature* is sated too low, this will affect the printing process, the adhesion between the filaments and implicitly the deposited layers will be missing or even make the filament impossible to be extruded. An over temperature will lead to energy waste (regarding from economic point of view) but more important the decrease of material performance (regarding from mechanical point of view), due to the fact that it has a much lower melting point than conventional plastics, the structural stability deteriorating above the melting temperature, which usually coincides with the printing temperature. Other trends that can be easily observed with increasing printing temperature are to spill, bend and wrinkle.

## 4. CONCLUSIONS

Based on analysis of experiments and previous researches it is confirmed that the printing preferences affect products both from technical and economical point of view. These results conclude the necessity to conduct further and deeper research with more detail printing properties involved.
In the present study, the obtained samples by using FDM, are significantly influenced by process parameters that can be controlled directly or indirectly before the printing of the model begins. Selecting the optimal printing parameters is quite difficult, if the aim is to obtain a sample/part with the highest possible mechanical characteristics and also to take into account economic efficiency. From an economic point of view, the next conclusions can be drawn:
- for simple part geometries, are recommended to follow the economic indicator, manufacturing time, as the longer it is, usually gives a higher resistance part and in some cases even a higher precision and surface quality;
- the manufacturing time indicator becomes very important when it is desired to obtain a complex prototype in a short time, therefore this indicator is closely related to the requirements of the client who decides whether he wants a high-performance sample/part or one with limited functional properties;
- the economic indicator, amount of material used, becomes important when complex models are made, due to the additional need to build and support the model.

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