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STUDY ON DIMENSIONAL DEVIATION OF PARTS MANUFACTURED IN 3D PRINTING

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ABSTRACT

3D printing is widely used in the fields of manufacturing with many kinds of materials applied such as polymer filaments, metal powders, and biological materials. 3D printing can create many products with complex profiles by building layer by layer. The paper presents the process of 3D printing with PLA plastic material and investigates the geometric deviation and size of holes by different printing conditions and printing directions. The theoretical model is built to analyze the causes of geometric errors and dimensions that is to propose the compensation for dimension. Research results show that the size error is directly proportional to the print layer thickness and then predict functions of size error has proposed. Research results can be applied exclusively in design and production parts by 3D printing technology.

Key words: 3D Printing, Design, Dimensional deviation, PLA filament.

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1. INTRODUCTION

3D printing technology is one of the fastest-growing manufacturing technologies today. This technology directly creates products with complex profiles without the use of multiple tools. Products made from 3D printing are applied in fields from engineering, fine arts to medicine using the layering principle. [1]. This technology is being widely used in the field of manufacturing with many materials applied from polymer resins, resins, metals, to biological materials [2]. Among the branches in 3D printing, Fused Deposition Modeling (FDM) is one of the most popular technologies in which objects are created directly from computer-aided design (CAD) models using the principle of a thin layer of plastic fiber material through heated nozzle [3, 4]. FDM is mainly used for making prototypes for molding processes. Besides, FDM is also used to produce direct replacement parts for small machines. The limitation of products made with FDM is that they have low mechanical properties. To gradually overcome the above disadvantage, there have been many types of research and applications of hybrid technologies to improve the mechanical properties of parts by many methods such as combining, mixing different materials, and treating temperatures during printing, combining ultrasonic vibration during printing [5-7]. Besides improving the mechanical properties of products, geometric accuracy is also interested in many scientists. Factors considered affecting 3D printing product size accuracy include printer structural errors, including table bed flatness, drive mechanism. Besides, the effects of print layer thickness, material heating process, and shrinkage during cooling should also be controlled. [8-11]. Detailed printing directions also have a lot of research to find the causes of errors. Because in the formation of objects in layers, one on top of the other, products with an inclined or arc shape will create a ladder shape on the curved surfaces of the product. [12]. Current, the degree of size error depends greatly on the size of the details, surface topography and geometrical profile. In the this paper, the author presents the size error of round holes in the range from 5 to 10mm in 02 directions of horizontal and vertical printing with 04 different printing modes. To provide a specific and systematic view of errors occurring in 3D printing technology. The research results serve as a prerequisite for further studies to find the value of error correction during 3D printing design, reduce errors and shorten the post processing after printing.

2. EXPERIMENTAL PROCEDURES

To conduct experiments, first, the rectangular block is designed as an object using CATIA V5 software, the block size is 20x20x110mm. Round holes are made through the face of the block with a hole diameter of 5, 6, 7, 8, 9 and 10mm. The 3D CAD model is then converted to a triangular grid pattern (triangle) with STL format, a specialized mesh format for 3D printing. STL files continue to be processed by Ultimaker Cura 3D printing software. The model has been layered by different conditions, and then transferred to G-Code. G-Code files are exported to 3D printers (Creality Ender 3) for printing models. Test samples are printed by biodegradable polylactic acid (PLA) 1.75mm via print nozzle 0.4mm. After printed, the surface of the products has been surveyed on the Microscope Cameras from Teledyne Lumenera to observe the layer structure. Images were then be reconstructed by CAD software to analyze errors on surface. The research results have clarified the relationship between the ratio of a hole size error and printing layer thickness.

In the process of setting parameters on Cura, the software features geometric shape simulation and printing process. This simulation makes it possible to predict the shape of an object after printing. Figure 1 shows the object printing process from Ultimaker Cura software and the object surface after printing. From figure 1, it is found that the round hole is perpendicular to the direction of printing (vertical printing) as shown in Figure 1a whose shape is the circles as solid and concentric lines. Meanwhile, the circular hole is located on a plane parallel to the printing direction (horizontal print) as shown in figure 1b with the shape created by discontinuous segments. From this, it can be deduced that the round hole in figure 1a firmer structure with higher accuracy and better surface contact with the round shaft than the circular hole in figure 1b. Similarly, due to the vertical method of layering, the side surface of the object is a sequence of layers stacked according to the thickness to be set. Therefore, the dimensional error in the vertical direction is influenced by the setting parameter which is the print layer thickness. To investigate the size error, each sample is printed in four printing modes and printed in two different directions (vertical and horizontal printing) in which the thickness of the printed layers is divided into four levels including 0.28mm, 0.20mm, 0.16mm and 0.12mm. Detailed print settings are described in table 1. The print results of the print layer thickness of 0.28 are shown in figure 1.

Table 1 Print parameter setup

Parameter	Unit	Value
Print nozzle diameter	mm	0.4
Plastic thread diameter	mm	1.75
Print layer thickness	mm	0.12; 0.16; 0.2; 0.28
Wall thickness	mm	1.2
Top / Bottom layers	count	4
Fill rate	%	20
Print speed	mm/s	50

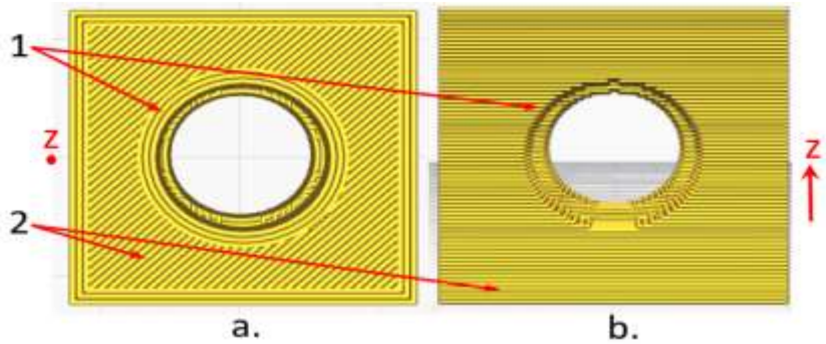

Figure 1 Simulation of the layers in printing by Ultimaker Cura.

From figure 1, it is shown that the profile of the circular hole printed in the vertical direction is almost perfectly circular throughout from the bottom to the top. While the shape of the round hole is printed in a rough, horizontal direction.

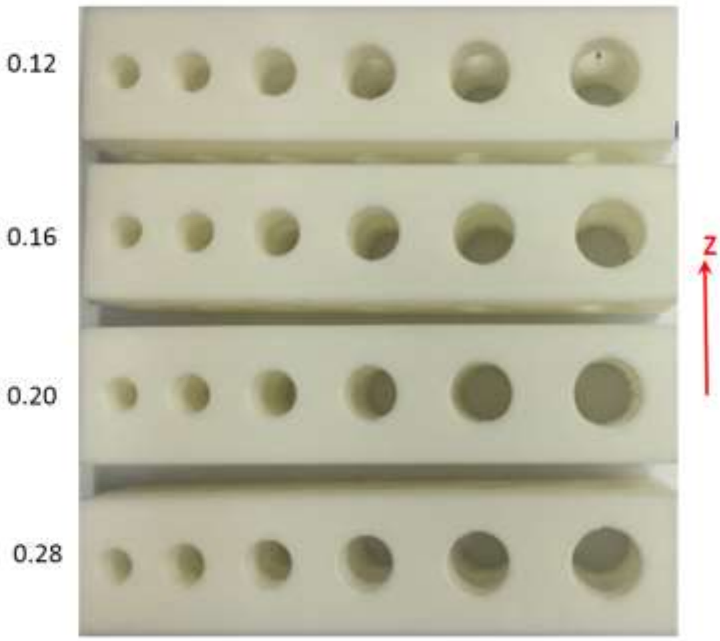

Figure 2 Samples was printed from 3D printer under different conditions.

In order to analyze the profile of the round holes, the printed sample was observed under a microscope. Setting the sample on microscope optical machine is shown on figure 3.

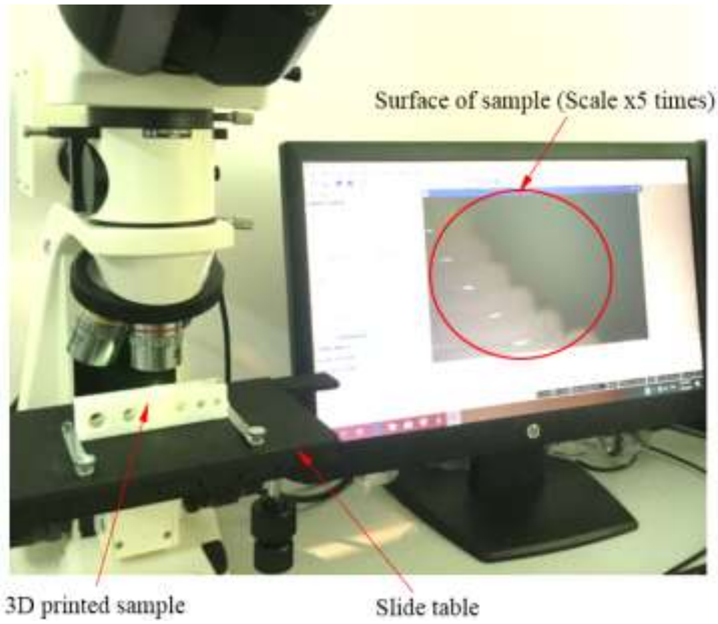

Figure 3 Measurement setting of the sample on microscope optical machine

3. EXPERIMENT RESULTS

The objects are checked for size errors by micrometer measuring holes. The results show that the vertical print holes are about the same size and shape as the original design. Particularly, the printed holes in the horizontal direction have changes in surface undulating, the degree of undulating depends on the thickness of the printing layer. To better understand the cause of the size error that increases with the thickness of the print layer, the print surface is observed under a magnifying microscope for 5 times on the Microscope Cameras as shown in figure 4

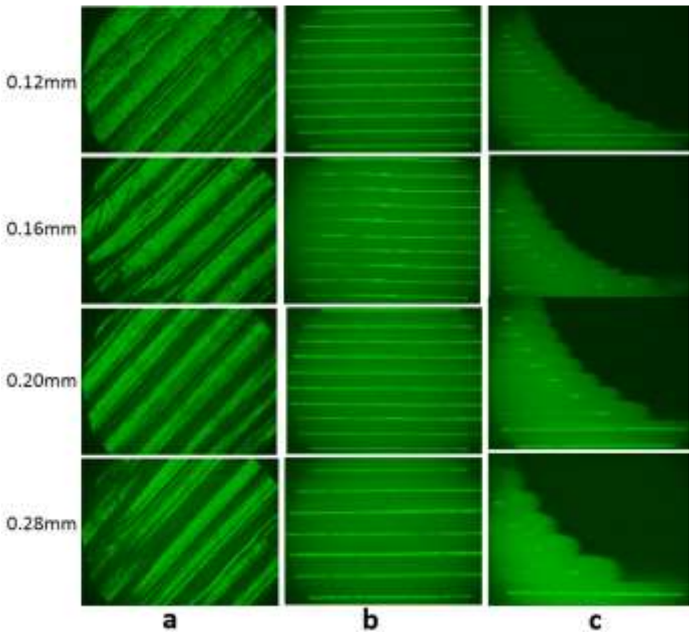

Figure 4 Image of sample surface were printed under different layer thickness; a. Top view, b. Side view, c. at corner of hole

Figure 6 shows that, when the product is printed with a thickness of 0.12mm layer has a smoother surface, the number of layers printed more. The arcs of the circle are more even and continuous than the rest of the print modes. The product prints in 0.28 mode for the poorest quality, with intermittent layers of space and discontinuous arcs. To understand the dimensional errors, the CAD model was reconstructed as described in figure 7. In which, the inner circle is the design part, the outer part describes the cross section of the product after printing. The underscore is the size error of the object after printing compared to the original design. Between the design circles (inside) and the printed layers there is a tangent section. The tangent line is made up of an arc whose diameter is the same as the print layer thickness.

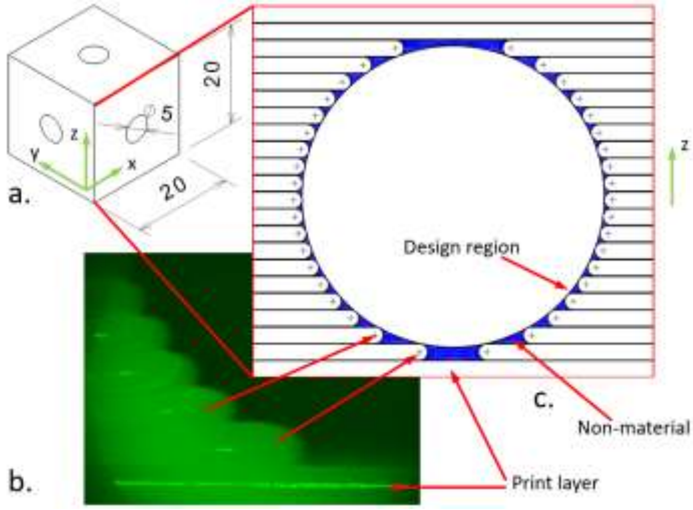

Figure 5 Model of vertical section of sample with printed layers;
a. part design; b. printed sample; c. model develop

Figure 7, we can easily observe and can count the number of contacts between the design circle and the arcs on the holes. It can be seen that the more the hole profile is in contact with the design circle, the lower the size error. The models are then further developed for the remaining cases and are shown in figure 8. In particular, the circles on the first line describe the hole surface profile when designing and the circles in the remaining line describe the product in landscape printing in four different printing modes. It can be seen that a hole printed with a thickness of 0.12 gives the least undulating profile and is almost the same as the original design. Meanwhile, the printing layer thickness of 0.28 gives the highest undulating profile and the highest dimension errors. The size of the diameter of the circular holes is also measured at the average line, the measurement value is always greater than the design value. Also, the error increases as the thickness of the printing layer increases. It can conclude that the higher the thickness of the print layer causes the bigger the size error.

4. MODEL DEVELOPMENT

To determine the deviation of dimension, the surface area of samples are rebuilt on AutoCAD and measured. The measurement results are described in table 2 and Eq. (1) is applied to calculate the area error. The deviation of areas are presented in Table 3.

$$\Delta(\%) = \frac{A_d - A_p}{A_d} \times 100 \qquad (1)$$

Where A_d and A_p are areas of design and print respectively

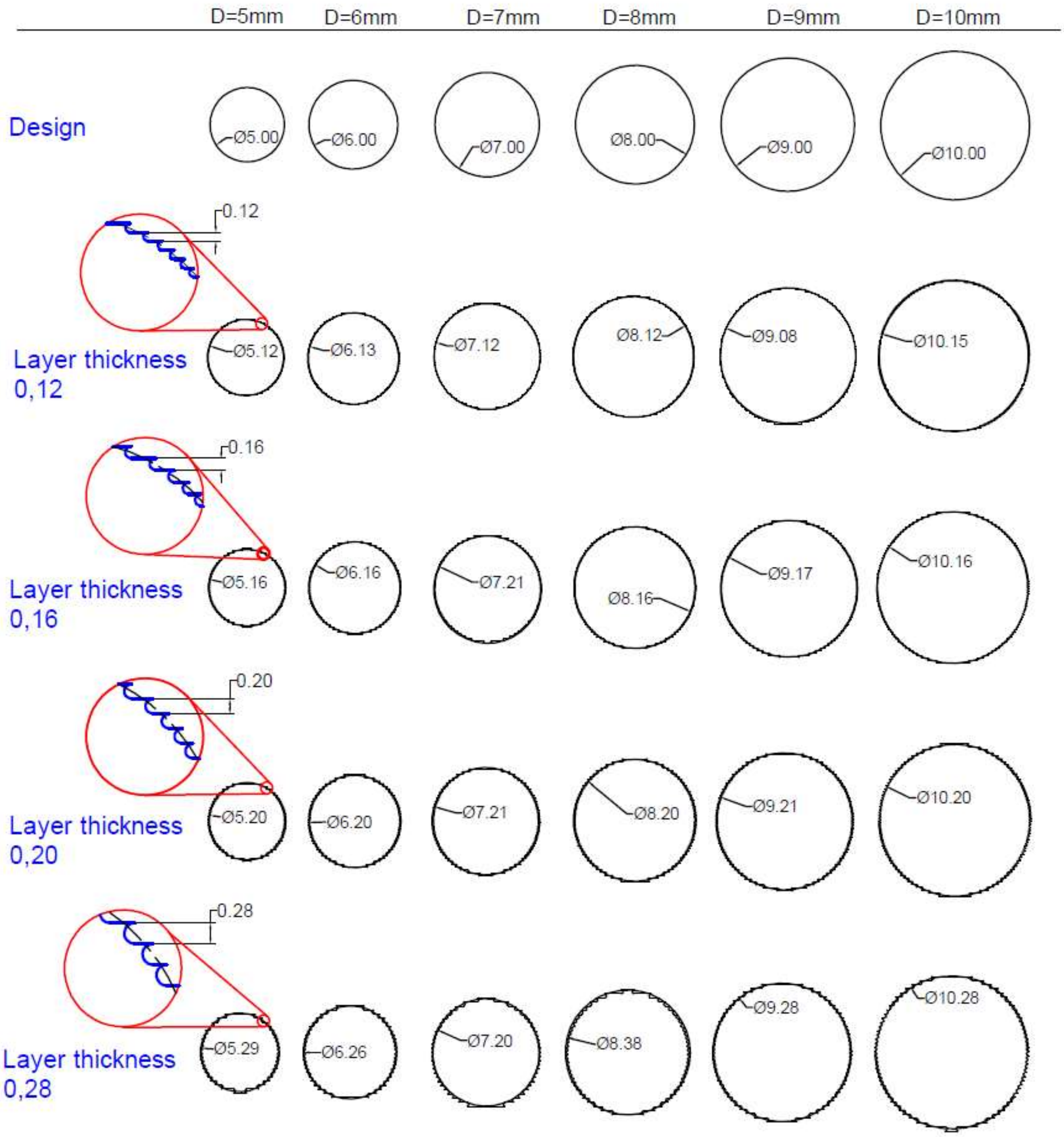

Figure 6 Simulation of curve profile in design and 04 printing modes.

Table 1 Measurement results of cross-section area on CAD model

Diameter (mm)		**Area by layer thickness (mm^2)**			
		0.12	**0.16**	**0.2**	**0.28**
5	19.63	20.07	20.27	20.35	20.46
6	28.27	28.82	29.07	29.26	29.55
7	38.48	39.13	39.35	39.56	40.01
8	50.56	51.05	51.31	51.58	52.06
9	63.61	64.46	64.72	65.00	65.63
10	78.54	79.25	79.76	80.17	80.71

Table 2 Error of the size of the hole is calculated percentage

Diameter (mm)	Error size by layer thickness (%)			
	0.12	**0.16**	**0.2**	**0.28**
5	2.24	3.27	3.67	4.23
6	1.96	2.84	3.52	4.51
7	1.70	2.25	2.80	3.97
8	0.96	1.48	2.01	2.97
9	1.33	1.74	2.18	3.18
10	0.91	1.56	2.09	2.77

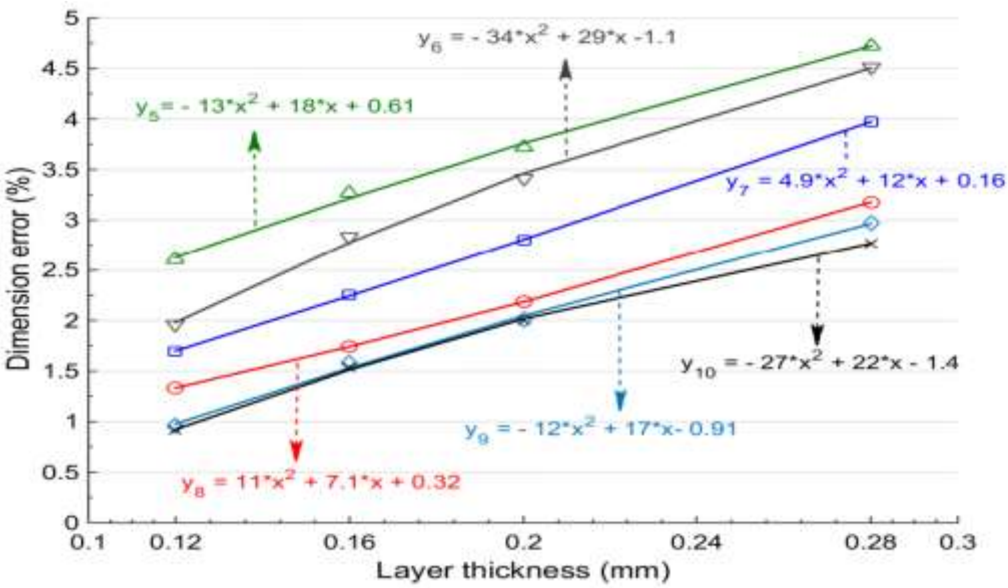

Figure 7 Simulate size errors under different print conditions

Figure 9 describes the hole size error in the case of horizontal printing with 04 different printing modes. The horizontal axis indicates printing conditions (layer thickness). The vertical axis represents the dimension error in the percentage of the surface area of the hole. Marks (Δ), (∇), (□), (°), (◊), and (×) present the value of the size error for holes ϕ5, 6, 7, 8, 9, and 10mm respectively. The curves along with functions show the trend of size errors. The figure also shows the trend of the size error that increases following the layer thickness. Moreover, the smaller size hole is the bigger error. The best-fitting curves are used to obtain predict functions of size error trend for each printed case as shown in Eq. (2~7).

$$y_5 = -13x^2 + 18x + 0.61 \quad (2)$$

$$y_6 = -34x^2 + 29x - 11 \quad (3)$$

$$y_7 = 4.9x^2 + 12x + 0.16 \quad (4)$$

$$y_8 = 11x^2 + 7.1x + 0.32 \quad (5)$$

$$y_9 = -12x^2 + 17x + 0.91 \quad (6)$$

$$y_{10} = -27x^2 + 22x + 1.4 \quad (7)$$

In Eqs., y is a dimension error for the hole, x is printing layer thickness. Eqs can be used for estimate a size compensation coefficients. It can be conclusion, when design for 3D printing as in this study, components with printed holes in the vertical direction, the hole size should be smaller than the desired size to be printed, which value is equal to the corresponding value of y as shown in the Eqs. above

5. CONCLUSION

In this paper, the investigation for the dimensional error of the hole in 3D printing was carried out. The cause of the errors has also been mentioned and analyzed. The surface of the material after printing was also presented. The profile of the round hole in the four printing modes was also described. This study has calculated the error rate and provide predict function to estimate size errors and propose a size compensation coefficients. Research results can be applied exclusively in design and production parts by 3D printing technology.

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