# Survey of process parameters for a better product quality in industrial production with a low-cost 3D printer

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***Abstract:*** *The most important areas of the industry, need products with short development stages. Additive manufacturing (AM) techniques, as Fused Deposition Modelling (FDM), are an integrated solution to the overall conception and product development cycles; the same competition is based on the development of new products with technological features, design and functional solutions in the shortest time. In this paper are discussed different process parameters for fused deposition modelling that affects the parts quality by using a low-cost 3D printer machine in order to produce an industrial product. The process parameters taken into the analysis, resulted effective in improving final parts quality.*

***Keywords****: ADDITIVE MANUFACTURING, FUSED DEPOSITION MODELLING, 3D PRINTING, PARTS QUALITY*

## *1. Introduction*

3D printing is a growing manufacturing process that competes with other manufacturing processes such as machining, casting, and forging. This manufacturing method is used in a variety of industries, including construction, prototyping, and biomechanics. This process has many advantages, including low material loss, freedom of shape of the part during design, low manufacturing cost, and simplicity of the process.However, there are some drawbacks to 3D printing, as the often-long printing time-poor mechanical properties, a limitation in the materials that can be used, the "layer by layer" appearance, or even poor surface condition. 3D printing by FDM (for Fused Deposition Modeling) is an additive manufacturing process that makes it possible to manufacture 3D parts directly from the models generated on design software. The process consists of printing several layers of material on top of each other in order to eventually form a volumetric part. A continuous filament of thermoplastic polymer is used to print the layers of material. The filament is typically purchased on a spool and continuously fed to the printer nozzle, where it is heated to a paste-like state so it can be deposited on the printer bed. The thermoplastic nature of the material is essential for the proper functioning of this process since it allows the deposited filaments to bind during printing and then solidify at room temperature after printing. The geometric precision or mechanical characteristics of 3D printed parts may vary depending on the printing parameters used and the shape of the parts. However, these characteristics are not always well mastered, and numerous studies are conducted to investigate the impact of printing parameters on the final part. The subject of this report will thus be the investigation of the impact of printing parameters on thermo-mechanical properties of the part.

## *2. Literature review*

The bibliography has been divided into two sections: the geometric and the mechanical section. In the geometric sections are discussed the effect of printing settings on the geometric precision and/or surface roughness of the printed item. In the mechanical section, are discussed the effect of printing settings on the mechanical qualities of the printed part.

### *2.1. Geometric*

Surface roughness is high in FDM 3D printing compared to other more traditional machining processes (in FDM, surface roughness is greater than 12 μm). In addition, there is great variability in the results depending on the measurement point [1] The deviations from the nominal values rise as the size of the geometric components increases. Also, there are larger deviations from nominal values for cuts (holes) than for extruded shapes in the X-Y plane. The results obtained for the holes were all below the nominal value while those of the extruded shapes were well distributed around the nominal value [2]. Some characteristics may not have a significant impact on the geometric correctness or surface roughness of the component on their own, but their interactions with other parameters may make them more influential [3]. For ABS and PLA pieces, a layer thickness of 0.1mm to 0.2mm appears to be optimal. Low extrusion temperatures in the specified range are preferred, however, this parameter appears to rely little on the kind of material. The parameters are also affected by the shape of the component. [4].

#### *Influence of parameters: parameters with great influence*

The results have been gathered in order to emphasize the parameters that have the greatest impact on the geometric precision and roughness of components manufactured in 3D using the FDM technique. The parameters that seem to have a great influence on the geometric accuracy are: layer thickness, number of layers, the gap between layers, printing speed, and extruder temperature. The layer thickness seems to be the parameter having the most influence on the surface roughness of the parts.

#### *Influence of parameters: parameters with low influence*

The findings are grouped in order to reinforce the parameters which have the least influence on the geometric precision and roughness of 3D printed components by using the FDM technique. The filling density tends to be a parameter with hardly any impact on the part's geometric precision. Print speed, print path, and extruder temperature do not exhibit a significant impact on component surface roughness.

### *2.2. Mechanic*

A comparison of samples printed in PLA by FDM and injection molded PLA samples was carried out. The tensile strength of the two types of samples was similar [10]. Two different types of rupture appear for components printed by the FDM process: "classic" tensile rupture occurs when a tensile force is applied in the direction perpendicular to that of the layers while the layers peel off when the tensile force is in the direction parallel to the layers [11].

#### *Influence of parameters*

In order to emphasize the elements that have the largest effect on the mechanical qualities of 3D printed components using the FDM technology. Young's modulus and tensile strength decrease as layer thickness decreases. The greater the infill density, the greater Young's modulus, and tensile strength. The printing orientation also has a significant impact on mechanical properties: if a tensile force is applied parallel to the layers, the tensile strength will be reduced (layer detachment starts earlier than rupture by "classic" traction). However, the effect on Young's modulus is negligible. The printing ambient temperature seems to have a fairly significant impact on the mechanical properties of the part as well, due to the fact that it influences the quality of the bond between the layers during printing.

## 3. Methodology

Tensile tests were performed to determine the thermo-mechanical behavior of a material: Young's modulus and Poisson's ratio. This assessment is characterized by its own simplicity of use and the volume of information presented. The principle of this test is to apply a tensile force to a tensile sample of defined dimensions until it breaks, after a loading procedure at a consistent strain rate. To measure deformations, we employ optical methods. Therefore, we installed a camera in front of the traction machine to acquire images every 1 second. Digital Image Correlation (DIC) [12-14] is used to determine the displacement and strain field on the surface of the specimens. The method consists in following the displacement of subareas during loading from a speckle painting of the surface of the specimen. The strain fields are quasi homogenous in the zone of interest, then the average strains are calculated and allow us to plot the stress-strain ($\sigma$-$\varepsilon_{xx}$ and $\sigma$-$\varepsilon_{yy}$ curves) as shown in fig. 2. The x direction is the longitudinal direction of the samples (the tensile direction) and the y direction is the transverse direction.

***Fig. 1:*** *Specimen production*

The following code is used to name the samples used in the following:

- **Material: ABS or PLA**
- **Manufacturing: Molding = M or Printing 3D = 3D**
- **Direction of extrusion = 1 or 2 (for solid ABS only)**
- **Direction of printing: Vertical = d or A Horizontal = p or Edge = t**
- **Layer thickness = 0,1 or 0,2 mm**
- **Fill density = 25% or 50% or 100%**
- **Wall thickness = P0,5 or P1 or P2 (only if the infill density is different from 100%) ;**

### 3.1 Analytical results

The deformations in the transverse and longitudinal directions, the force exerted as well as other quantities. The true stress is calculated by the ratio between strength and area of section

There are two types of stresses that may be calculated: nominal stresses and actual stresses. Because the real constraint is of interest here, a variable section will be used at each moment, calculated from the initial section ($a_0b_0$) and the deformation.

The section s is calculated:

$$\boxed{s = a_0 b_0 (1 + \varepsilon_{yy})^2}$$

The Young's modulus E is given by the slope coefficient m of the regression line $\sigma i = m\varepsilon_{xx} + n$ obtained from the measured points ($\sigma$, $\varepsilon$) on the elastic part of the behavior. Similarly, the Poisson's ratio $\mu$ is given by the slope coefficient m of the regression line $\varepsilon_{xx} = m\varepsilon_{yy} + n$.

Increasing the filling density rate makes it possible to have a higher Young's modulus and therefore a more rigid material. Similarly, the higher Young's modulus, the more the thickness of the layer. This first point is consistent with the bibliographic research mentioned in the first part: the filling density found to have a significant impact on the mechanical resistance and Young's modulus of the sample. In the context of ABS, the components produced by 3D printing are more rigid than the solid examples. This is an un excepting conclusion since we would have expected the contrary. This is almost obviously due to the bulk material's amorphous form, whereas the printed material behaved almost like a crystalline material. The other parameters such as the direction of printing, the layer thickness have no influence on the rigidity of the material. It can therefore be noted that although the direction of printing influences the type of rupture and the value of the elastic limit of the material, it does not influence the Young's modulus and therefore the stiffness of the material.

### 3.2 Comparison of solid ABS / printed ABS behaviour

In the case of ABS, we compared the curves of the solid samples with those of the samples obtained by 3D printing. The following graph represents the evolution of the deformation (along the x and y directions) as a function of the stress (MPa) for two samples: that in solid ABS in direction 1 and that printed in the "flat" direction.

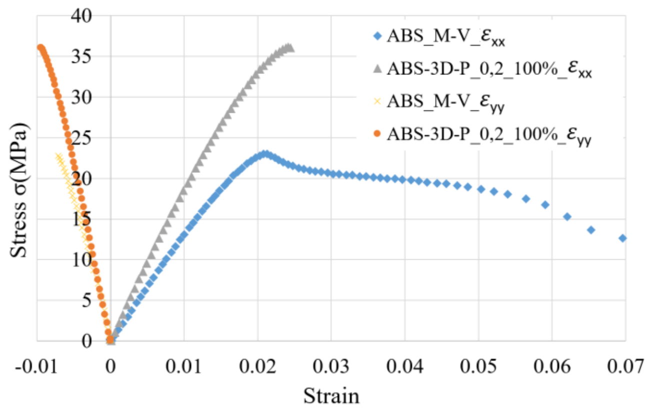


***Fig. 2:*** *Deformation at the center of the specimen as a function of stress for solid and printed ABS*

### 3.3 Comparison of thermo-mechanical behaviour

The average values of the temperature in the center of the samples as a function of time were used in order to plot the curves studied below. We decided to work with the relative temperature in order to be able to ignore the initial temperature of the specimen. We then grouped the relative temperature curves of the PLA and ABS samples on two separate graphs (one per material), allowing us to observe the potential differences in the thermal behaviour of the samples during the tensile tests. In order to facilitate the comparison, we constrained all the curves to a value of 0° at the start of the tensile test (about 10s). The temperature evolution in the elastic behaviour of the materials is the same for PLA and ABS samples. As a result, the filling density, the fact that it is printed in 3D or solid, and so on have no effect on the energy involved during the tensile test. The difference in plasticity behaviour between the solid and printed ABS test samples may also be shown. Indeed, the printed samples are fragile and fracture as soon as they leave the elastic zone, but the massive samples display the plastic behaviour that thermoplastic polymers are known for.

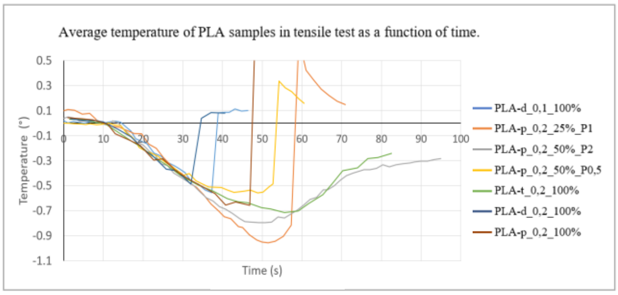


*__Fig. 3:__ Evolution of the absolute temperature of PLA samples in tensile test as a function of time*

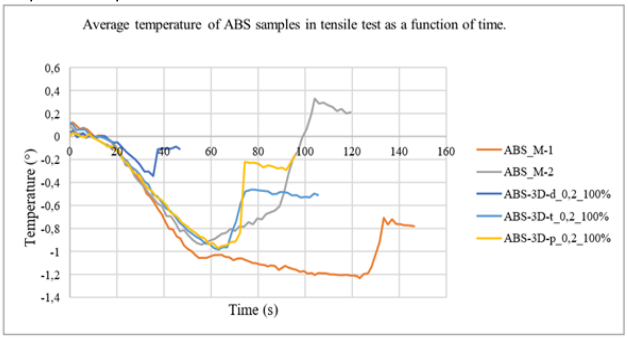


*__Fig. 4:__ Evolution of the relative temperature of ABS samples in tensile test as a function of time*

### 3.4 Comparison of the results

It is important to note that several parameters must be taken into account to make a useful comparison: in this first case, we sought to highlight the shape of the surface after rupture. The first image shows a sample filled at 50%, while the second shows a sample filled at 100%: in the first, the rupture appears to occur between the intersection of two layers of triangles (triangle fill the shape), whereas in the second, it appears to correspond to an almost clean separation of the layers. We found an interesting phenomenon: depending on the filling density of the component, the break does not always occur in the same position: for a complete filling, the break occurs near the zone taken in the holding jaws. It might possibly be because the sample was placed improperly. Whenever the density is low, the rupture occurs closer to the centre of the component, which is the weakest zone of the sample.

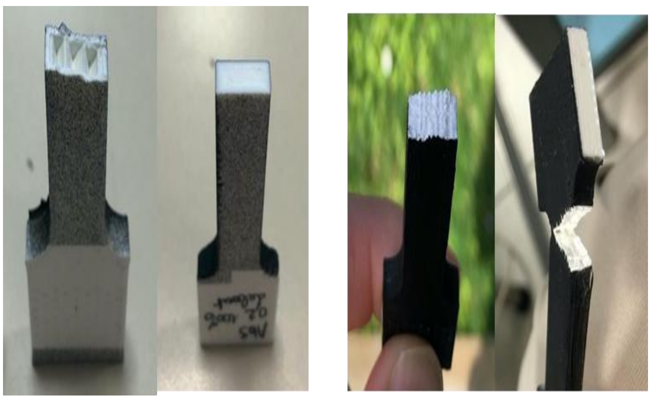

*__Fig. 5:__ In the case of ABS made by 3D printing, the rupture also takes place near the jaws, but it seems to have "striations" on the surface.*

## 4. Conclusions

In this paper, an experimental technique was developed to evaluate the thermo-mechanical behaviour of 3D printed objects. This experiment was conducted with twelve samples: two solid samples and ten 3D printed samples. We employed the Young's modulus (stiffness) and the Poisson's ratio (contraction of the material perpendicular to the direction of the applied force) to examine the mechanical behavior of these samples' materials. The study focused on five parameters: material type (PLA and ABS), printing orientation, layer thickness, filling density, and layer thickness. The main findings are presented below:

i. The filling density has a great influence on the stiffness of the material. At 100% infill density Young's modulus is higher so the material is stiffer. We were able to observe this for the two types of materials considered;

ii. The results obtained are in agreement with the bibliographical research carried out: as expected, the filling density, as well as the layer thickness, are the most influential parameters in the resistance of the part;

iii. The direction of printing and the layer thickness has no influence on the stiffness of the material, which corresponds to the results of the bibliographic research as well. However, the direction of printing influences the type of rupture and the value of the elastic limit of the material;

iv. Whether for PLA or ABS samples, the evolution of the temperature in the elastic behavior of the materials is identical. The filling density or the fact that it is printed in 3D or solid, therefore does not influence the mechanical energy involved during the tensile test on the surface of the specimen

v. So, because differences between the Poisson's ratios are minimal, the changes in the contraction of the material perpendicular to the direction of the force applied in the test samples may be ignored.

vi. Parts obtained by 3D printing are more rigid than solid samples.

It could be interesting to analyze the results in order to carry out the geometric component characterization and therefore have a solid base of optimal parameters to employ for each characterization. Furthermore, because this work focused on the characterization of polymeric materials, it can be easily envisioning a follow-up investigation utilizing alternative materials to see whether the behaviors are the same, and if not, to discover new processes

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