

An Empirical study and analysis of Process parameters influence in additive manufacturing

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ABSTRACT

Additive manufacturing is a burgeoning technology. In contrast to traditional production systems that rely on material removal, it enables the creation of extremely complex 3D objects by adding layers of material. The advancement of additive technology resulted in the creation of a generation of additive manufacturing techniques that were initially limited to industrial applications, but their extraordinary level of innovation has allowed the spread of household systems. Nowadays, the most common domestic systems use a fused deposition modelling process to create 3D parts. Such systems have low productivity and typically produce objects with low accuracy and unreliable mechanical properties the severity of these side effects can vary depending on the process parameters.

The goal of this work is to investigate the effect of some typical additive manufacturing process parameters on the characteristics of prototypes. The effect of layer thickness on shape and dimensional accuracy has been studied in particular. Cylindrical specimens were created using ABS filaments on a 3D printer, the Da Vinci 1.0A by XYZ printing.

Dimensional and shape inspection of the printed components was carried out using a standard reverse engineering method. The point clouds of the surfaces of the various specimens, in particular, were acquired using a 3D laser scanner. Following that, the acquired point clouds were post-processed, converted into 3D models, and analysed for any shape or dimensional differences from the original CAD models. The obtained results may serve as a useful guideline for selecting the best set of process parameters to obtain printed components of high quality in a reasonable amount of time while minimising material waste.

Keywords: 3D Printing, Additive Manufacturing, Reverse Engineering, Process Parameters

INTRODUCTION

The term Additive Manufacturing (AM) refers to all of the technologies that enable the creation of 3D objects by sequentially adding very thin material layers.

The advancement of additive technology resulted in an initial generation of AM systems limited to industrial applications, but their extraordinary level of innovation has allowed their widespread

adoption.

Nowadays, the terms Additive Manufacturing and 3D Printing are commonly used by a wide range of users, many of whom are not engineering specialists. Indeed, the proliferation of low-cost 3D printers has enabled the use of this technology among domestic users, who can now produce 3D objects at home in a short amount of time (and at a lower cost).

The most common domestic systems use a Fused Deposition Modeling (FDM) [1-3] process to create 3D parts. This technology is based on the idea that any 3D object can theoretically be subdivided into multiple sections or thin layers by slicing. As a result, any 3D object can be created by superimposing many physical layers on top of each other. Using the FDM methodology, a thermoplastic filament is heated in an extruder and then deposited on a support plane along a path that defines one of the multiple layers into which the object to be produced has been virtually subdivided. Typically, the extruder can move along a horizontal plane to achieve the correct shape of each single layer. Vertical movements of the support plane or the extruder can result in the superimposition of different layers. Unfortunately, low-cost FDM 3D printers are inefficient and produce objects with poor dimensional and geometric accuracy [3-6]. These constraints, Of course, this is due to the hardware and software solutions, but it is also due to the mechanical components, which, due to the printer's low cost, cannot have high performance. In any case, some of these side effects can be effectively mitigated by selecting the appropriate printing process parameters [7-10].

The goal of this research is to look into the dimensional and geometric accuracy of a common low-cost 3D printer, as well as how some process parameters affect the geometrical and dimensional characteristics of the prototypes. Accuracy analyses have been performed, in particular, on cylindrical specimens obtained using different values of the layer thickness. The physical prototypes were inspected using a 3D laser in a typical reverse engineering approach [11-13].

MATERIALS ANDMETHODS

The prototypes under consideration were created on a Da Vinci 1.0A 3D printer (Fig.1). The Da Vinci 1.0A supports ABS and PLA filaments, has a maximum build volume of 20x20x20 cm, and is controlled by the proprietary "XYZware" software. Unfortunately, this software does not allow you to edit the printing parameters individually and precisely. The software "Slic3r" and "Simplify3D" were used for this purpose. The ".gcode" files generated by these programmes, which contained the imposed set of printing parameters, were imported into the XYZware software to begin the printing phase.



Fig.1. the Da Vinci 1.0A 3D printer

As previously stated, the quality of AM prototypes can be heavily influenced by a number of process parameters [7, 9].

This paper presents some of the findings from a larger research project that sought to establish a link between the main printing parameters (layer thickness, extrusion width, printing speed, slicing direction, and extrusion temperature) and the shape and dimensional accuracy of printed objects.

Preliminary results for layer thickness, which represents the thickness of each slice, will be presented at this stage.

The survey was carried out on the cylindrical feature depicted in figure 2.



Fig.2. Dimensions of the analysed cylinder and two prototypes printed with 0.2mm (on the left) and 0.05 mm (on the right) layer thickness values

Prototypes were tested using two different layer thickness values (0.2 mm and 0.05 mm) (fig. 2). In terms of other printing parameters, the Da Vinci printer's default values were used (table 1), and the sliding direction was imposed along the z-axis.

Table 1. Main printing parameters

<i>Parameter</i>	<i>Value</i>
Nozzle diameter	0.4mm
Print speed	5mm/s
Bed temperature	90°
Nozzle temperature	210°

Filldensity	25P•
Wallthickness	0.7mm

Some attempts have also been made to evaluate various sliding directions. Unfortunately, no acceptable prototype has been obtained (fig. 3). These printing failures reveal the printer's remarkable technical limit.

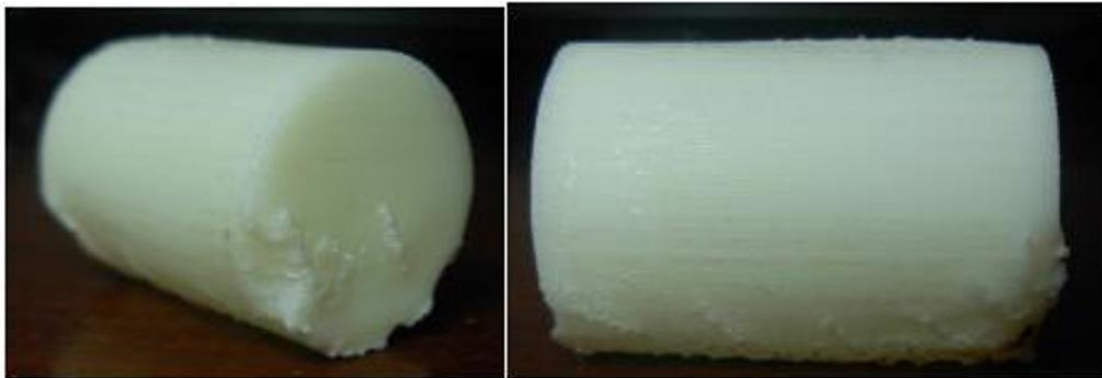


Fig.3. Cylindrical specimens obtained with sliding direction along the x-axis

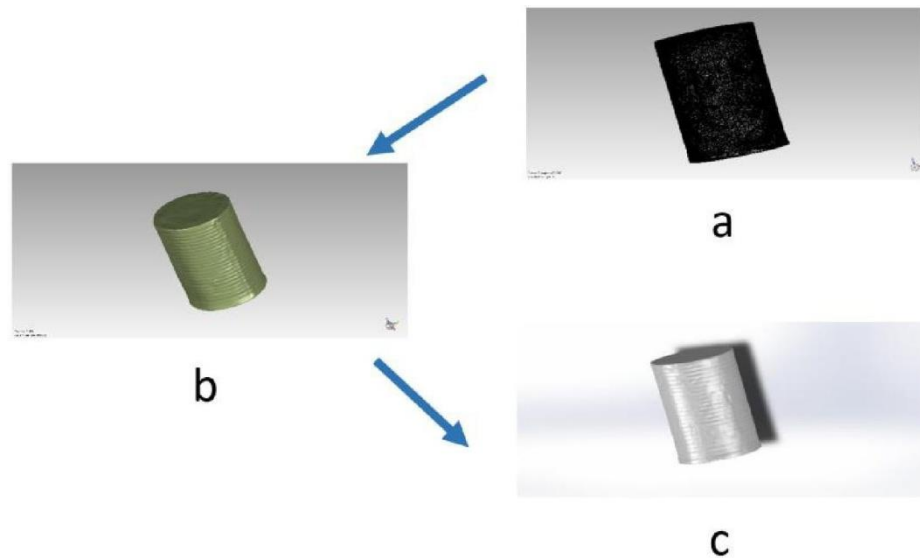
1.1 3D acquisition and CAD modelling

The printed components were inspected for dimensional and shape accuracy using a standard reverse engineering approach [14-15]. Hexagon metrology acquired all of the prototypes using a triangulation-based 3D laser scanner [16-18]. (Fig. 4) This system has adjustable line lengths and can acquire point clouds at a high rate (150000 points per second) with a high level of accuracy (0.013 mm).



Fig.4. Hexagon metrology 3D laser scanner HP-L-20.8

The acquired point clouds (fig. 5, a) were post-processed and converted into NURBS surfaces (fig. 5, b), yielding models that differed from the point clouds by less than 0.035 mm. The NURBS surfaces were converted into CAD solid models in the final step of the process (fig. 5, c).



Each prototype CAD model has been successively aligned with the nominal CAD model (fig. 6).

Fig.5. a) Point cloud, b) NURBS surfaces and c) CAD model of a printed cylinder

The alignment was obtained by minimising the distance between the points of comparison using iterative algorithms [7, 18]. To achieve this goal, two approaches were used sequentially: first, the models were roughly aligned using a small number of comparison points; then, during the fine adjustment phase, the model alignment was optimized using a larger number of comparison points. Dimensional and shape inspections of the printed prototypes were performed as soon as all CAD model alignments were completed.

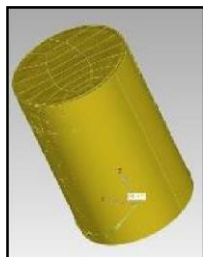


Fig.6. Aligned (acquired and nominal) CAD models.

2 DIMENSIONAL INSPECTION

The dimensional inspection was carried out by measuring the deviation values, which were defined as the shortest distance between the acquired model and any point on the nominal CAD model. In order to gather information about the dimensional accuracy of the printed object, Root Mean Square Errors (RMSE) has also been estimated.

Table 2 summarises the obtained results.

Table2. Layer thickness values and comparison results of the prototypes

Prototype	Layer Thickness(mm)	Deviation{ mmJ	RMSE(mmJ
1	0.2	-0.589	0.324
2	0.2	-0.550	0.254
3	0.2	-0.641	0.318
4	0.05	-0.524	0.298
s	o.os	-0.663	0.297
s	o.os	-0.609	0.324

Figure 7 depicts coloured maps corresponding to the distributions of deviation values over the prototypes' CAD models. These maps show that large differences between the acquired models and the nominal CAD model occur along the z-axis. In fact, all of the prototypes are smaller than the nominal cylinder.

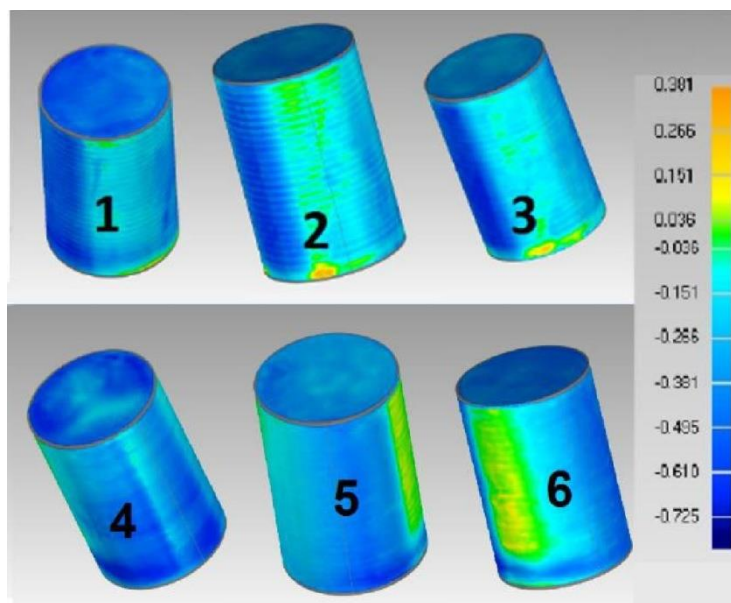


Fig.7. Deviation (mm) maps of printed cylinders

According to the results, the maximum deviation (absolute) value ranges from 0.524 mm to 0.663 mm, while the RMSE ranges from 0.254 mm to 0.324 mm. The prototype 4 has the lowest values of deviation, while the prototype 2 has the lowest RMSE.

Following the previously described alignment procedure, a comparative survey among the prototypes was conducted to assess the repeatability of the results. The prototypes 1-2-3 (created using the same set of printing parameters) were compared two by two in particular. The comparison results are summarised in figure 8's deviations maps.

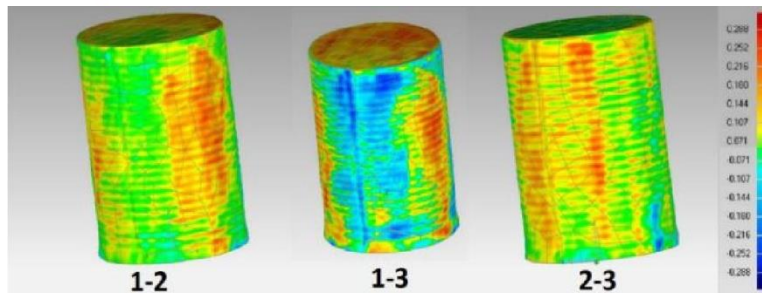


Fig.8. Comparison between printed cylinders: deviations (mm) maps

The maximum deviation for the three comparative analyses was measured at similar levels (around 0.280 mm).

The maximum deviation value, 0.288 mm, was discovered between prototypes 1 and 2.

These results show that the printer's quality is moderate in terms of repeatability of the produced objects.

3 CIRCULARITY AND CYLINDRICITY CONTROL

Controls for circularity and cylindricity of the specimens were also performed.

A qualitative analysis of the circularity has been conducted. Cross sections (along the x-y plane of fig. 2) of the cylinders at half height were extracted and compared to the nominal circular section.

The obtained results are depicted in Figure 9. The cross sections of all prototypes are not perfectly circular, but rather have a pseudo-elliptical shape, demonstrating a repetitive circularity error.

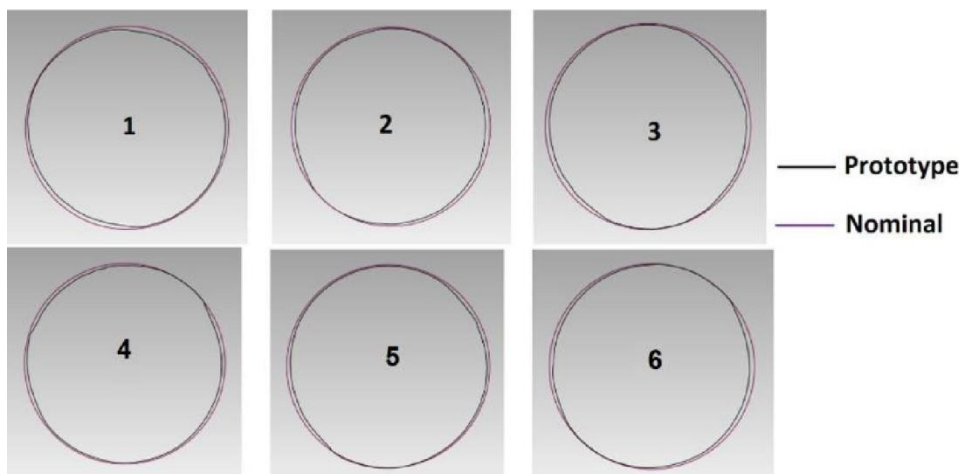


Fig.9. Comparison of cross sections (x-y plane)

Cylindricity has been controlled by determining the tolerance region for each specimen, which is the zone bounded by two concentric cylinders ("inner" and "outer") within which all points of the cylindrical surface lie (fig. 10).

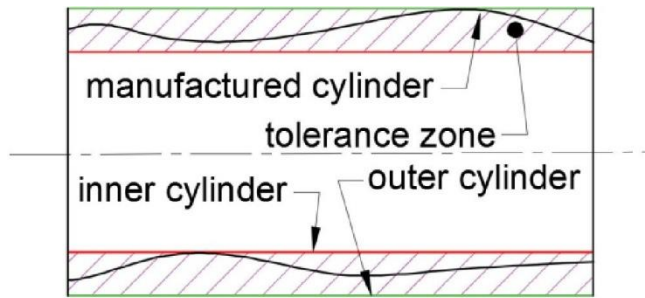


Fig.10. Cylindricity tolerance zone

The inner and outer cylinders of each prototype were located and their diameters were measured in order to calculate the cylindrical tolerance zone as $T_c = (D_o - D_i)/2$.

Table 3 summarises the cylinder control data. The prototypes 4 and 5, printed with a 0.05 mm layer thickness, produced the best results in terms of lowest tolerance. All of the obtained data show that the printer's geometric accuracy is of poor quality.

Table3. Cylindricity control data (nominal diameter =20 mm)

Prototype	Outer cylinder	Innercylinder	Cylindricity
	diameter (mm)	diameter (mm)	tolerance T_c (mm)
1	20.130	18.727	0.702
2	20.370	18.808	0.781
3	20.242	18.673	0.785
4	20.180	18.834	0.673
5	20.238	18.908	0.665
6	20.238	18.804	0.717

4 CONCLUSIONS

The findings of a study on the influence of some parameters of AM processes are presented in this paper. A comprehensive survey was conducted to assess the geometric and dimensional accuracy of a low-cost 3D printer. Some cylindrical specimens, in particular, have been printed with varying values of layer thickness. These prototypes were obtained using a traditional reverse engineering approach and converted into CAD models. Following that, the maximum deviation values and root mean square errors were calculated by comparing these models to the nominal CAD model. Controls for circularity and Cylindricity were also carried out.

Analyzing the obtained results reveals that, in terms of dimensional accuracy, comparable maximum deviation values have been calculated for prototypes printed with 0.2 mm and 0.05 mm layer thickness.

The RMSE was also found to be similar for the 0.05 mm and 0.2 mm layer thickness prototypes.

There has been no discernible effect of layer thickness on circularity. In fact, all of the specimens had some irregularities in the cross sections with a pseud-elliptical shape.

In terms of Cylindricity control, prototypes printed with a layer thickness of 0.05 mm outperformed those printed with a layer thickness of 0.2 mm.

As a general rule, given the printer used, the printing parameters chosen, and the geometrical feature examined, the best arrangement could be obtained with a 0.05 mm layer thickness.

The results discussed have shown that when using low-cost printers, the achievable geometric and dimensional accuracies are quite poor. Furthermore, it has been discovered that the appropriate selection of printing parameters can significantly alter the quality of the printed object.

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