Experimental study on the settings of Delta and Cartesian 3D printers for samples printing

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Abstract. This paper presents the first part of the experimental procedures developed at the beginning of a larger research, consisting of printing, on two 3D printers, one parallel and one cartesian, of some test specimens, in different working conditions and with different settings of some parameters, and then investigation of the tensile and compressive behavior of the test specimens. The research was carried out on two sets of standardized samples, printed with three types of the commonly used and low-cost material, Polylactic acid (PLA), Carbon fiber PLA (CF-PLA), and Polyethylene terephthalate glycol (PETG). The purpose of the study is to create a database with the results obtained, which will be a working basis for future printings with these printer models, available in our laboratory, in order to understand the 3D-printed material behavior under certain available working conditions.

1. Introduction

In the last decades, due to multiple advantages and lower costs, the use of 3D printing in manufacturing processes is in a more and more quickly growing. At present, there are a large range of additive manufacturing technologies (AMT) or 3D printing processes, the most popular of them, together with the most common applications and materials, being presented in [1]. The most widely used 3D Printing technology, belonging to the category Material extrusion, of AMT, is considered Fused Deposition Modeling (FDM), or Fused Filament Fabrication (FFF), in special regarding its quickly and cost-effective possibility of producing plastic prototypes. But, this type of additive manufacturing technology is used, at present, not only to fabricate diverse and complex plastic prototypes but also to produce more and more final products, in different industrial sectors and in the most diverse areas.

The advantages of 3D printing over traditional manufacturing techniques (speed of fabrication, single-step manufacture, cost, risk mitigation, complexity and design freedom, customization, ease of access and sustainability), and the growth of the number of printers sold are exposed in [2]. Choosing the most suitable 3D printing process has to be made from different perspectives (like required material, characteristics of the end parts or certain process capabilities)as presented in [3]. If, initially, the most used 3D printers were that with a cartesian configuration, in recent years, Delta parallel printers have appeared and are widely used, considered more advantageous, from several points of view [4].

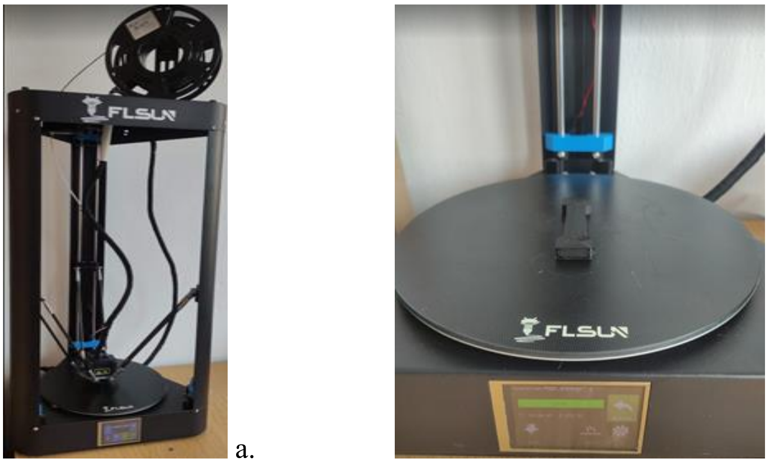
A large range of materials can be used for FDM printing, and other new materials appear as this technology becomes more and more widespread. The most popular and used is Polylactic Acid (PLA), along with many others as Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polyethylene Terephthalate (PET), Polyethylene Terephthalate Glycol (PET-G), Polyether Ether Ketone (PEEK) or High-Impact Polystyrene (HIPS), base materials or with various inserts, such as carbon fiber, to improve the properties of the filament. A comprehensive review on the characterization of the mechanical properties of the structures and materials used in the FFF process is presented in [5] considering an extensive number of experimental, computational and theoretical approaches.

With the increasing interest and use of 3D printing process, a lot of experimental research has been done, and numerous scientific articles have been published, each addressing, in a different manner, the 3D printing and testing of specific standardized test specimens mainly at traction and compression. An extensive state-of-the-art review regarding the optimization of the FDM additive manufacturing process in order to achieve the maximum tensile strength, through a comparative study with PLA, PC, PEEK and ABS is presented in [6].

Considering the results of the previous studies, as well as the available material capacities, we resorted to our own research, by using three types of filaments, various printing parameters and different working conditions, in order to establish the best 3D printing variants in our laboratory.The experimental study regarding the settings of Delta and Cartesian 3D printers, for printing two types of test specimens, is further presented in this paper. Their testing, on the tensile and compressive, and the results obtained, will be presented in another paper.

2. Technical specifications of 3D printers and software used

The two models of 3D printers, available in our laboratory, are part of the medium printing category, one being the FLSun QQ-S PRO Delta model, which guarantees speeds between 60-120mm/s on an area with a diameter of 260mm and a maximum height of 360mm, and secondly, the Cartesian model TEVO Tornado, which guarantees speeds between 60-150mm/s, with the printing platform of 300x300mm and height 400mm. These two printers have a 0.4mm extrusion nozzle or nozzle. The Delta printer has a much better print resolution than the Cartesian one, several upgrades on the controller side as well as motor drivers, which makes its motors more precise, but also much quieter during printing.

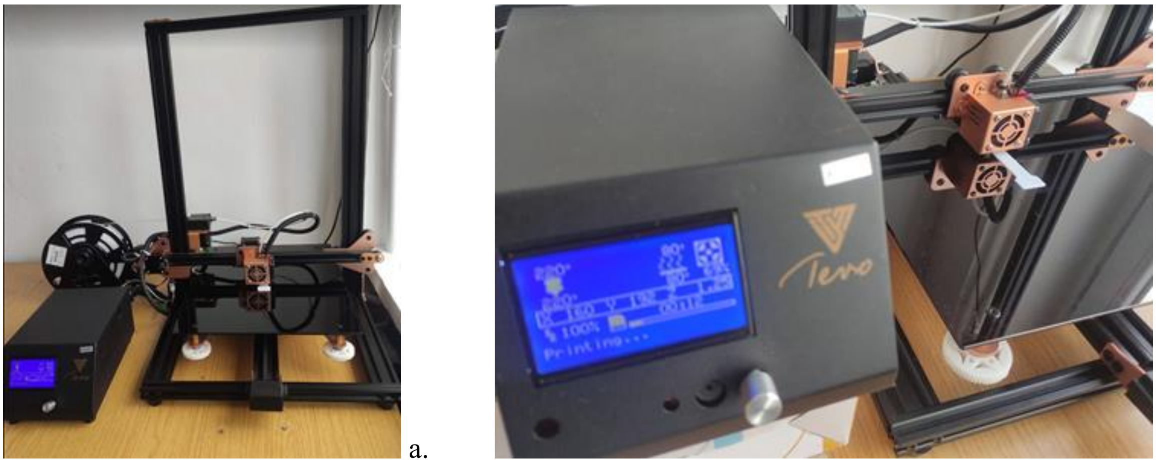


a. b.

Figure 1. Delta FLSun QQ-S PRO 3D printer and PLA sample.

The Delta FLSun QQ-S PRO 3D printer, shown in figure 1, during the printing of the sample, in large view in figure 1.a and with the sample printed in figure 1.b, allows you to select the speed during printing, increase or decrease the print speed, or increase or decrease the filament feed speed, if certain inconveniences occur, such as the inability to insert both filaments, as long as the nozzle allows its extrusion. The problem that may arise is with the filament insertion motor, the motor starting to jump steps. The controller also allows the temperature to rise or fall during printing, which allows us to increase the temperatures. The controller also allows us to raise or close the z axis at the beginning of printing to the bed on which it is printed, when the first layer is made, if the nozzle is too close to the bed, it can also rise 0.05 mm on the z axis whenever this is desired until a layer equal to the original layer in the printer settings is created. There is also the possibility to adjust the z-axis with the sensor in the printer, which can be easily mounted on the print head and to select the print bed height check setting in 21 points from the printer menu. This printer allows building layers of at least 0.05 mm, each such layer being created due to the trapezoidal screw and the motor that allows this printing resolution.

The Cartesian printer model Tevo Tornado, shown in figure 2, during the printing of the sample, in large view in figure 2.a and with the sample printed in figure 2.b, has the capacity of a layer thickness of 0.1mm; this resolution is given by the motor driver controllers, it can not be lower, only with an upgrade to TMC 2208 drivers that allow the movement of 256 microsteps/revolution . The controller of this printer does not allow us to change the temperature, speed or other details after printing, all remain exactly as in the program used.



a. b.

Figure 2. Tevo Tornado Cartesian 3D Printer and PET-G sample.

For both printers, the gcode creation software Ultimaker Cura 4.7.0 is used, the version used for its very good statistics, in which most of the gcode generation problems or other printing problems have been solved.

3. 3D printing settings

The work profiles for these two printers were set over approximately 6 months of use, with these profiles using approximately 80% of its print capacity for the Delta printer and 60% of its capacity for the Cartesian printer. These limitations have been introduced because, for higher speeds, to both models, a box for keeping temperature must be used for the printed filament, as it contracts and lifting off the printing bed. This problem leads, at best, to raise the corners of the part by about 0.5 mm, or, in the worst case, to detach it completely. Problems with filament contractions occur when any airflow enters the printing area, the filament tending to often detach from the Cartesian printer because it has a glass bed. The good adhesion temperature of the PLA filament is at least 60^{o}C, and for PLA with carbon insert and PET-G of 80^{o}C.

Often the layers at the beginning come off, as presented in figure 3, even due to the low temperature of the bed, because they suffer a rapid contraction due to the ventilator mounted to cool them, the propagation of airflow becoming much more pronounced in areas of angles below 90^o. This problem is often solved by raising the bed temperature, but it can also be solved by adding the "brim" function to the program. This creates successive layers in the first layer, and they attach the parts much better to the printing bed.

The filaments used for printing the samples are PLA, PET-G and PLA with 20% carbon fiber insertion. These filaments are from the printing area of these printers, so for the PLA filament the printing temperature is between 190-220ºC, each increase in temperature by 5ºC leading to an increase in speed by about 15 mm/s, all depending on the ambiental temperature in which are printed the samples.

Figure 3. Parts detached from the printing bed.

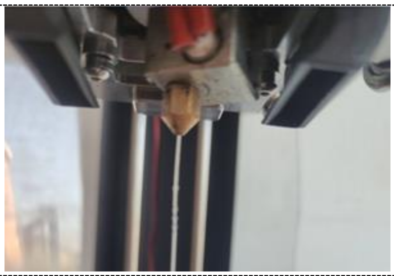


Figure 4. Lumpy on the filament.

In the settings for the Delta printer, with the use of PLA filament, a printing temperature of 225ºC was reached, a set speed of 85mm/s for the initial samples, the printing temperature for bed of 60 ºC, and for the first layer was set the temperature of 210ºC, because the speeds at this layer are up to 24.5mm/s.

For the Cartesian printer, the settings are slightly different, in this case, the printing temperature was 220ºC, the printing speed of 65 mm/s for all samples, the temperature for the printing bed of 60ºC, and the speed at the first layer of 20 mm/s.

The adhesion of the filament on the printer bed is different for the first layer, because the Delta has a layer of matte foil with holes pierced on the glass surface, for very good adhesion and preventing lifting up during printing, and on Cartesian is printed directly on the heated glass.

Both printers have, for both the nozzle heating resistance and the bed heating resistance, the PID use functions, these helping to keep the temperature around ±0.3 ºC, which is very important because it does not allow the production of very high temperature variations during printing. If it were a PWM type system, it, depending on the supply frequency, would act much too much above the set temperature, both during heating and when it is off and too cold. The same happens in the case of simple on-off hysteresis controllers, these being two-stage or on-off controllers, they have feedback that switches between two states, so there is no middle state, these controllers being systems with variable structure.

All samples were printed at an indoor temperature of 28ºC, except for the last cube sample, sample 3 from PLA CF, which was printed at an indoor temperature of 25ºC. It is very important that the print nozzle temperature to be stable, because any sources of air currents can cool the nozzle top from brass, copper, or steel, and may even cause the filament blocking in the extruder.

It was observed that the PET-G filament, after a period of printing time at an ambient temperature of 28ºC, absorbs moisture from the air, so that when the filament melts, the moisture in the filament reaching the extruder block, reaches the boiling point as a result, when it is pushed, it explodes into small particles, and the printed filament is no more uniformly applied.

For printing the second type of test specimen, the 20x20x20 mm cube-type model, was chosen the printing of a single piece on the bed, in order to avoid the passage between the pieces and the appearance of filament threads on the outside of the piece, but also to avoid changing the settings while printing the piece. The printing settings were determined according to the printing capacity of the filament used, for each filament the temperature was changed, this being that differentiates all the pieces from each other, because the composition of the material for the three types of filaments differs greatly. Therefore, this second type of specimen was also printed using the temperatures specified above, in the case of printing the first type of specimen, the standard settings for all three materials being chosen.

The layer height for all the samples used was chosen at 0.2 mm, a height that is widely used for the good adhesion of the layers with the previous ones, and also very good for the fluidity of the filament, and for the faster printing time. For a height of 0.1 mm, time is doubled, which is not always to the advantage of the operator, and for a height of 0.3 mm it is already enough that the next layer does not adhere properly to the previous one, and, also, the resolution grows very much, visibly, the extruded filament sometimes generating filament bubbles due to the pressure exerted on the 0.4 mm nozzle, as appears in the figure 4. The problems of avoiding the bubbles that appeared in the printed piece can be solved by simply reducing the flow by 5%. If its decrease does not help, then it can be reduced by another 5% or even 10%.

When printing the cubes, 2 exterior walls were used for the first five samples and 5 exterior walls for the following ones. When determining the exterior walls, the function of printing 0.5 mm walls with a 0.4 mm nozzle can be used, as this function increases the flow of filament, creating a much deeper joint of the layers.

When choosing the parameters for these cubes, a filling percentage of 100% was established for two models. In the first case, using the line filling model, with the thickness of each printed line of 0.5 mm, it is obtained, for each layer, on the diagonal of the square, a passing model next to each other, this model being the only one that intertwines. The other models are different and are created according to the preset parameters in the software. For the second case, with the filling setting of 100% with the cubic subdivision model, simple division networks are created inside the part, these forming a network of equilateral triangles which, in 3D view, on the z axis, have an angle of 60^{o} compared to the base.

In the next figures, two sets of test specimens, printed from different filaments and with various printing settings and working conditions, are presented. In figure 5 are presented samples that will be tested to tensile, and in figure 6 samples for compressive testing. Their experimental testing at the tensile and compressive, and the results obtained, will be done and presented in future work.

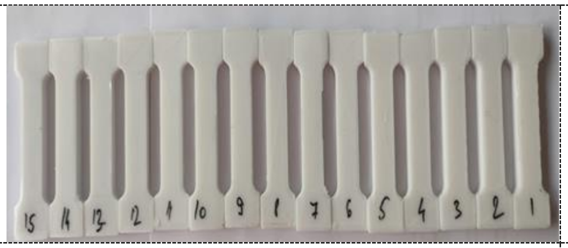


Figure 5. Samples printed for tensile testing.

Figure 6. Samples for compressive testing.

4. Conclusion

Considering the wide interest regarding the 3D printing process, the previous studies, as well as the available material capacities and the principle of the minimum costs, an experimental study on the finding the optimal settings of Delta and Cartesian 3D printers, for printing two types of test specimens, was developed and presented in this paper. The testing on the tensile/compressive strength of the printed samples will be done further and the results obtained will be exposed in a future paper. The purpose of the study is to create a database with the results obtained, which will be a working basis for future printings with these printer models, available in our laboratory, in order to understand the 3D-printed material behavior under certain available working conditions.

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