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Research Article

THE RELATIONSHIP BETWEEN THE FUSION TEMPERATURE AND DIMENSIONAL ACCURACY OF 3D PRINTED PARTS

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ABSTRACT

The aim of this study is to investigate the relationship between the fusion temperature and dimensional accuracy of the 3D printed components. The Computer Aided Design (CAD) model of specimens were prepared using Autodesk Inventor Software. Then the models were exported to STL file format for rapid prototyping. Prusa İ3 desktop type 3D printer with 90-300 microns layer height manufacturing capacity was used to produce the samples. The printer settings were prepared with Simplified3D software. Infill density and layer height of specimens were determined as 20% and 200 microns, respectively. The heated bed temperature was selected as 60 °C to increase the bonding and surface quality. The specimens were produced as sphere with the diameter of 10 mm. The samples were manufactured with five different extruder temperatures (185, 195, 205, 215, and 220 °C) that directly affect the fusing temperature and process. Three samples spheres were produced for each fusion temperature. After the design and manufacturing processes the dimensions of produced samples were measured with image processing techniques. The obtained results were compared with each other to find the relationship between the dimensional accuracy and fusion temperatures. The results showed that the minimum dimensional error was obtained from the fusion temperature of 185 °C with the value of 0.290797 mm and percentage of 3%.
Keywords: Bonding and surface quality, coordinate measurement machine, dimensional accuracy, fusion temperature, image processing.

1. INTRODUCTION

Additive manufacturing technologies have developed significantly in order to integrate manufacturing companies with Industry 4.0 technologies. For this purpose, several techniques are used to improve the manufacturing processes in additive manufacturing. Rapid Prototyping Technologies that is the one of the additive manufacturing method, has been investigated in many academic studies.

3D printing important technique among the Rapid Prototyping methods has commonly preferred for many different application areas such as automotive, aerospace, food, medicine and

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biomechanical industry because of its fast and low cost manufacturing ability. 3D Printing creates the geometries and structures from 3D dimensional model data. According to ASTM Committee F12, "3D printing is the fabrication of objects through the deposition of a material using a print head, nozzle, or other printing technologies. 3D printing is a process of using successive layers of printed material to form solid 3D objects of virtually any shape from a digital model" [1]. This technique was first developed by Charles Hull in 1986 as stereolithography (SLA) and it had a great deal of developments, such as inkjet printing, fused deposition modeling (FDM), powder bed fusion, contour crafting (CC) etc. [2].

Most commonly used method of 3D printing is known as Fused Deposition Modelling (FDM). FDM brings parts onto a base plate material with deposition of the stream of hot viscous material. Solidification of the molten material is obtained by natural cooling; so theoretically any thermoplastic or heat fusible material can be used in this process [3]. It has some advantages advantages such as high manufacturing speed, low cost and simplicity beside this there are some disadvantages such as weak mechanical properties, layer-by-layer appearance and poor surface quality. Although mechanical properties of the produced parts with FDM can be improved using fiber-reinforced composites, there are some factors that should be taken into account such as fiber orientation, bonding between the fiber and matrix and void formation in 3D printed parts [2]. The surface quality and dimensional accuracy of parts with high surface roughness cause to the dimensional errors. For these parts, it is much more significant to reach the sufficient dimensional accuracy on the top part of the surface [4]. There is a thermal energy of the extruded material because of the melting solidification mechanism of FDM and the formation of bonds among filaments. Bonding quality is changed significantly with this thermal energy [5, 7]. Sun et al. found in their study that the nozzle & environment temperatures and cooling condition had important effects on bonding & surface quality and dimensional accuracy [5, 6].

Image Processing provides different forms of an image to get improved forms or extracting some convenient features from it. Image Processing Systems enclose handling images with two dimensional signals even as applying already set signal processing methods to them [8]. Image processing techniques can be implemented for measurements, determining data such as particles and shape identification, and size distribution [9].

Some important applications of processing are summarized below [8]:

- Visualization; to observe the invisible objects.
- Image sharpening and restoration; to generate a better image.
- Image retrieval; to seek for the image of interest.
- Pattern measurement; to measure several objects in the image.
- Image Recognition; to differentiate the objects in the image.

In this study; the relationship between the fusion temperature and dimensional accuracy of the 3D printed components was investigated. The specimens were produced as sphere with the diameter of 10 mm. The samples were manufactured with five different extruder temperatures (185, 195, 205, 215, and 220 °C) that directly affect the fusing temperature and process. Three samples spheres were produced for each fusion temperature. The images of the specimens were acquired using 20.2 Megapixels high resolution CCD camera. The obtained images were processed by different image processing techniques such as binarizing, edge detection, edge enhancement and image correlation.

2. METHODOLO GY

2.1. Design and Producing of Specimens

The dimensional accuracy measurement samples were printed using Prusa İ3 desktop type 3D printer with 90-300 microns layer height manufacturing capacity with the 1.75 mm diameter PLA filament. The printer parameters were set with Simplified3D software (Figure 1).

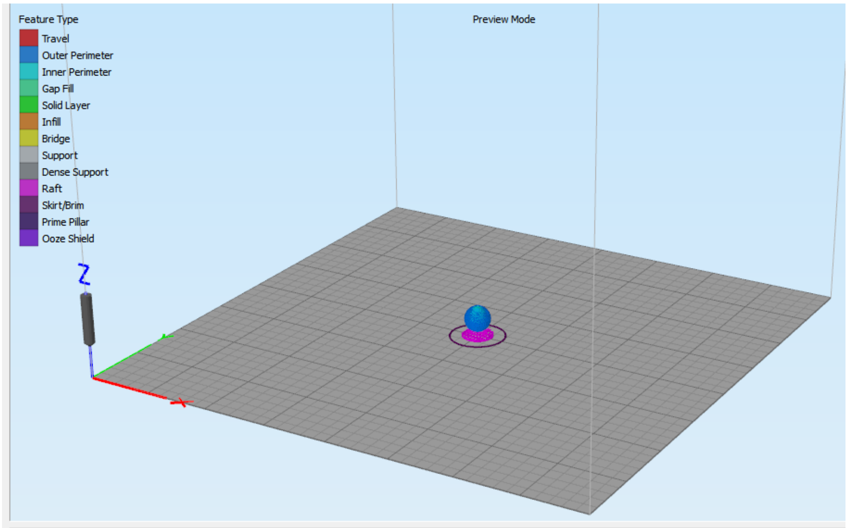

Figure 1. Printer settings of measurement samples.

The technical specifications of Prusa İ3 desktop type Printer were given in Table 1.

Table 1. Technical specifications of Prusa İ3 3D Printer [10].

Properties	Unit	Value
Layer Resolution	μm	90-300
Build Volume	*mm*	200 x 200 x 180
XY Positioning Precision	μm	12
Z Positioning Precision	μm	4
Filament Diameter	*mm*	1.75
Extruder Temperature	^{0}C	170-275
Print Material	-	PLA , ABS

The Prusa İ3 3D printer has ability to produce the parts with PLA and ABS material. The dimensional accuracy measurement specimens were designed using a CAD software (Autodesk Inventor 2018). The samples were designed and produced as sphere with the diameter of 10 mm (Figure 2). The designed models were exported to STL file format for 3D printing. In the printing process; the heated bed temperature was selected as 60 °C increase the bonding and surface quality. The samples were manufactured with five different extruder temperatures (185, 195, 205, 215, and 220 °C) that directly affect the fusing temperature and process. Shell of the specimens were created with the thickness of 0.8 mm Layer heights were selected as 0.2 mm. Number of shells were used as 2 and print speed was determined as 80 mm/s.

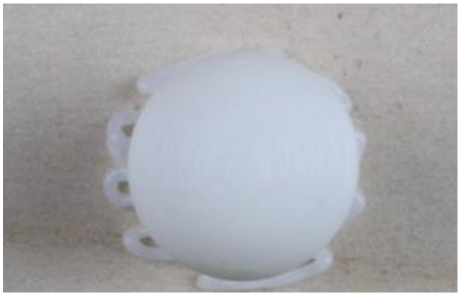

Figure 1. The produced sphere shape samples.

2.2. Image Processing for the Measurement of Dimensional Accuracy

In the digital image processing, an edge can be the result of the changes in light, color and texture. The changes can be used to define the depth, size orientation and surface properties of the image. To filter the unnecessary information to select the edge points, digital analysis of the image can be used. Edge detection is a basic and important tool in the main areas of image processing such as feature detection and feature extraction [11]. The flowchart of the edge detection in image processing is shown in Figure 3.

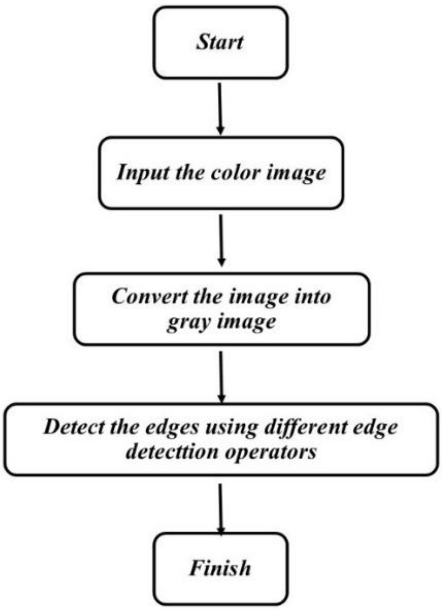

Figure 2. Flowchart of edge detection.

The Prewitt operator was in this study for edge detection. It is a discrete differentiation operator to calculate the relation of the gradient of intensity. The results of Prewitt operator is the gradient vector or the norm of this at each point in the image. Mathematically, the operator uses two 3×3 kernels that are convolved with the original image to calculate approximations of the derivatives one for horizontal changes, and one for vertical as shown in Figure 4.

$$\mathbf{G_x} = \begin{bmatrix} +1 & 0 & -1 \\ +1 & 0 & -1 \\ +1 & 0 & -1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G_y} = \begin{bmatrix} +1 & +1 & +1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} * \mathbf{A}$$

Figure 4. 3x3 kernels used in Prewitt operator.

The roundness errors of the samples were calculated using single trace roundness design. According to the approach, the measured diameter of the sample images were normalized to the designed diameter as 10 mm from the pixel values. The differences of the diameter from design and produced samples were found horizontally and vertically. The mean and standard deviation values were also found.

3. RESULTS AND DISCUSSION

The images obtained from image processing (RGB, Gray scale and edge detected) are shown in Figure 5.

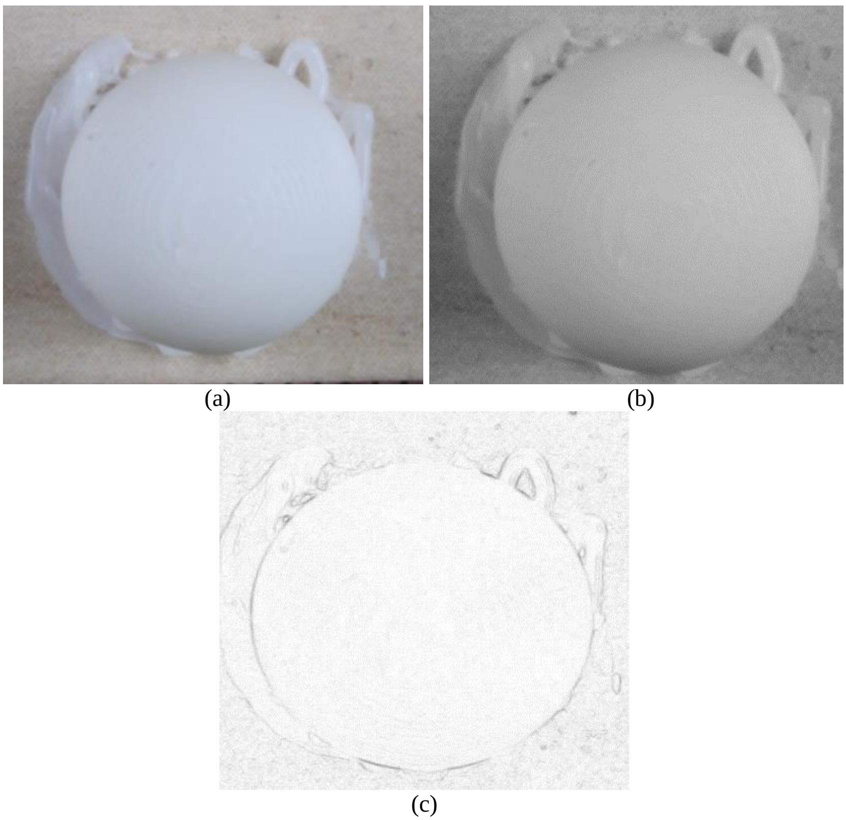

Figure 5. The obtained images from image processing (a) RGB (b) Gray scale (c) Edge detected.

The obtained diameter values from the image processing are given in Table 2.

Table 1. The obtained results from the image processing for dimensional accuracy.

Temperature (°C)	No of Image	Ruler Pixel	Horizontal Diameter (Pixel)	Vertical Diameter (Pixel)	Normalized Horizontal Diameter (mm)	Normalized Vertical Diameter (mm)	Mean of Vertical and Horizontal Diameters (mm)	Difference
	1	582	597	603	10.25773196	10.36082474	10.30927835	0.309278
185	2	585	601	601	10.27350427	10.27350427	10.27350427	0.273504
	3	587	607	601	10.3407155	10.23850085	10.28960818	0.289608
							Mean	***0.290797***
							Standard Deviation	***0.017917***
	1	585	610	609	10.42735043	10.41025641	10.41880342	0.418803
195	2	587	612	616	10.42589438	10.49403748	10.45996593	0.459966
	3	589	615	612	10.44142615	10.39049236	10.41595925	0.415959
							Mean	***0.431576***
							Standard Deviation	***0.024627***
	1	593	621	615	10.47217538	10.37099494	10.42158516	0.421585
205	2	591	619	615	10.47377327	10.40609137	10.43993232	0.439932
	3	587	617	613	10.51107325	10.44293015	10.4770017	***0.477002***
							Mean	***0.446173***
							Standard Deviation	***0.028230***
	1	589	617	617	10.475382	10.475382	10.475382	0.475382
215	2	585	605	611	10.34188034	10.44444444	10.39316239	0.393162
	3	591	625	619	10.57529611	10.47377327	10.52453469	0.524535
							Mean	***0.464360***
							Standard Deviation	***0.066376***
	1	581	617	609	10.61962134	10.48192771	10.55077453	0.550775
220	2	583	611	609	10.48027444	10.44596913	10.46312178	0.463122
	3	581	607	607	10.4475043	10.4475043	10.4475043	0.447504
							Mean	***0.487134***
							Standard Deviation	***0.055665***

The means of differences of the diameters between the designed and produced specimens were computed as, respectively;

- 0.290797 mm for 185 °C fusion temperature,
- 0.431576 mm for 195 °C fusion temperature,
- 0.446173 mm for 205 °C fusion temperature,
- 0.464360 mm for 215 °C fusion temperature,
- 0.487134 mm for 220 °C fusion temperature.

In this study; the nozzle temperature to produce the measurement samples were selected in the range between 185 °C and 220 °C as the processing temperature of the PLA was around 180 °C to

220 °C [12]. For the dimensional accuracy the minimum diameter error was obtained from 185 °C fusion temperature with the value of 0.290797 mm. It was also observed that the diameter error reached to 0.487134 mm for 220 °C fusion temperature environment. The dimensional error was about 3% for 185 °C while it was 4.8% for 220 °C.

The fusion temperature has effect on the elasticity and strength of the produced object with PLA material. While the increasing fusion temperature is resulting with higher ultimate strength, it decreases the elasticity [13]. It can be also understood from the measurement results in dimensional accuracy that the increasing fusion temperature causes to more dimensional errors. The reason of these results can be that higher level of the fusion temperature helps to material to fill the gaps caused from air void and increase the level of ultimate strength. However, it leads to the dimensional errors.

4. CONCLUSION

In this research, the relationship between the fusion temperature and dimensional accuracy of the 3D printed components have been studied. Results showed that:

1. The minimum dimensional error was obtained from the fusion temperature of 185 °C with the value of 0.290797 mm and percentage of 3%.
2. The specimens were produced with the maximum dimensional error with the value of 0.487134 mm and percentage of 4.8% for fusion temperature of 220 °C.
3. It could be concluded from the results that the fusion temperature has important effect for the dimensional accuracy of 3D printed components.

Further researches are planned to understand the effect of the other producing parameters such as infill type, environmental conditions and heated bed temperature effects to the dimensional accuracy of 3D printed components.

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