The influence of parameters and strategies on parts manufactured by FDM process

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Abstract

Additive manufacturing has gained an important role in manufacturing parts and prototypes. This article discusses on the influence of additive manufacturing parameters and strategies on the quality of the product obtained by FDM (Fused-deposition modeling) process. This technology assists the productive sectors for the creation of prototypes and customized final products, which can be manufactured inside the offices, being one of the pillars of industry 4.0, it favors mass customization, fast product delivery, and high added value. In FDM process, the main variable for the quality of the parts is the temperature. If it is elevated it will cause deformations in the parts, otherwise it will not allow adhesion between the layers. The deposition speed is related to the process temperature, causing a decrease in the viscosity of the polymer that should be adjusted so as not to cause failures in the part. The production time of the piece is directly linked to the deposition speed and the filling method available. The filling method is defined according to the necessary mechanical resistance of the part for its operation. It is possible to use the manufacturing method with low filling and subsequently add resin in cavities, significantly increasing the strength of the manufactured component.

Keywords
Additive Manufacturing, Industry 4.0, Product Design, FDM

1. Additive Manufacturing

Additive Manufacturing (AM) can be used to obtain high strength metal alloys, using laser or electron beams (Martin et al., 2017), custom drugs by FDM (Fused-deposition modeling) process (Gayathri et al., 2018), food customization, providing new textures, complex shapes and nutritional content (Iman et al., 2018), the manufacture of structural elements printed on concrete (Buswell et al., 2018), even the production of a full boat (UMaine, 2020).

AM is a group of processes based in addiction of material to build layers making a part or component. Studies related to manufacturing show the influence of processes on the properties of components (dos Santos et al., 2020; Miranda et al., 2016; Miranda et al., 2017; Nascimento et al., 2017; Nascimento et al., 2018; Nascimento et al., 2019; Santos et al., 2017; Da Cruz et al., 2020; Dos Santos et al., 2020). This work is focused on the area of manufacturing technology, a greater emphasis is given to the influence of parameters and strategies of the FDM (Fused-deposition modeling) process on the quality of the manufactured components, as it involves important technological concepts of materials and manufacturing processes.

FDM consists of forcing a polymeric filament Figure1, such as ABS (Acrylonitrile Butadiene Styrene) or PLA (polylactic acid) through the nozzle which is heated, melting the filament, forming thin threads, determined by calibrated diameter of the nozzle output, which will be deposited in layers according to the part format and the filling parameters established via software (Vosynek et al., 2018). The nozzle is typically mounted on an XYZ drive system, which XY axes are used to generate the part profile layer and the Z axis after finishing this step increases in height until the part is completed.

Before performing the printing of the part it is necessary to ensure that the CAD model file (computer aided design) has the desired characteristics. Often, customized projects are used and it is necessary to perform the file conference or in case of a new project, model the part fully. There are several software that can be used to model the part, some free such as FreeCAD, OpenSCAD, Google SketchUp and 123D Design or paid such as AutoCAD, SolidWorks, Solid Edge, CATIA, 3DMAX, among others. The choice between each software will depend on the type of part to model, parts for engineering, architecture or design, as the software offers specific features to streamline modeling. The resource available for the acquisition of the software will be a major factor, in the case of paid software, the investment for the acquisition will be a few thousand dollars. Regardless of the modeling software used, the generated file should be STL (STereoLithography), in the process of converting the file, problems can occur in the surfaces such as missing faces that generate holes in printing. There are some software used to check and fix these issues, such as Netfabb, MeshFix, ReMESH and MeshLab.

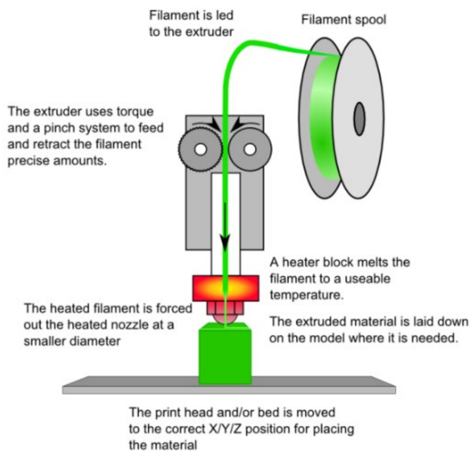

Figure 1. FDM process (Raprep, 2020).

2. Parameters

2.1 Temperature

The filament melting temperature is very important for the quality assurance of printing, so it should be adjusted according to the acquired filament. For ABS the nozzle temperature is 220° to 240°C and the heating table 110°C, for the PLA from 195° to 220°C and the room temperature table up to 70°C. It should be noted that some printers do not have table heating, a fact that can change the printing temperature. Changing the batch or manufacturer of the printing material can also generate temperature variations. A practical way to know the ideal working temperature is using the temperature tower, which consists of one or two towers, with graduation of the printing temperature, which will be possible to see the best range of printing temperature, as shown in Figure 2 (a) In the print program, you change the temperature ranges for each layer interval (3DALB, 2020).

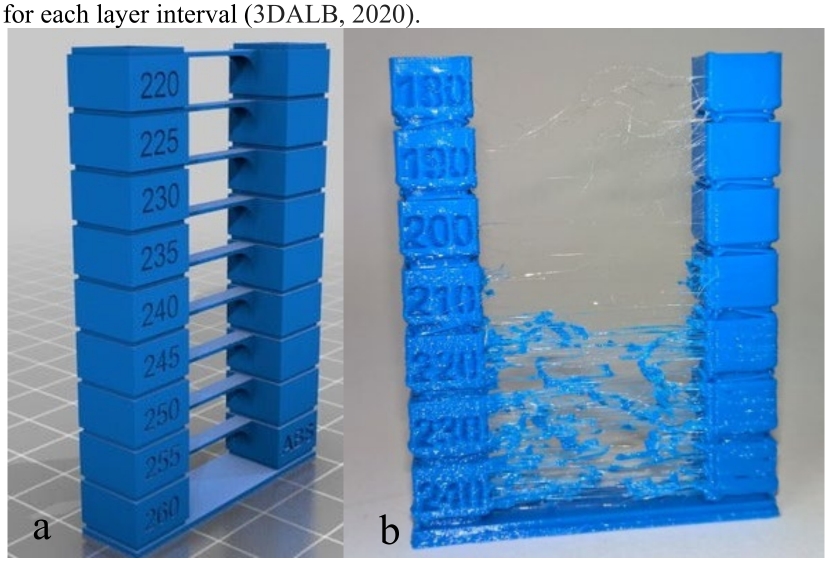

Figure 2. (a) Temperature tower (Thingiverse, 2020) and (b) Temperature Tower (3dprinting, 2020).

It will be possible to easily perceive if problems arising from excess temperature, such as the oozing defect. This defect is characterized by small wires that are in the path of printhead, as shown in Figure 2 (b). This problem is caused by the temperature in a PLA piece (3DALB, 2020). The increase in temperature causes the circular profile of the filament to deform due to decreased viscosity, this effect causes deformation in the product and influences its finish, however increases adhesion between the layers (Sood et al., 2012).

The deposition flow is directly tied to the temperature and speed of movement axes. In case of high temperature, which resulted in greater fluidity of the polymer, working with low deposition speed will result in material accumulation (Figure 3). However, if the speed is too high, spaces may occur between layers or the interruption of the filament.

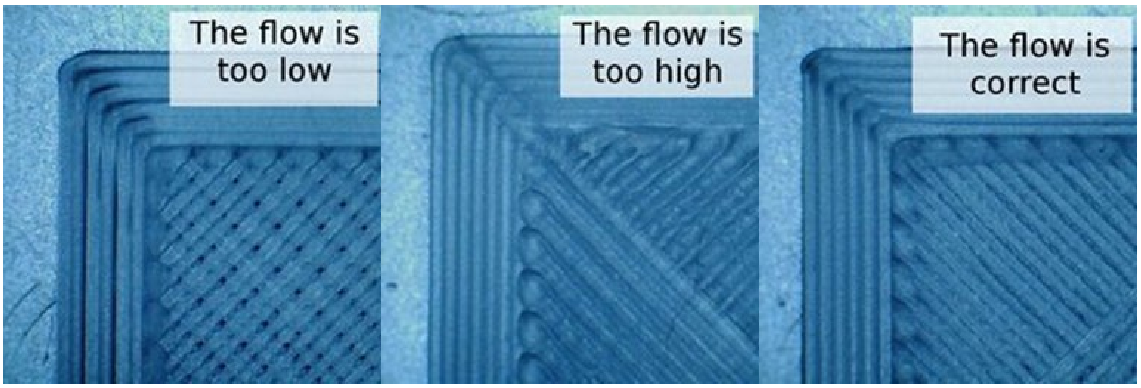

Figure 2. Influence of deposition flow (Gtmax3d, 2019).

2.1.1 Cooling

Print quality is determined primarily by temperature. Too high temperature will deform, too low there may be no adhesion between the layers. One way to adjust the temperature is by cooling the newly deposited material, solidifying and serving as a base for the next layer. We can mention two usual techniques for this purpose, start a fan or slow down the printing speed if the layer time is too fast. These techniques can be triggered via software and will depend on the material in use and part geometry. The relationship between temperature and speed can be seen in Figure 4.

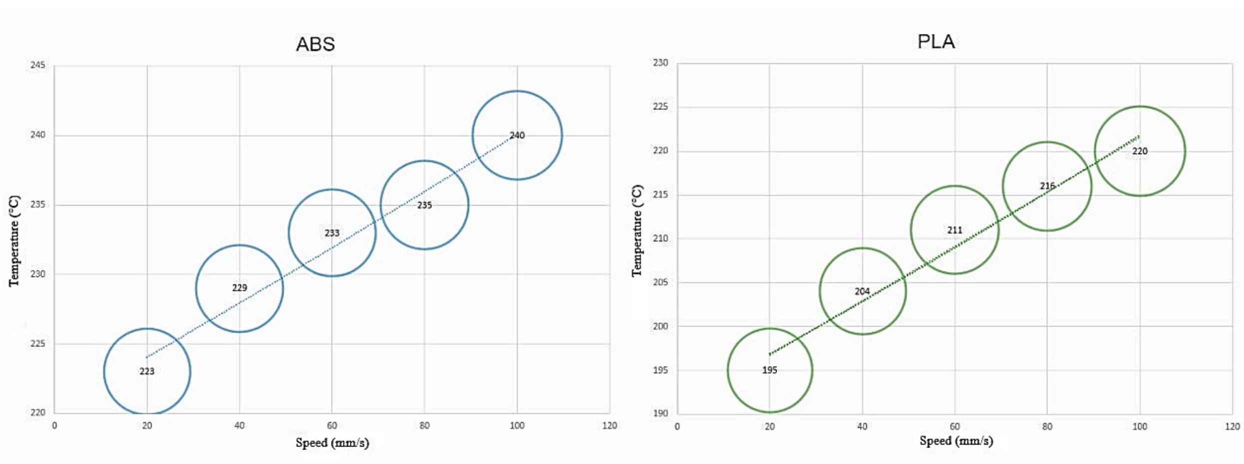

Figure 3. Relationship between print speed and temperature for ABS and PLA (3DALB, 2020).

3 Printing strategies

3.1 Layer height and Infill patterns

It is the height of the layer of cross-sections that composes the part, the smaller the piece, the more accurate and better the finish, but there is a significant increase in printing time. Values may vary depending on the diameter of the extrusion nozzle and printer resolution (GTMAX3D, 2019). The height of the layer is defined via software that will generate the program that will be sent to printer for part manufacturing. This software has free versions such as Cura, Repetier, Slic3r, Tinkerine Suite, CraftWare, SliceCrafter, IceSL, Z-Suite, ideaMaker, MakerBot Print, MatterControl, OctoPrint, PrusaSlicer and paid versions such as Netfabb Standard, Simplify3D, SelfCAD, and KISSlicer. The slicing program assists in the orientation and positioning of the model on the printing table, arranging the pieces in the best way possible, in the creation of filling structure, in the definition of the support structures and in the choice of printing parameters.

The orientation of the part on the table will define the printing direction of the layers, which will influence in mechanical resistance; according to Figure 5 we can identify the part on the left being positioned so that the layers are horizontal and the part on the right side has been tilted relative to the print table plane so that the layers would be at a certain angle but with the use of support material. This printing strategy aims to increase the tensile strength of the part, making the layers not perpendicular to the pull direction, considering the Z axis of the workpiece (3DLAB, 2020).

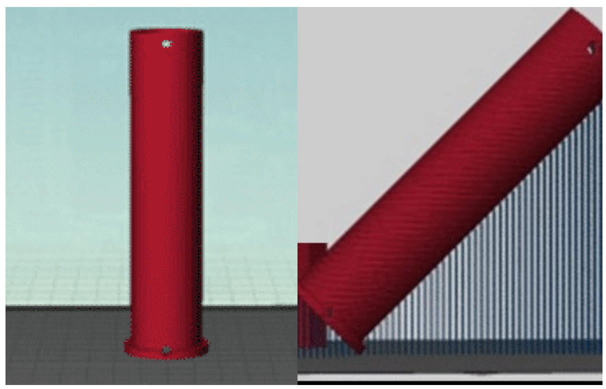

Figure 5. Workpiece on left printed in horizontal plane, workpiece on right using support material and tilted print plane (Adapted from 3DLAB, 2020).

In the slicing process the workpiece can be set to be printed with solid filling or with infill patterns and percentage of filling. There are several types of fill that can be used, being Honeycomb, Concentric, Line, Rectilinear, Hilbert Curve, Archimedean Chords, Octagram Spiral. The infill patterns and their percentage serve to shorten the printing time, without drastically reducing the resistance of the part, a fact that would occur if printed the piece in shell. Figure 6 shows the models and their infill percentage.

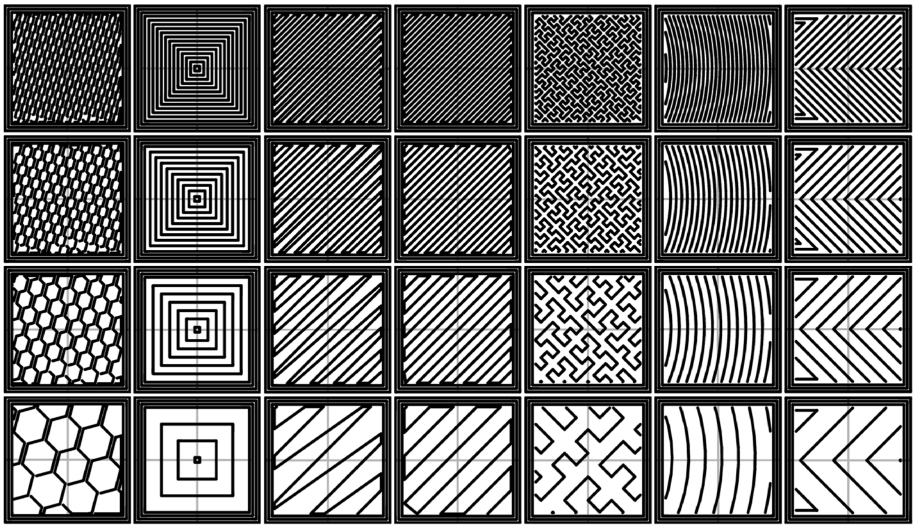

Figure 6. Infill patterns at varying densities. Top to down: 20%, 40%, 60%, 80%. Left to right: Honeycomb, Concentric, Line, Rectilinear, Hilbert Curve, Archimedean Chords, Octagram Spiral (Hodgson, 2013).

Another technique used to increase mechanical resistance and decrease printing time is by combining patterns as mentioned earlier and filling them with epoxy resin (Belter and Dollar, 2015). In this process, according to the researcher, there was a significant increase in mechanical resistance, bending and weight reduction compared to solid printing. Figure 7 shows the specimens used with epoxy filling.

Figure 7. Cross sections filled with epoxy and solid samples printed of ABS (Belter and Dollar, 2015).

3.2 Skirt

It is the external contour that is generated around the part before printing the first layer, which has the function of cleaning the print nozzle and improving the extrusion flow to start printing.

3.3 Raft 3D

It is a disposable horizontal layer that will be used as a basis for part printing. It consists of a predetermined number of layers, with a specific fill percentage, which will make it easier to remove the print later. This technique is mainly used with ABS filament to help control possible warping and favor the adherence of the part to the printing table (3DLAB, 2020).

4 Conclusions

In the process of manufacturing by FDM, the temperature is a major factor in the quality of the piece and the infill patterns and percentages filling for their mechanical resistance. The temperature will influence the quality of the part in two occasions, when there is excess or when it is insufficient temperature. Excess temperature will increase the fluidity of the material, which may generate excess deposited material that can be minimized by increasing the nozzle drive speed, however, the increase in speed may cause discontinuity of the filling. Excessive temperature also causes deformation of the part, as the previously deposited layer will not be solid enough to hold the new layer, which will cause deformities. Insufficient temperature not adequately melt the material to be extruded by the nozzle, which have a lower flowability leading to interruption in the filling, which can be solved by decreasing the movement speed of the nozzle. However, another problem resulting from the low temperature is the lack of adhesion between layers, as the material solidifies before there is contact with the layer previously deposited, causing detachment between layers.

To reduce the manufacturing time, we can manufacture the part in shell or apply infill patterns and the percentage filling, the lower the percentage of filling, the less material will be deposited in the interior size of the part, reducing the manufacturing time. However, this method reduces the part strength, but can be offset using the liquid resin for filling the voids of the workpiece, which will increase the resistance of the part without significantly altering its production time.

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