Fusion deposition modeling (FDM) 3D printing parameters correlation: An analysis of different polymers surface roughness

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Abstract. One of the most popular methods for manufacturing new products is FDM (Fusion Deposition Modeling). In which two segments are established: industrial and desktop. The latter group has had notable growth in recent years. One of the disadvantages found in this method is its surface finish, which presents a remarkable roughness. In this research work, the correlation that exists in the printing configuration parameters and the resulting roughness analyzed by means of the ISO 4287-1997 standard will be analyzed. The configuration parameters to take into account are: layer height, printing speed. The materials to be analyzed are: PLA, PET-G, ASA, Wood Filament, TPU. Besides, the equipment used is a Prusa brand desktop printer with the manufacturer's software. What is more, the acceleration, extruder temperature and bed recommended in the software are used for each material. Hence, the constant printing characteristics are: perimeter thickness, 10% infill, extrusion diameter 0.4 mm. The objects to be evaluated are printed and the roughness on the walls of the Z axis, base plane and upper plane is measured. This analysis was carried out by means of the correlation by the use of the analysis of variance ANOVA. The printing speed does not affect the resulting surface roughness in any plane, while the layer height only shows a significant correlation (<0.05) with the roughness of the lateral plane of the samples.

Keywords: 3D printing, surface roughness, polymers, correlation, Anova.

1. Introduction

3D printing has made great strides in the manufacturing industry, making it ideal for low production processes or prototyping machining [1]. Additive manufacturing challenges the production industry, making possible to produce designs that cannot be made on CNC. New design methods and new engineering needs are supported by these new manufacturing methods [2].

The 3D printer revolution can reach not only factories, but also homes. The desktop printer has become popular in recent years allowing people to buy an affordable machine and use it in their house.
Desktop printers have an annual usage increase of 170% [3]. In the desktop printers the more popular are the FDM (Fusion deposited modelling). The most popular desktop printers are using the FDM (Fusion deposited modelling) method, which uses polymers as a deposition material, generally.

The new modular concept for manufacturing initiated with the desktop printers can be used not only in the home, industries, laboratories and academia use them. Although all the advantages 3D printers bring to users, there are limitations in novel design production. Thus, the manufacturing process is slow, the price increases with each replica, the mechanical aspects are not excellent, as it is done by the adhesion of polymers that can break depending on the mechanical stress that can be applied to it.

Another weakness of 3D printing manufacturing based in FDM is the superficial roughness. The research in other states that some of the studies show improvements in the post processing of the product, otherwise some research find out the correct setup in order to decrease the roughness [4]. The superficial roughness is important in many aspects, such as a professional finish, molding procedures, the friction than can be caused if the new product is used into a mechanism.

In order to take advantage of the infinitive applications for 3D printing, the user needs to know how to setup optimal parameters for every material, so the roughness, strengthens, size will be the predicted. In addition, is important to lower the time, energy consumed and the material wasted.

2. Materials and Methods

2.1. Investigation methods

The investigation is both quantitative and deductive. Further, the strategy used is experimental and transversal [5]. The data collecting method was done through laboratory testing and it was used bibliographic research, too.

2.2. Materials and parameters

The materials selected for the research were TPU, PLA, Wood Filament, ASA, PET-G. The group of materials was selected under three parameters: bibliographic research, stock in the market and usability. These materials were the most stable and suitable for non-enclosure printers [6, 7].

The constant printing characteristics are perimeter thickness, 10% infill, extrusion diameter 0.4 mm. The print speed selected was 30 mm per second and 60 mm per second. That speed was used in each sample for: speed inside, outside and filled [3, 8]. The other variable was layer height, which depends on the machine capacity. This could be 0.05 mm up to 80% of the nozzle size. In this investigation, a common size of 0.4 mm nozzle was used. The height of layer used was 0.1 and 0.2 mm. In Table 1, it was described the information and parameters of printing configuration recommended by the users experience and the machine manual.

| Material         | Speed min | Speed max | Layer height min. | Layer height max. |
|------------------|-----------|-----------|-------------------|-------------------|
| TPU              | 30 mm/s   | 60 mm/s   | 0.1 mm            | 0.2 mm            |
| PLA              | 30 mm/s   | 60 mm/s   | 0.1 mm            | 0.2 mm            |
| Wood Filament    | 30 mm/s   | 60 mm/s   | 0.1 mm            | 0.2 mm            |
| ASA              | 30 mm/s   | 60 mm/s   | 0.1 mm            | 0.2 mm            |
| PET-G            | 30 mm/s   | 60 mm/s   | 0.1 mm            | 0.2 mm            |
2.3. Samples dimensions
The samples were cubes of 4*4*4 cm, model based in [8,9]. The authors mention that some inclination or shape in the sample should create a different measure in the superficial roughness. The focus in this investigation is the setup parameters and their incidence in the roughness, for that reason the samples are made with fully vertical and horizontal planes.

2.4. Null hypothesis
There is no relation between variables in 3D printing process (speed and layer height) and the superficial roughness (measured in the three planes first layer, last layer and height layer).

2.5. Surface roughness testing
Mitutoyo SJ 210 equipment shown in figure 1 was used in order to comply with ISO 4287-1997. The roughness test is carried out on the specimens of the 5 different materials in each of the axes; base, height and top layer. Once the tests were performed on the 14 samples, the graphs and the values of Ra, Rz and Rp (as shown in Figure 1) were obtained, which describe the average roughness, the roughness between the highest peaks and the roughness in the valleys.

![Image](Figure 1. Mitutoyo SJ 210 roughness meter)

![Image](Figure 2. Graph and values shown by the roughness meter)

In table 2 the average values for each sample were tabulated.
2.6. Usage of data and statistical test
All the Ra values were tested to prove that the group meets the conditions of normality. Then, each parameter (Layer height and speed) was compared with every result of Ra in the three planes. ANOVA test was selected to establish correlation between the data.

Table 2. Average measures per each sample

| Material      | N° sample | Layer height (mm) | Speed (mm/s) | Top plane | Lower plane | Lateral plane |
|---------------|-----------|-------------------|--------------|-----------|-------------|---------------|
| PLA           | 1         | 0,2               | 60           | 6,45      | 11,87       | 12,79         |
|               | 2         | 0,1               | 60           | 2,83      | 16,48       | 8,22          |
|               | 3         | 0,2               | 30           | 5,03      | 15,67       | 12,15         |
|               | 4         | 0,1               | 30           | 3,46      | 15,83       | 6,94          |
| Woodfilament  | 5         | 0,2               | 60           | 3,74      | 9,77        | 13,55         |
|               | 6         | 0,1               | 60           | 5,18      | 9,8         | 8,61          |
|               | 7         | 0,1               | 30           | 6,11      | 9,84        | 8,99          |
|               | 8         | 0,2               | 30           | 6,82      | 8,96        | 12,84         |
| PETG          | 9         | 0,1               | 30           | 5         | 17,31       | 6,98          |
|               | 10        | 0,2               | 30           | 6,55      | 17,26       | 12,35         |
| ASA           | 11        | 0,1               | 60           | 4,51      | 14,88       | 7,6           |
|               | 12        | 0,2               | 30           | 3,76      | 15,81       | 13,09         |
| TPU           | 13        | 0,1               | 30           | 1,15      | 6,3         | 7,64          |
|               | 14        | 0,2               | 60           | 1,72      | 7,05        | 14,51         |

3. Results and Discussion
Table 3 shows the results from Anova test using the relationship between Layer height and Ra Values. In addition, Table 4 shows the results from Anova test using the relationship between Speed and Ra Values.

Table 3. Anova test comparing layer height and Ra

|                | Sum of Squares | df | Mean Square | F      | Sig. |
|----------------|----------------|----|-------------|--------|------|
| Ra Top plane   | Between Groups | 2,428 | 1 | 2,428 | 0,758 | 0,401 |
|                | Within Groups  | 38,458 | 12 | 3,205 |        |      |
|                | Total          | 40,885 | 13 |        |        |      |
| Ra Lower plane | Between Groups | 1,172 | 1 | 1,172 | 0,070 | 0,796 |
|                | Within Groups  | 200,871 | 12 | 16,739|        |      |
|                | Total          | 202,043 | 13 |        |        |      |
| Ra Lateral plane| Between Groups | 94,121 | 1 | 94,121| 150,598 | 0,000 |
|                | Within Groups  | 7,500 | 12 | 0,625 |        |      |
|                | Total          | 101,620 | 13 |        |        |      |
Table 4. Anova test comparing speed and Ra

|                | Sum of Squares | df | Mean Square | F      | Sig.  |
|----------------|---------------|----|-------------|--------|-------|
| Ra Top plane   | Between Groups| 1  | 2.512       | 0.785  | 0.393 |
|                | Within Groups | 12 | 3.198       |        |       |
| Ra Total       | 40,885        | 13 |             |        |       |
| Ra Lower plane | Between Groups| 1  | 2.169       | 0.130  | 0.725 |
|                | Within Groups | 12 | 16,656      |        |       |
| Ra Total       | 202,043       | 13 |             |        |       |
| Ra Lateral plane| Between Groups| 1  | 7,845       | 1.004  | 0.336 |
|                | Within Groups | 12 | 7,815       |        |       |
| Ra Total       | 101,620       | 13 |             |        |       |

Although there are differences between the Ra values in the three planes analyzed, no significant difference is shown in any of the materials tested in their upper and lower planes. The variation of the parameters layer height and speed do not affect the surface roughness of the upper and lower planes. In the lateral planes (Z axis) it is shown that there is a significant correlation between the variation of the layer height and the surface roughness of the sample, regardless of whether it is in one material or another. On the other hand, the speed parameter does not affect the surface roughness of the lateral planes in any material.

Refer to other results, on print roughness analysis by the FDM method, was carried out a study with variables such as speed, nozzle type and layer height. The roughness analysis is done at 0° to 45° and 90° [4]. The material used is PLA. The researcher obtains that the best characteristic is given in a nozzle width of 0.3 mm and a layer height of 0.2 mm and the roughest element was formed with a nozzle of 0.5 mm and a layer height of 0.1 mm. This is because the nozzle expels more material, because of its thickness, and the space in which it is distributed layer by layer is smaller, allowing tiny folds of plastic to form and these generate more roughness to the object.

Also, parameters such as nozzle temperature, printing speed and layer height are considered. The material used in the study is PLA [9]. It is determined that the surface roughness is defined at 66% by the value given to the height of layer, while the other two variables such as speed (measured from 30 to 60 mm / s) provides 24% and temperature (measured from 190 ° C to 215 ° C) with 6.6%. The parameters were measured up to a layer height of 0.3 mm, the higher this number the wider the roughness.

4. Conclusion
The present study found that the best setup for PLA was 0.1 mm layer height and 30mm/s in order to achieve the lowest surface roughness on the lateral planes of the cubes used as samples. Further research is needed comparing other parameters as nozzle temperature, printing time and extrusion diameter will give deeper understanding about the behaviour of the surface roughness. In addition, vary the planes angles should be tested in order to define more interactions between the results.

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