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Optimization of influence parameters for 3D printing using statistical methods

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Abstract
The aim of this research was to develop a method that would allow users of 3D printers to optimize the configuration of the parameters that influence the technological process, given that one of the problems they face is the deformation of thin products. The variability of the parameters that modify the results of 3D printing leads to the need to use a statistical method that, by application, allows the choice of the best configuration option. In this sense, the parameters that can be modified were established, namely: working temperature, nozzle diameter, thickness of the deposited layer and printing speed. Experiments have confirmed that the method can be used successfully.
Keywords: *3D printing, Optimization of influence parameters, Design of experiments.*

1. Introduction

FDM, 3D printing, has become a widely used technology. Intense research has allowed the process to innovate so that it becomes effective. Thus, the possibilities to create unique models, very quickly and cheaply led to a wide spread. The development manifested itself both in the field of equipment and materials used and in the field of increasing the complexity of the types of products made. Research has led to new opportunities to increase working speed, increase working accuracy, reduce costs. With the diversification of products, new challenges have arisen for users.

Thus, the appearance of deformations in long and thin pieces was identified [1]. The processes of bending, rolling and transforming the shape, which appeared when the parts cooled, can be identified. The minimization of these effects is the object of this research paper. The material used in the experiments was polylactic acid (PLA). The properties of the material largely determine its behavior during the cooling process [2] but it can be seen that this behavior is also influenced by the configuration parameters of the process. Extensive research in the field of stress bending by Jaya et all (2016) [3], Teoh et all (2018) [4], Selvaraj et all (2021) [5].

The multitude of factors that influence the results of 3D printing cause the process to be affected many times and the effects to be unpredictable. This leads to loss of material, time and increased production costs. In this way, a statistical analysis of the influence of the factors that determine the unpredictability of the results becomes useful and can be a starting point in optimizing the configuration of 3D printing machines. Thus, Peng et all (2014) [6], Schaechtl et all (2016) [7], Sheoran and Kumar (2020) [8] used different statistical methods in their research on 3D printing. Krotky et all (2016) [9], researched deformations that occur during cooling and reheating of the work table.

The present paper aims to investigate the influence of the configuration factors of the 3D printing process, namely the working temperature T [^{o}C], the nozzle diameter D [mm], the thickness of the deposited layer k [mm] and the printing speed V [mm / s], on the deformation of a thin sample from PLA.

2. Methodolgy

Deformation of the printed material occurs when it cools from the temperature at which it is deposited to the ambient temperature. In this sense, tests were performed, with different configurations, and then they were measured on the control table. The planning of experiments for several parameters having several levels, considering all the possibilities, requires very laborious statistical calculations. For this reason, limiting the number of parameters in the process configuration is absolutely necessary. For this purpose, a preliminary research is required to determine the importance of the identified parameters in influencing the desired result. Also, for an optimal economic configuration, it would be useful to limit the possibility of selecting the number of values (levels) that these parameters can adopt.

In order to verify the deformation of the samples, several prints were performed according to Fig. 1.

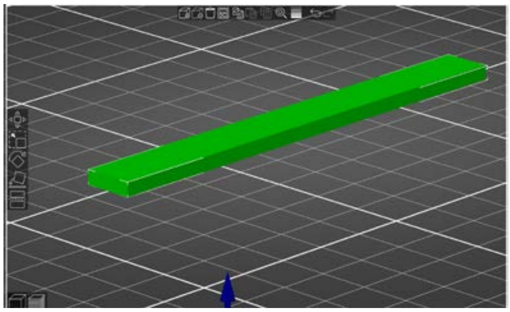

Fig. 1 Setting the sample size (3x10x100 [mm]).

The configuration of the parameters was done by modifying two factors at a time, the other two, remaining fixed. Thus, a relationship was obtained between the two modified factors and the result. The graphs regarding the influence of the two factors were then drawn, obtaining a classification of them according to the influence they have on the result, aiming at minimizing the deformation.

3. Experiments

The experiments were performed on the Prusa i3 MK3S + printer. The software used was Catia V5 for creating the geometry of the sample, PrusaSlicer2.3.3 for choosing the working mode and Minitab for interpreting the results. The deformation of the samples was measured using a Mitutoyo 2046SB comparator with a resolution of 0.01 mm. The measurement was made according to Fig. 2, at 10 cm from one end of the sample, keeping the other end fixed on the control table with a flange, 8 hours after printing. The test material was PLA. The design of the experiments was based on the use of statistical methods and graphical interpretations.

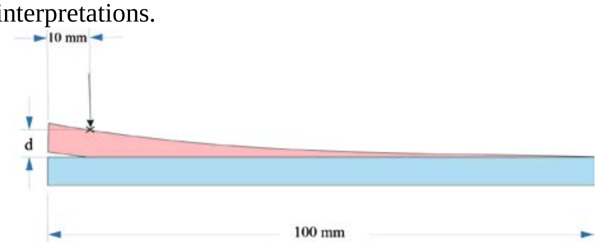

Fig. 2 Modul de masurare si dimensiunile probelor

The influencing factors and their values were chosen according to table 1.

Table 1: The values of the influence parameters used in the experiments

Parameters	***Value 1***	***Value 2***	***Value 3***
Temperature T [^{o}C]	200	215	230
Nozzle diameter D [mm]	0.2	0.4	0.5
Thickness of layer k [mm]	0.05	0.15	0.30
Print speed V_p [mm/s]	20	30	-

The chosen material (PLA filament) has the following properties: diameter 1.75 mm, density 1.24 g / cm3, tensile strength 59 MPa, elastic modulus 3500 MPa, Poisson's ratio 0.36, Young modulus 1280 MPa, Rockwell hardness 88 HRC. [10].

All experiments were performed under identical conditions twice. The samples were measured and the result consisted of the arithmetic mean of the two values. The experiments whose results had values exceeding the difference of 20% between them, were repeated.

4. Results

The results of the measurements have been recorded and are shown in the tables below:

Table 2: Values of deformation depending of temperature and nozzle diameter

Temperature T [^{o}C]	***Nozzle diameter D [mm]***	***Thickness of layer k [mm]***	***Print speed V_p [mm/s]***	***Deformation d [mm]***		
				Test 1	***Test 2***	***Media d_v***
200	0.2	0.15	30	0.98	1.01	0.995
200	0.4	0.15	30	0.83	0.84	0.835
200	0.5	0.15	30	0.8	0.79	0.795
215	0.2	0.15	30	1.12	1.09	1.105
215	0.4	0.15	30	0.99	1.03	1.01
215	0.5	0.15	30	0.91	0.95	0.93
230	0.2	0.15	30	1.27	1.31	1.29
230	0.4	0.15	30	1.14	1.12	1.13
230	0.5	0.15	30	1.04	0.98	1.01

Table 3: Values of deformation depending of temperature and thickness of layer

Temperature T [^{o}C]	***Nozzle diameter D [mm]***	***Thickness of layer k [mm]***	***Print speed V_p [mm/s]***	***Deformation d [mm]***		
				Test 1	***Test 2***	***Media d_v***
200	0.4	0.05	30	0.75	0.76	0.755
200	0.4	0.15	30	0.83	0.84	0.835
200	0.4	0.30	30	0.92	0.90	0.91
215	0.4	0.05	30	0.84	0.88	0.86
215	0.4	0.15	30	0.99	1.03	1.01
215	0.4	0.30	30	1.08	1.11	1.095
230	0.4	0.05	30	0.95	0.93	0.94
230	0.4	0.15	30	1.14	1.12	1.13
230	0.4	0.30	30	1.21	1.26	1.235

Table 4: Values of deformation depending of temperature and print speed

Temperature T [^{o}C]	***Nozzle diameter D [mm]***	***Thickness of layer k [mm]***	***Print speed V_p [mm/s]***	***Deformation d [mm]***		
				Test 1	***Test 2***	***Media d_v***
200	0.4	0.15	20	0.80	0.80	0.8
200	0.4	0.15	30	0.83	0.84	0.835
215	0.4	0.15	20	0.92	0.91	0.915
215	0.4	0.15	30	0.99	1.03	1.01
230	0.4	0.15	20	1.01	1.04	1.025
230	0.4	0.15	30	1.14	1.12	1.13

For a greater accuracy of the results, two tests with the same configuration were performed, the final result being considered the arithmetic mean between the two values dy [mm]. The configuration values were modified at two of the parameters, the other two being kept fixed at the average value. In this way it was possible to observe the influence of the modified factors on the deformations of the product. In table 3,4,5 certain configurations are repeated. No new measurements were made for these configurations, so that the results could be interpreted uniformly and be consistent with each other. Next, the Minitab program was used to interpret the results, with the help of which the graphs were drawn representing the influence that 2 parameters have in common on the deformations that appeared in the samples after their cooling. These are shown in Figures 2, 3 and 4.

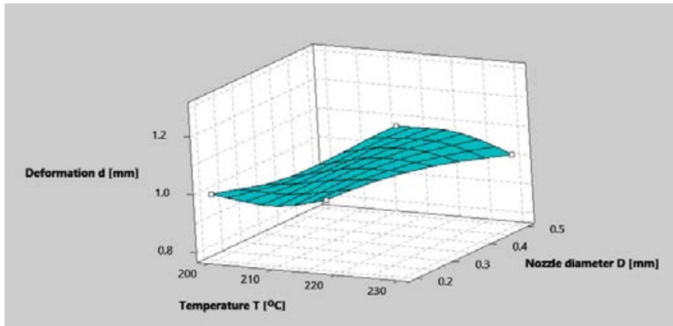

Fig. 3 The influence of temperature and nozzle diameter on the deformation of the product

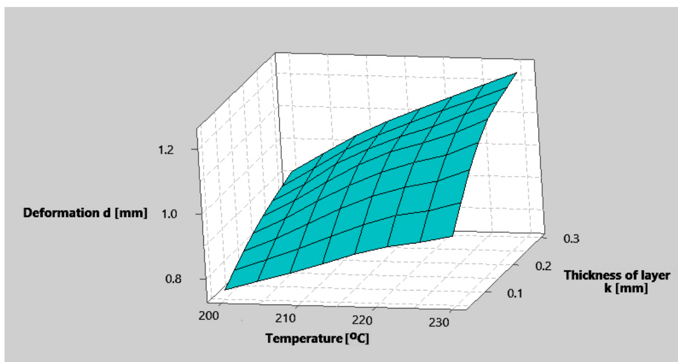

Fig. 4 The influence of temperature and layer thickness on the deformation of the product

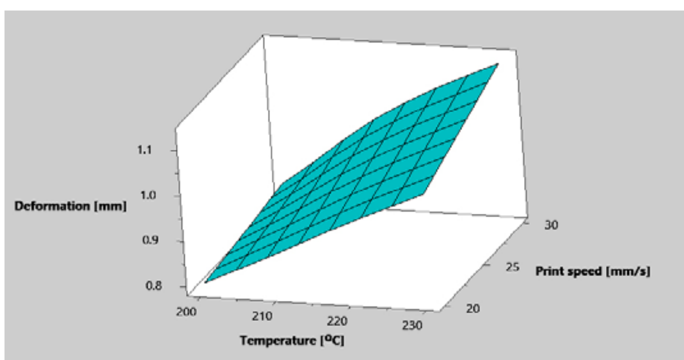

Fig. 5 Influence of temperature and printing speed on product deformation

5. Conclusions

From the analysis of the graphs, it can be seen that the printing speed has the least influence on the deformation appeared in the printed product, in relation to the temperature. Increasing the deformation of the samples occurred with increasing temperature, increasing the deposition layer, increasing the printing speed and decreasing the nozzle diameter.

In conclusion, the method can be applied with relatively little evidence on any parameter influencing the technological process, giving the user the possibility to optimize its configuration.

The purpose of this paper was to demonstrate that by statistical methods, 3D printing can be optimized in order to minimize the deformation occurred when printing thin parts, after cooling them.

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