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Dimensional Precision of Abs Parts Manufactured By Additive Manufacturing in FDM Technology

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Abstract **-** This article presents a study carried out with 24 parts printed using 3D FDM printer. The main objective of the research was to contribute to the optimization of printed parts in additive manufacturing by fused deposition modeling (FDM). To make this possible, the DoE methodology was used together with the Taguchi's method. This study confirmed that the three-dimensional printing FDM parameters influence the dimensional accuracy of the parts. When using FDM additive manufacturing, it is recommended to analyze the position in which the part will be printed, to guarantee it dimensional accuracy. Also, it is important to check the layer height and print speed of the fill, which reflects on the print time, to ensure the part has high dimensional accuracy.

Keywords**:** Dimensional precision; Dimensional quality; FDM; Additive Manufacturing.

1. Introduction

Additive Manufacturing is a general term used to describe the processes of adding input material, building layers upon layers in order to make a product [4]. To produce an object using Additive Manufacturing, it is necessary in advance to elaborate a three-dimensional project in a 3D CAD software, which will be responsible for guiding all the process. Then, the project is converted to the Standard Triangle Language (STL) format and transferred to the machine, which will start the production cycles according to the guide design, depositing layers of material until the object is formed. After, the object goes to the treatment stage, where the excesses of materials that remained from the printing are removed. Subsequently, the object heads to the final cleaning for use [3],[6].

The industrial market is under transformation by the insertion of Additive Manufacturing [2]. Things that were previously difficult to manufacture, either by cost or by labor/tools, today there is the possibility of manufacturing almost anything without large equipment - even products with a certain complexity - making this technology stand out before the manufacturing market [5] Also, in terms of market, hundreds of products are made from additive technology, manufactured with the same quality and/or even higher, for a lower cost and less aggression to the environment, point in which must be considered nowadays.

Currently, the medical industry has developed much research about 3D printing due to its great potential for application. As an example, a human heart made from a 3D printer, which helps cardiology surgeons closely analyze single cases and perform tests before the effective surgery on their patients [4]. In addition, it also assists in reducing medical errors, since the prototype is made from accurate data taken from patients through laboratory tests [1]. Thus, surgeons as well as students have the chance to study thoroughly several treatment options for patients and present a solution with greater precision even before surgery [1].

Despite its numerous advantages and benefits, there are still some disadvantages. According to [6], the precision and surface finish of the parts produced by additive manufacture are lower than those the parts obtained by conventional processes, such as machining. The author explains [6] that every part manufactured by additive manufacturing will have dimensional deviations in the Z direction, which, in large part, is due to the simple fact that the height of the part is not exactly a multiple of the layer thickness used in the construction process. This error can reach a maximum value of up to the thickness of a layer. In general, the dimensional accuracy of parts obtained by additive manufacturing is higher in the XY plane than in the Z direction.

The process of product development within companies increasingly requires that good prototypes be made for analysis and testing. According to [6] the use of a prototype mold is essential and the application of additive manufacturing in this area has been sought since the first generations of the equipment.

Due to the great demand for prototypes and objects printed in 3D with high dimensional accuracy and good quality, this study aims to ascertain what is the combination of some FDM printing factors that have the lowest dimensional variation, being: layer height, extruder temperature and filling printing speed. In addition, the study analyzes the influence of printing time on dimensional accuracy.

Therefore, this project aims to contribute to the optimization of printed parts in additive manufacturing by fused deposition modeling (FDM), answering the following research question: How do process parameters influence the dimensional quality of 3D-manufactured parts?

Having this, objectives of the research were defined as:

1) Evaluate how process parameters influence the dimensional quality of parts manufactured by 3D.

2) To investigate what is the combination of some FDM printing factors that have the lowest dimensional variation.

3) Analyze the influence of printing time on dimensional accuracy.

2. Materials and Methods

Initially, through the ProKnow-C (Knowledge Development Process – Constructivist), a bibliographic survey of materials for the construction of the bibliographic review was conducted using the academic search bases Scopus, Web of Science and Science Direct. The keywords used in these search bases in different combinations, were: “Additive manufacturing"; "FDM"; "dimensional accuracy"; "printing factors"; "additive manufacturing in ABS"; "3D printing".

The selection of the papers was based on the relation with the themes: additive manufacturing, FDM technology, dimensional accuracy, roughness, ABS polymer and 3D printing factors. To rate the factors chosen, the Design of Experiments (DOE) methodology was used. For this, two levels with three factors were selected, which are presented in Table 1.

Table 1: Parameters used in the study

Factors	LEVEL 1	LEVEL 2
Fill Print Speed	40 mm/s	90 mm/s
Layer Height	0,1 mm	0,3 mm
Extruder Temperature	225°C	245°C

This study was done using the complete factorial, with 2^3 the number of experiments (parts), resulting in eight. Based on Taguchi’s methodology, in the Minitab statistical software, the combinations of parameters for each part and the print order were obtained, shown in Table 2.

Table 2: Combinations and print order of experiments

Print order	Experiment	Fill print speed (mm/s)	Layer height (mm)	Extruder temperature (°C)
5°	1	40	0,1	245
1°	2	40	0,1	225
8°	3	90	0,3	245
7°	4	40	0,3	245
2°	5	90	0,1	225
4°	6	90	0,3	225
6°	7	90	0,1	245
3°	8	40	0,3	225

The 3D modeling of the parts was done using the online program Tinkercad and saved as STL format. The geometry chosen was a rectangular model measuring 10mm height, 20mm length and 15mm width, as represented by the Figure 1. In the upper left corner of each part there is the respective number of the experiment, with a depth of 1 millimeter.

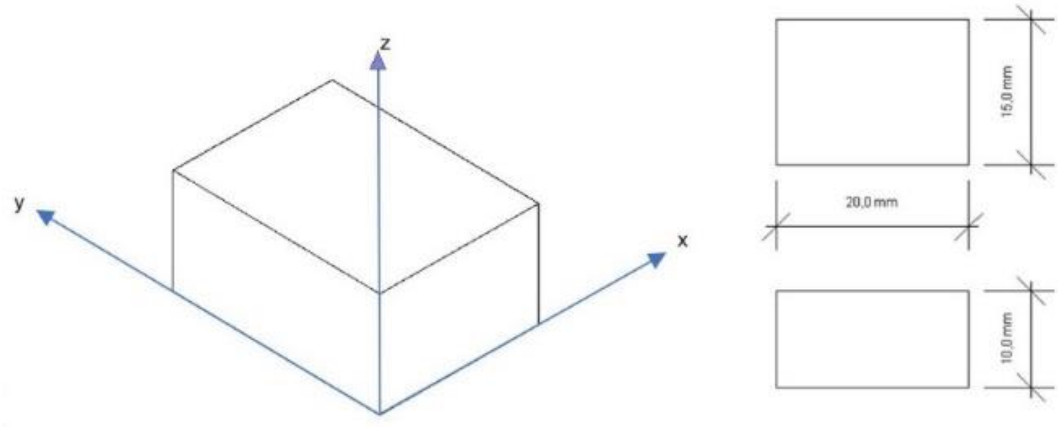

Figure 1: Geometric representation of printed parts

The molds were sliced in the Repetier-Host software, where the other fixed parameters were defined, see Table 3. The material chosen for printing was the ABS by ESUN brand in black color, with a diameter of 1.75mm.

Table 3: Fixed parameters

Height of the first layer	0,2mm
Solid contour layers (vertical, on the outer faces of the part)	3
Solid bottom layers (horizontal, on the face close to the table)	5
Solid top layers	5
Fill in solid layers (bottom and top)	rectilinear
Fill angle	45°
Fill Type	rectilinear
Fill Percentage	60%
Print speed of perimeters	40mm/s
Printing speed of small perimeters	25mm/s
Print speed of external perimeters	20mm/s
Solid fill print speed	20mm/s
Top layer solid fill print speed	15mm/s
Print speed of support material	70mm/s
Bridges print speed	45mm/s
Gap filling speed	20mm/s
Travel speed	175mm/s
First-layer print speed	30mm/s
Skirt loops (for nozzle cleaning)	4
Distance from object	10mm
Skirt height	1 layer
Brim (contour in the first layer to increase grip on the table)	0mm
Table temperature	110oC
Cooling (cooler)	off

The measurements of width, length and height were made using a digital caliper, each measurement was repeated three times. Analyzing the results, it was defined which combination of printing factors obtains the best dimensional accuracy. Take a look at Figure 2, printed parts.

Figure 2: Printed parts

3. Results and Discussion

Each of the 8 parts was printed three times on the A8 FDM 3D printer, resulting in 24 parts. Following the order established in the Minitab software, the first 8 were printed, in the same order more 8 equal parts and then, also in the same order, the other 8 parts. Due to the fact that they have different print parameters, each part was printed with different times. As shown in the table 4.

Table 4: Part printing time

Part	Printing time
1	37 minutes
2	36 minutes
3	15,36 minutes
4	18,25 minutes
5	35 minutes
6	15,57 minutes
7	35 minutes
8	16 minutes

The dimensions - height, length, and width - were measured with the digital caliper three times, so the arithmetic mean was performed and used for analysis purposes. The results are presented in Tables 5 and 6.

Table 5: Measurements of the 3 sets of parts

First Set of Parts									
	1ª Measurement			2ª Measurement			3ª Measurement		
Part	Hight	Width	Length	Hight	Width	Length	Hight	Width	Length
1	9,530	14,930	19,950	9,600	14,950	19,950	9,530	14,930	19,940
2	9,660	14,940	19,930	9,660	14,930	19,930	9,640	14,940	19,940
3	10,010	15,250	20,160	10,120	15,260	20,180	10,140	15,220	20,170
4	9,980	15,340	20,350	9,910	15,220	20,180	9,930	15,330	20,350
5	9,740	14,970	19,980	9,740	14,960	19,960	9,720	14,960	19,970
6	10,000	15,250	20,170	10,010	15,270	20,200	10,000	15,220	20,200
7	9,760	14,960	20,030	9,800	14,970	19,990	9,750	14,970	19,970
8	10,000	15,220	20,180	9,980	15,210	20,200	10,190	15,190	20,270

Second set of parts									
	1ª Measurement			2ª Measurement			3ª Measurement		
Part	Hight	Width	Length	Hight	Width	Length	Hight	Width	Length
1	9,790	14,910	19,910	9,820	14,910	19,900	9,810	14,900	19,900
2	9,730	14,930	19,920	9,740	14,930	19,910	9,730	14,930	19,910
3	9,960	15,170	20,130	10,030	15,160	20,070	9,990	15,130	20,140
4	9,950	15,150	20,090	9,870	15,170	20,100	9,880	15,090	20,120
5	9,720	14,920	19,910	9,740	14,920	19,900	9,710	14,930	19,910
6	9,930	15,160	20,130	9,930	15,170	20,110	9,910	15,110	20,130
7	9,680	14,910	19,880	9,730	14,880	19,880	9,700	14,900	19,870
8	9,850	15,200	20,130	9,710	15,170	20,130	9,850	15,190	20,190

Third set of parts									
	1ª Measurement			2ª Measurement			3ª Measurement		
Part	Hight	Width	Length	Hight	Width	Length	Hight	Width	Length
1	9,730	14,930	19,900	9,770	14,920	19,910	9,760	14,930	19,890
2	9,810	14,920	19,890	9,870	14,910	19,900	9,820	14,910	19,890
3	9,970	15,180	20,130	10,050	15,150	20,090	10,030	15,140	20,130
4	9,880	15,140	20,080	9,920	15,160	20,080	9,900	15,100	20,120
5	9,680	14,910	19,890	9,690	14,900	19,880	9,670	14,920	19,890
6	9,910	15,180	20,120	9,960	15,190	20,150	9,850	15,130	20,180
7	9,670	14,900	19,880	9,730	14,900	19,890	9,670	14,890	19,870
8	9,830	15,200	20,120	9,750	15,170	20,090	9,910	15,150	20,190

Arithmetic means of the 3 sets of parts:

Table 6: Arithmetic Means

	1° set of parts			2° set of parts			3° set of parts		
Part	Average Height	Average Width	Average Length	Average Height	Average Width	Average Length	Average Height	Average Width	Average Length
1	9,553	14,937	19,947	9,807	14,907	19,903	9,770	14,927	19,900
2	9,653	14,937	19,933	9,733	14,930	19,913	9,803	14,913	19,893
3	10,090	15,243	20,170	9,993	15,153	20,113	10,003	15,157	20,117
4	9,940	15,297	20,293	9,900	15,137	20,103	9,893	15,133	20,093
5	9,733	14,963	19,970	9,723	14,923	19,907	9,680	14,910	19,887
6	10,003	15,247	20,190	9,923	15,147	20,123	9,907	15,167	20,150
7	9,770	14,967	19,997	9,703	14,897	19,877	9,690	14,897	19,880
8	10,057	15,207	20,217	9,803	15,187	20,150	9,830	15,173	20,133

Considering the means of the dimensions of each part, the analysis of percent deviation was performed in modulus of each one. In table 7, it is possible to observe in ascending order of deviation, that is, the part which closest to the original measure is in first place and the one that suffered the most deviation is in last.

Table 7: Set deviations

1° set of parts

Part	Percent Deviation (height)	Part	Percent Deviation (width)	Part	Percent Deviation (length)
6	0,033%	7	0,222%	7	0,017%
8	0,567%	5	0,244%	5	0,150%
4	0,600%	1	0,422%	1	0,267%
3	0,900%	2	0,422%	2	0,333%
7	2,300%	8	1,378%	3	0,850%
5	2,667%	3	1,622%	6	0,950%
2	3,467%	6	1,644%	8	1,083%
1	4,467%	4	1,978%	4	1,467%

2° set of parts

Part	Percent Deviation (height)	Part	Percent Deviation (width)	Part	Percent Deviation (length)
3	0,067%	2	0,467%	2	0,433%
6	0,767%	5	0,511%	5	0,467%
4	1,000%	1	0,622%	1	0,483%
1	1,933%	7	0,689%	4	0,517%
8	1,967%	4	0,911%	3	0,567%
2	2,667%	6	0,978%	6	0,617%
5	2,767%	3	1,022%	7	0,617%
7	2,967%	8	1,244%	8	0,750%

3° set of parts

Part	Percent Deviation (height)	Part	Percent Deviation (width)	Part	Percent Deviation (length)
3	0,033%	1	0,489%	4	0,467%
6	0,933%	2	0,578%	1	0,500%
4	1,067%	5	0,600%	2	0,533%
8	1,700%	7	0,689%	5	0,567%
2	1,967%	4	0,889%	3	0,583%
1	2,300%	3	1,044%	7	0,600%
7	3,100%	6	1,111%	8	0,667%
5	3,200%	8	1,156%	6	0,750%

Comparing the percent deviations of the three sets and considering the same part of each set, the following results were obtained:

Table 8: Results regarding dimensional accuracy

			1° set of parts	2° set of parts	3° set of parts
HEIGHT	THE BEST PART	6	0,033%	0,767%	0,933%
	WORST PARTS	5	2,667%	2,767%	3,200%
		7	2,300%	2,967%	3,100%
WIDTH	BEST PARTS	5	0,244%	0,511%	0,600%
		1	0,422%	0,622%	0,489%
	WORST PARTS	8	1,378%	1,244%	1,156%
		6	1,644%	0,978%	1,111%
LENGTH	BEST PARTS	5	0,150%	0,467%	0,567%
		1	0,267%	0,483%	0,500%
	THE WORST PART	8	1,083%	0,750%	0,667%

Analyzing all data presented in the tables, it is possible to notice that width and length are related. In each set the ordering of the parts (from the smallest to the largest deviation) is practically the same as the length and width. Being able to visualize this in the three sets.

Regarding height, part 6 can be considered the best, since its variation was less than 1% and its position varied between the first and second place in the three sets. Parts 5 and 7 can be considered the worst, since their respective variations were high, when compared to the other parts, and occupied low positions in the three sets. In addition, part 4 ranked third in the three sets.

When it comes to width, parts 5 and 1 can be considered the best since they ranged between 0.24% and 0.62% and in the three sets were in one of the first three places. Part 8 can be considered the worst, because, although in set 1 it did not rank in one of the last two places, it presented a high percent deviation in the three sets. Parts 3 and 6 also didn't perform very well in all tests, occupying penultimate or antepenultimate position in the sets.

Regarding length, part 1 can be considered the best if the constancy is analyzed in a good position in the ranking of percent deviations, since it occupied second or third place. In addition, part 5 can also be considered appropriate, because in the third set it was in an intermediate position. The worst one is part 8 because in all sets it occupied low placement.

Width was the dimension that suffered the lowest variation in all sets and height was the dimension that showed the most changes. The parts of set 1 were the ones that presented results with more expressive variations in all parts. This may be explained by undetected climatic or other reasons, since they were printed a few days before set 2 and 3, which were printed on the same day. However, the greater variation, when compared to the other two sets, did not significantly affect the increasing order of the standard deviations of the parts in height, width, and length.

Thus, for dimensional accuracy, the best and worst combinations of parameters of the printing factors were, Table 9:

Table 9: Results for parameter combinations

	Part	Fill Print Speed (mm/s)	Layer Height (mm)	Extruder Temperature (°C)
Best Parts (length and width)	1	40	0,1	245
	5	90	0,1	225
Best Parts (height)	6	90	0,3	225
Worst Parts (length and width)	8	40	0,3	225
Worst Parts (height)	5	90	0,1	225
	7	90	0,1	245

3. Conclusions

The study carried out confirmed that the three-dimensional printing FDM parameters influence the dimensional accuracy of the parts. Parts with a layer height of 0.1 mm suffer less percent deviation in length and width, therefore, they have better dimensional accuracy. Differently from what happens to the parts with 0.3 mm of layer height, which presented the highest percent deviation regarding length and width. This effect occurs inversely when height is analyzed. The pieces with 0.3 mm of layer height are the ones with the smallest percent deviation in this axis and the parts with 0.1 mm of layer height are the ones that suffered the most percent deviation.

As [6] stated and this research proved, the dimensional accuracy of parts obtained by additive manufacturing is greater in the XY plane (width and length) than in the Z (height) direction, which was the one with the highest percentage deviation in the experiments, being double or more compared to the deviations in length and width.

The factor that seemed to have the greatest influence on dimensional accuracy was the layer height, as the filling print speed and extruder temperature showed to be variables between the best and worst parts. However, the printing time of the parts, which was influenced by the filling printing speed, is related to the dimensional accuracy of the XY axis. The parts with the greatest dimensional precision in terms of width and length were parts 1 and 5, which also had the longest printing time, 37 and 35 minutes, respectively.

Therefore, when using FDM additive manufacturing, it is recommended to analyze the position in which the part will be printed, in order to guarantee the dimensional accuracy. Also, check the layer height and print speed of the fill, which reflects on the print time, to ensure the part has high dimensional accuracy. All in all, it is considered that the objectives of the research were achieved. As a future direction, we suggest expanding this study to different materials such as PLA and composites from it.

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