Analysis of the Influence of the Layer Height on the Strength of 3D Printed Structures

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Abstract. *This paper aims to analyze the influence of layer height on the strength of the final product obtained based on 3D printing technology. This paper considers a comparative study between FDM and SLA printing, the use of an Ender 3 Pro printer from Creality (FDM type-PLA material) to obtain test specimens and, to verify the strength of the specimens with a dynamometer. Current studies bring a rich contribution to the study and understanding of the importance of using 3D printing technology in all technical fields and beyond. The diversification of printing methods, of the materials, lead, inevitably, to the need to study them to optimize and improve the printing processes. This paper tries to bring a contribution in this direction, in terms of the practical knowledge of our group of work. The conclusion of this study highlights the fact that the printing height leads to a decrease in the tensile strength of the final product.*

Keywords: 3D printing, PLA, dynamometer, layer.

Introduction

All 3D printing processes build objects layer by layer. Due to the additive nature of 3D printing, the thickness of each layer determines the resolution of a print like the number of pixels determines the resolution of a screen. The lower height of the layer usually leads to parts with smoother surfaces. The disadvantage is that the start height influences the completion time of the product.

If the height of the layer is the same as the diameter of the nozzle, the shape of the extruded filament will be perfectly circular. As the height of the layer decreases, due to the constant diameter of the nozzle, the extruded filament is flattened, thus creating a larger area of contact with the subsequent layer. Also, decreasing the height of the layers involves increasing their number to achieve the same dimensions of the printed object.

This paper aims to analyze the effects of the height of the printing layers on the strength of printed structures. It is assumed that decreasing the height of the layers would lead to increased resistance.

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3D printers build the piece one layer at a time but use different methods. These methods have a significant influence on the molecular structure of the printed part. For example, FDM (melt molding) printers melt plastic over another layer. Between these layers the phenomenon of mechanical adhesion takes place.

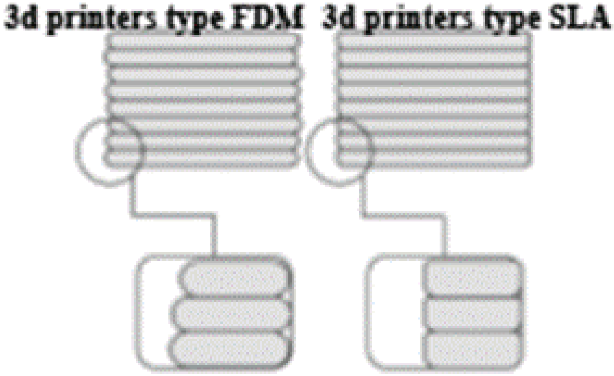

Figure no. 1. Comparison between printed layers with FDM technology and coated layers with SLA technolog

According to current studies (Grames, E., 2020; Cain, P., 2019), the possibility of printing parts using a different thickness for layers helps to shorten the printing time. Thus adjusting the printer to use a thicker layer for printing, the part completion time is considerably shortened. Generally, using a thicker layer for printing, the piece loses its fine appearance, the layers being easily visible (lower quality resolution). Although printing using thinner layers costs more time, the advantage is the increased resolution of the part.

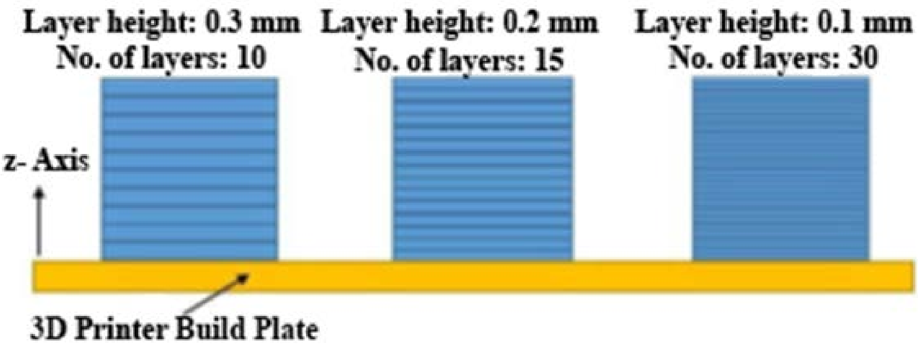

Figure no. 2. Comparison between the numbers of layers concerning their thickness

A little known thing in the 3D printing community is that most 3D printers have a much better vertical resolution than the horizontal ones. This is because the movement on the Z-axis is much rarer than the movement in the XY plane. The movement on the Z-axis takes place only between the transition from one layer to another and in the intermediate printing sequences on the XY plane.

In terms of strength, the thinner the layers, the more dispersed the stress in them. Of course, this stress can be negligible depending on the shape of the piece and the stresses to which it is exposed.

Filament-based 3D (FDM) printers offer the user the opportunity to choose the most convenient compromise depending on the case, as follows:

- Reduced printing time -> Low layer resolution -> Low strength
- High print time-> High layer resolution -> High strength

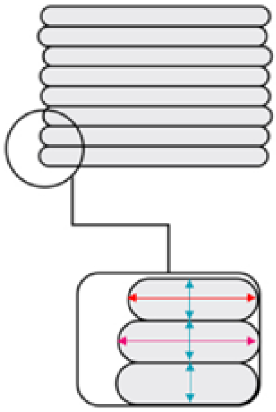

Figure no. 3. Graphical comparison between the XY plane error and the Z-axis error

There are some obvious shortcomings in FDM 3D printing:

- Due to errors during printing as well as calibration error before printing, spaces can be created where the layers did not stick together completely. Common errors that can cause such results are incorrect airflow, incorrect calibration, hitting the printer while printing, hardware, or software malfunctions.
- Due to the circular section of the filament, empty spaces are formed between the filament paths which reduces the resistance of the part.
- The molten filament extruded by the 3D printer nozzle has a circular section. This involves the connection (gluing) with other filament paths, in only 4 tangent points. (If the height of the printing layer is the same as the diameter of the nozzle) This demonstrates the reason why the height of the layers and implicitly of the diameters of the extruded filaments influences the strength of the printed object. If the height of the layers decreases then their number increases but also the number of filament traces increases. Thus, the number of contact areas is increased, increasing the amount of plastic glued.

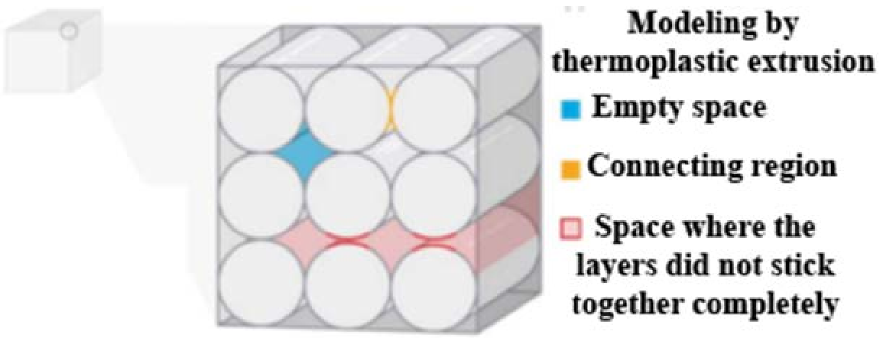

Figure no. 4. Common defects of FDM 3D printing

Therefore, objects made by FDM technology are anisotropic.(Validating Isotropy in SLA 3D Printing, 2020, August) Printed objects have different mechanical properties depending on the direction of application as opposed to objects produced by printing with resin or injecting plastics into the mould.

This project starts from the hypothesis that decreasing the height of the printing layers of 3D printed structures increases the tensile force required to detach the layers.

Materials and Methods

The method chosen for the experiment is the tensile test of a printed part with layers of different heights. The part is designed to have a recessed area and one in which the force will be applied. It is also designed to impose breakage in the middle area. To ensure the accuracy of the results and ease of calculations, the structure is printed with a 100% fill percentage. For each height (0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm) of the printing layer, 3 copies were printed. The equipment used: Creality Ender 3 Pro Printer (FDM); PLA filament with a diameter of 1.75mm; Digital dynamometer.

Creality Ender 3 Pro Printer (FDM): print volume: 220x220x250mm; accuracy: ± 0.1mm; nozzle diameter: 0.4mm; bed temperature: ≤ 110 ° C. Polylactic acid (PLA) stands out from other thermoplastic polymers in that it is derived from renewable sources such as corn starch or sugar cane. Biomass-derived plastics, such as PLA, are also called bioplastics. Also, polylactic acid (PLA) is one of the most common plastics used in thermoplastic extrusion molding (FDM) technology. PLA is classified as thermoplastic polyester due to its behavior at high temperatures. Thermoplastic materials have a melting point of 150-160 degrees Celsius. A dynamometer is a device for measuring force, the moment of force, or power. With the help of this instrument, the traction force applied to the samples is measured. Other secondary tools are sampling shafts, vise, and weights.

Figure no. 5. Attach the sample to the vise

Figure no. 6. Complete measuring system

The samples were embedded in the vise with the help of a rod placed in one of the two holes (Figure 5), thus leaving only two degrees of freedom (cylindrical coupling).

The printed samples were subjected to a tensile force gradually applied on their Z-axis. To ensure the parallelism with the Z-axis and to reduce the chance of creating a moment of force (detachment of the layers achieved by bending), a connecting device between the sample and the dynamometer was created (Figure 6). This creates a pendulum effect that ensures the collinearity of the force.

Results and discussions

The use of the method and equipment described above led to the following results in tabular (Table no.1) and graphical (Figure no. 7) form.

Table no 1. Table of recorded values

Layer height [mm]	Weight [kg]	Weight [kg]	Weight [kg]
0.1	17.43	7.54	12.3
0.2	6.68	11.32	10.66
0.3	6.81	11.57	8.83
0.4	10.23	9.4	6.3

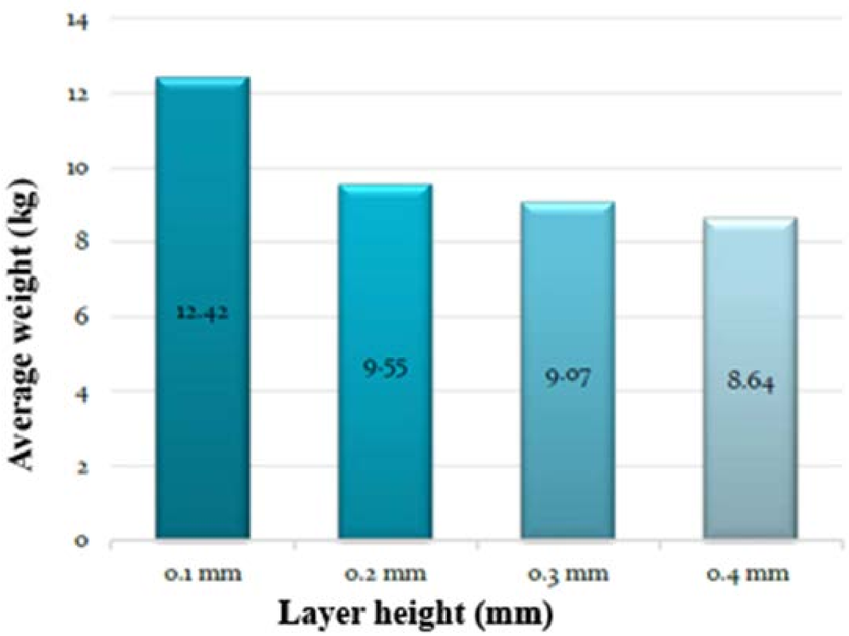

Figure no. 7. Column chart value average weight/layer height

Conclusion

Printing errors are destructive not by their existence, but by their variation between printing sessions (inconsistency of errors). It is necessary to reduce the variations of errors between prints, to be considered stable and thus negligible. According to the resulting graph, the inverse proportionality can be observed between the layer height and the load weight, confirming the initial hypothesis.

Acknowledgments

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