Dimensional Evaluation of Miniaturized Parts Manufactured by 3D Printing

Gean Vitor Salmoria[1*], Manoella R. Cardenuto[2], Loise Silva[3]
Universidade Federal de Santa Catarina – Departamento de Engenharia Mecânica, Laboratório NIMMA
Caixa Postal 476, Florianópolis - SC - Brasil - CEP 88040-900
*Corresponding Author

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Abstract— *The development of the manufacturing process to fabricate miniaturized components goes through aspects such as modifications of machines and tools, process optimizations, improvements in precision and accuracy, and fabrication of adapted geometries. Hot-embossing, laser abrasion, and microinjection molding are applicable methods of fabrication to a diversity of geometries and polymeric materials. Rapid prototyping and fabrication assist in the development of new products in a short amount of time with a reduction in costs, allowing the manufacturing of objects with tenths of millimeters and with an accuracy in the order of micrometers. 3D Printing process with photocurable resin is a recent method of rapid prototyping that is growing in the market. Intending to analyze how precise and accurate is the process of 3D printing of miniaturized models and analyze their dimensional tolerance, it was conducted a dimensional analysis of parts fabricated in a printer EDEN 250 by Objet. Qualitative results showed that EDEN 250 prints satisfactory small parts mainly with round formats. Parts with sharp edges show limitations regarding precision and accuracy. FullCure ® 720 is a resin with average quality since it absorbed moisture and is heat sensitive. Studied samples were classified according to the technical standard NBR 6158 as IT11 parts (max tolerance of ± 60 µm).*

Keywords— Rapid prototyping, 3D Printing, dimensional precision and accuracy.

I. INTRODUCTION

A change in part of the manufacturing industry of plastic components has been noticed, evidencing a tendency for miniaturization of devices and systems [1]. Market consolidation of miniaturized parts is demonstrated by the global growth between the years 2004 and 2009, from 12 billion to 25 billion dollars. It is known that the principal difficulty in the miniaturization of devices and parts is the existed limitation regarding precision and accuracy of fabrication processes. The development and adaptation of the manufacturing processes of miniaturized components go through aspects such as modifications in machines and tools, process optimization, improvements in precision and accuracy, and fabrication of adapted geometries [2][3]. The methods of miniaturization and micro-fabrication of polymeric components are an alternative with low cost for the technology of micro electromechanical system (MEMS) [4][5]. Hot-embossing, laser abrasion, and micro-molding by injection are applicable fabricated methods for a diversity of geometries and polymeric materials.

Prototyping and rapid-fabrication techniques as stereolithography (SL), selective laser sintering (SLS), and tridimensional printing (3DP) assist the development of new products in a short period with a reduction in costs [6][7]. These techniques allow the creation of objects in the range of hundreds to tenths of millimeters with an accuracy in the order of micrometers. EDEN 250 is a printer from Objet that allow the creation of models with layers of 0,016 mm and walls of 0,6 mm [8]. Intending to analyze how precise and accurate is the printing process of miniaturized models which are the dimensional tolerance according to ISO 286-2-1998, it was conducted an analysis of the dimensions of parts fabricated with the printer EDEN 250 from Objet based on the methodology developed for parts fabricated by SL in the Laboratory CIMJECT of the Department of Mechanical Engineering on the Federal University of Santa Catarina (UFSC) [9].

Rapid prototyping by 3D printing is a process similar of standard printers in which the printhead spurts ink in the paper. In the tridimensional printer a CAD model is created and loaded in the printer where the geometry is sliced, process similar with any kind of equipment for rapid prototyping. A printhead with resin or binder, depending on the process, spurts the resin or the binder on the equipment tray building the prototype.

Currently, three companies manufacture equipment for rapid prototyping by 3D printing, Z Corporation, Objet, and 3D Systems.

The *Z Corporation* 3D Printer uses technology with binder powder. Firstly, the printer spreads a thin layer of powder, then the printhead prints a binder on the powder layer just deposited. Next, a piston presses the binder/powder layer leaving the surface flat and ready for the next material layer. Once the part is completed, the part is surrounded and supported by the powder that wasn't used on the part, powder that can be used for the next print.

Objet and *3D Systems* use a different process, both companies use UV photosensitive liquid resins which makes the prototypes more detailed. *Objet Geometrics* was the first company to work, with success, with photocurable polymers. In 2000, the development of the technology *Polyiet* allowed the rapid manufacturing of prototypes of different sizes, complex models, and high quality.

The working principle of this printer is as follows, a 3D model is developed in CAD software, and the project is converted to an STL or SLC (for the jewelry market) and then sliced. Eight printheads deposits simultaneously identical quantities of photocurable polymer on the printer tray on each movement along the x-axis, building a thin layer of polymer that is cured by the UV bulbs presented on the printer head.

When the first layer is completed, the tray moves along the z axis initiating a new layer. The process occurs successively until the model in finished. In this process, the model is ready to use when finished, without the need of post-cure. The process for support elimination is simple, the support resin can be dissolved by a brush or a jet of water and leaves no burrs [10]. Figure 1 shows a work scheme of the printer.

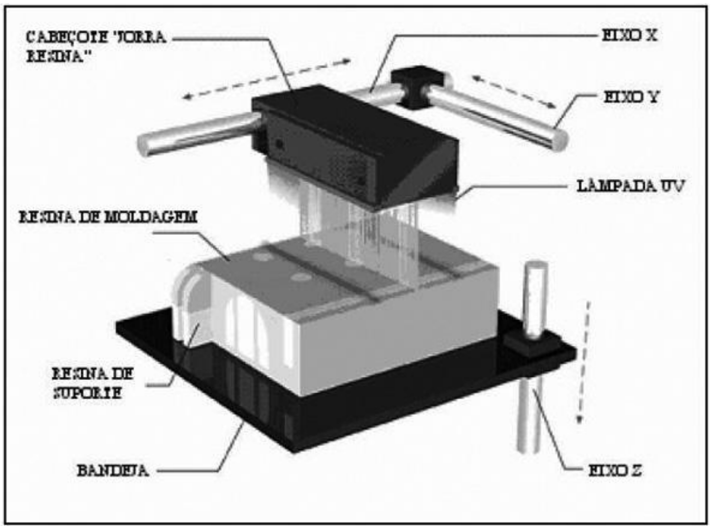


FIGURE 1: Work scheme of the printer 3D EDEN 250

Some of the advantages of the 3D EDEN 250 are high quality with layers with 0.016 mm of thickness resulting in models highly detailed and smooth. Resin properties allow walls and layers of 0.6 mm depending on the model. Allows an easy support elimination, no need of post-cure, variety of material properties and colors, and it allows the manufacture of more than one part each time, reducing production costs and time.

II. MATERIALS AND METHODS

2.1 Qualitative study

For the studies about the quality of miniaturized parts fabricated by 3D printing, a specimen with 112 x 60 x 3 mm, Figure 2, was project in a CAD software. The specimen was project with through holes with a variety of geometries (squares, circles, equilateral triangle and four-pointed star) and with dimensions between 500 µm and 10 mm. The parts were printed in a 3D EDEN 250 Printer with a FullCure® 720, epoxy and acrylic resin provide by the same manufacturer as the printer.

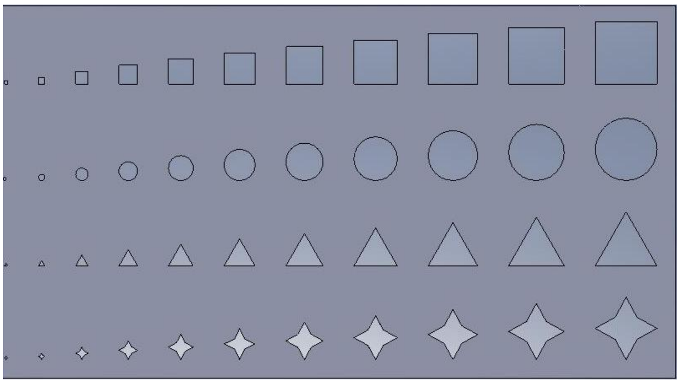


FIGURE 2: CAD Model of the part

Leica DMLM Microscopy was used to conduct the qualitative analysis of printed geometries.

2.2 Quantitative study

After the qualitative analysis, it was decided to proceed with a detailed study about the precision and/or accuracy of the prototypes printed in circular formats with 1.5 mm of diameter and quadrangular formats with lateral of 1.5 mm. Since it was not possible to have a complete visualization of the geometry with 1 mm on the minimum magnification of the equipment, it was printed geometries with 1.5 mm.

Geometries in triangular and star forms were discarded due to poor construction resulting in a considerable difficulty taking the measures.

Four specimens with 48 x 25,5 x 3 mm, 25 circulars through holes, and 25 quadrangular through holes were manufactured as well as four specimens with 74 x 36,5 x 4,5 mm, 25 circular pins, and 25 quadrangular pins. In total, 100 samples (between pins and holes) were printed and analyzed, as Figure 3. The pins have 3 mm in height and the holes have 3 mm in thickness.

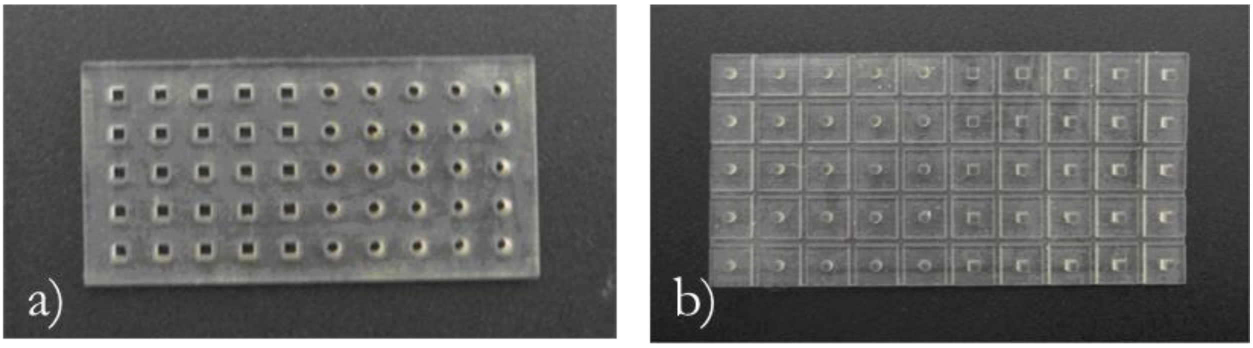


FIGURE 3: Specimens analyzed on the quantitative study. a) Part with holes b) Part with pins.

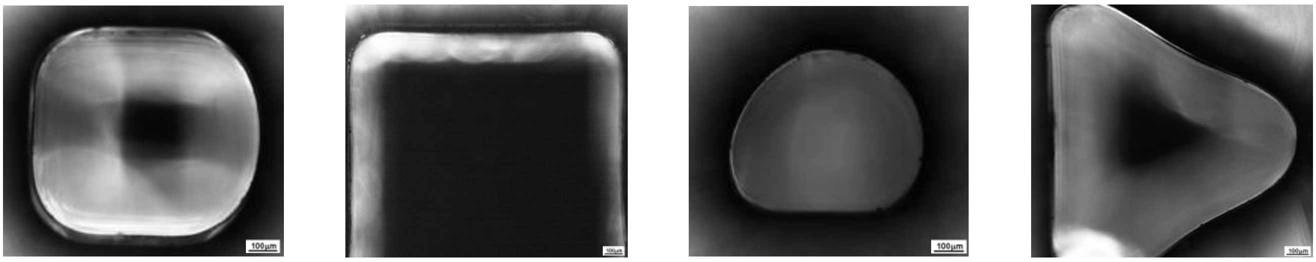
Pins measures were conducted with a microtome Mitutoyo Digimatic model MDC-25PJ. The through-holes were measured from images generated by a MO Leica – DMLM with a magnification of 5x and post-analysis in the software Adobe Photoshop CS3. Four diameter measures were taken in steps of 45° in all circular geometries, two measures in each lateral of the quadrangular geometries, and one in each diagonal.

III. RESULTS AND DISCUSSION

3.1 Qualitative study

In the manufacturing of holes with dimensions of 0.5 mm, the printer showed difficulty in building the geometries as projected by the CAD model. The printer wasn't able to print the holes with triangular and star formats of 0.5 mm size. Circular and square formats were printed, although the square format was not satisfactorily printed. The squares presented a format similar to circles.

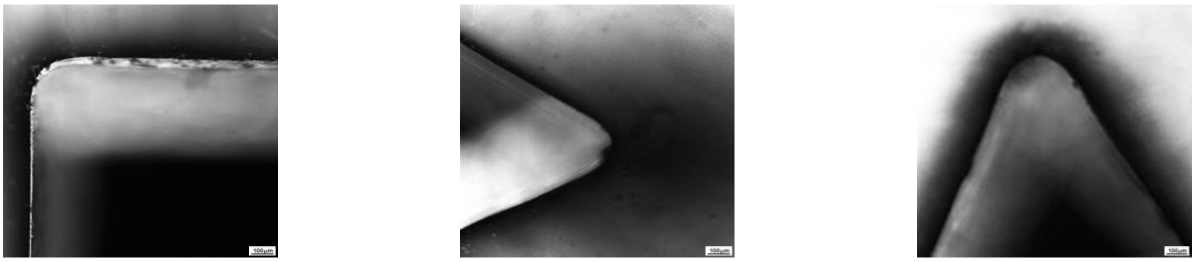
Holes with circular, square, triangular, and star geometries with 1 mm dimensions were printed, but they showed a circular/oval geometry. Holes printed with 2 mm showed geometries as projected by CAD model. Figure 4 presents the images of the holes with 1 and 2 mm in the square and triangular formats.



(a) (b) (c) (d)

FIGURE 4: Optic Microscopy of the printed holes. a) square with 1 mm. b) Square with 2 mm. c) Triangle with 1 mm. d) Triangle with 2 mm.

Figure 5 presents images of the holes with 10 mm. In the formats that have corners, the corners exhibit significative roundness even on the prints with 10 mm of dimension.



(a) (b) (c)

FIGURE 5: Optic Microscopy images of the corner of hole. a) Square with 10 mm. b) Triangle with 10 mm. c) Star with 10 mm.

3.2 Quantitative study

The two geometries printed presented a similar precision and accuracy behavior as shown in Tables 1 and 2. Since dimensions should have 1.5 mm, the square diagonal should have 2.121 mm.

When analyzing the holes, as shown in Table 1, the diameter average was 0.2 to 1.13 % below the diameter projected. The dimensions of the laterals were 1.5 to 1,8 % above the project, and the diagonals were 8.5 to 9.8 % below the expected.

TABLE 1
DIMENSIONS OF PRINTED HOLES

Holes		Circular	Squares	
		Diameter	Lateral	Diagonal
Specimen 1	Average (mm)	1,483	1,524	1,939
	Standard Deviation	0,012383	0,032195	0,024277
Specimen 2	Average (mm)	1,495	1,522	1,927
	Standard Deviation	0,016123	0,020444	0,017414
Specimen 3	Average (mm)	1,488	1,523	1,915
	Standard Deviation	0,028583	0,021456	0,018909
Specimen 4	Average (mm)	1,497	1,527	1,913
	Standard Deviation	0,013390	0,023041	0,016946

As shown in Table 2, the circular pins presented diameters 0.86 to 1.53% above the projected value. The laterals diverged from 3.46 to 4.13% above the expected and the diagonals between 6.6 % below to 5.23% above the CAD model.

The variation in the dimensions is because the printed samples in the square format presented round edges, as shown in section 3.1. For this reason, is noticed a more accentuated difference between the CAD model and the printed part.

TABLE 2
DIMENSIONS OF PRINTED PINS

Pinos		Circular	Square	
		Diâmetro	Lateral	Diagonal
Specimen 1	Average (mm)	1,513	1,562	2,001
	Standard Deviation	0,017202	0,030316	0,034433
Specimen 2	Average (mm)	1,518	1,552	2,010
	Standard Deviation	0,022647	0,036751	0,036498
Specimen 3	Average (mm)	1,519	1,554	1,981
	Standard Deviation	0,021990	0,036026	0,152309
Specimen 4	Average (mm)	1,523	1,562	2,010
	Standard Deviation	0,022723	0,035619	0,063927

IV. CONCLUSIONS

With qualitative results, it is possible to notice that EDEN 250 prints satisfactorily small parts, mainly with round formats. Parts with sharp corners do not perform as well as the round format, presenting poor precision and accuracy in the edges.

Even in bigger parts, with 100 mm, for example, the edges resolution is not satisfactory. The resin FullCure® 720 is a good resin for work, however it has high moisture absorption, and it is sensitive to heat.

Classifying the samples according with the technical standard NBR 6158, it is possible to classify the parts in the category IT11 (maximum tolerance of ± 0,06 mm). According with the experiments, the four specimens with circular and squares holes, had variation in the dimensions below the tolerance allowed, what demonstrate a great reliability in the printing process.

In the experiments with pins, most of the specimens presented variations below the maximum allowed. Specimens 1 and 4 of the square pins exceeded in 0.002 mm the tolerance allowed. Showing that the reliability of the printing process of square pins are 50%.

Analyzing the diagonals of the squares, all samples presented results above the maximum tolerance allowed, reaching 9.8% below the nominal size. Expected results due to the roundness of the sharp edges.

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