Examination and analysis of effect of printing parameters on roundness of fused deposition modeling (FDM) parts

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KEYWORDS

3D Printing,
Roundness,
Fused Deposition Modelling,
Dimensional Accuracy,
Geometric Tolerance.

ABSTRACT

The focus of the current research is on how different process variables affect geometrical tolerance, specifically how round a cylindrical PLA component is when printed using fused deposition modelling. Layer Thickness, Infill Percentage, and Print Speed are the three process parameters chosen for the current investigation. Examination and Analysis of Effect of Printing Parameters on Roundness of Fused Deposition Modelling (FDM) Parts is presented. It is found during investigation that layer height is most significant aspect for roundness of fused deposition modelling printed parts. From current analysis, it is found that the minimum roundness value is at 0.12 mm Layer Height, 90% Infill Density and Print Speed 60 mm/s.

1. Introduction

Rapid prototyping is an advanced manufacturing practice that consists of various technologies and methodologies for developing components for a variety of end implementations. Additive manufacturing is one of these advanced manufacturing process which uses only optimum required material with desired dimensional accuracy (Patil et al., 2022). Fused Deposition Modeling (FDM) is a rapid prototyping methodology for 3-D printing of thermoplastics (Nagendra et al., 2018). Steps involved in FDM are shown in fig.1. The very first step of FDM involves creation of CAD model of desired object. In next step, this CAD model is converted into a STL file (.stl extension). Using suitable slicing software, the STL file is then sliced into number of layers and the object is fabricated using a 3D printer. In the last step, fabricated parts are then undergo post-processing for cleaning and finishing based on their application (Deomore & Raykar, 2020; Patil et al., 2021; D'Addona et al., 2020; Raykar & D'Addona, 2019; Raykar et al., 2020).

The quality of the product produced which use Fused Deposition Modeling (FDM) method is much more reliant on the process parameters chosen (Nagendra & Ganesha Prasad, 2020). Geometric tolerance is a vital criterion for determining the functionality of products manufactured for industry applications which include shafts, bearings, and pulleys. Therefore, selection of particular set of process parameters is essential for better geometric properties and applicability.

Boschetto and Bottini (2016, 2014) discussed how the orientation of pieces has a significant effect on geometrical errors. Vertical walls had the smallest deviations, according to the findings. A smaller or larger angle than 90° results in increase in deviations. Using Design of Experiment (DoE) methodologies, Sood et al. (2009) investigated the effect of various factors on geometrical

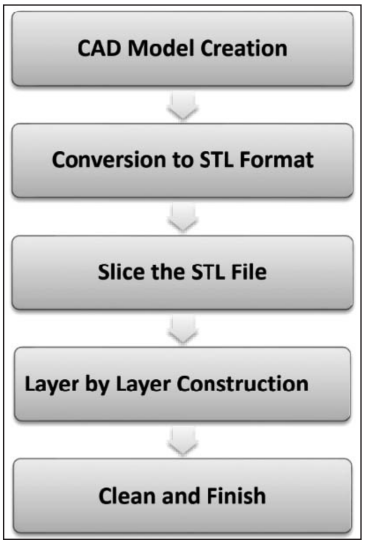

Fig. 1. Steps Involved in FDM. (Deomore & Raykar, 2020)

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accuracy and discovered significant factors and effective parameter configurations to reduce geometrical deviations (Sood, 2011; Sood et al., 2009). A geometry with flexible form surfaces that show deviations from nominal dimensions ranging from 5% to 15% was presented by (Mahesh et al., 2004). A 2.5 mm divergence was brought on by a form distortion in one instance. The impact of process variables on geometrical accuracy hasn't been fully explored yet.

Chinmay et al. (2022) investigated the effect of a process parameter on the surface roughness of FDM parts using Analysis of variance: ANOVA, Mean Effect Plots, and Contour Plots. The parameters that had the greatest influence on surface roughness, in their investigation, were build orientation and layer thickness. They concluded that orientations 0˚ to 15˚ and 85˚ to 90˚, with layer thicknesses ranging from 0.12 to 0.16 mm and infill densities between 80% and 90%, are the optimal working ranges for attaining surface roughness below 6 µm. They used a filament of 1.75 mm diameter and 0.4 mm nozzle diameter.

Dimensional tolerances are studied with two aims: methodical establishment of dimensional tolerances for additive manufacturing processes and optimization of machine parameters and manufacturing impacts to reduce dimensional deviations (Lieneke et al., 2015). The dimensional correctness of a component part is measured by its size (size tolerance) and shape (geometric tolerance, including form, orientation, and location), as per present dimensioning and tolerance standards (ASME Y14.5, 2009; AS1100, 1984). Size variation is very vital when fitting component parts together since size has a direct impact on clearance conditions. In their study on cylindricity errors, Ollison and Berisso (2010) looked at how construction direction, printhead life, and feature size affected cylindricity. With three alternative orientation angles of 0, 45, and 90 degrees, they created two components with diameters of 0.75 and 1 inch. The cylindricity error was found to be lowest at a build angle of 0 degrees and largest at a build angle of 90 degrees after conducting an ANOVA analysis on the components.

From literature review, it can be seen that very few research has been carried out on geometrical tolerances of cylindrical parts. The current work is based on effect of various process parameters on geometrical tolerance particularly on roundness of cylindrical component of PLA printed by Fused Deposition Modeling technology. From previous research, for current analysis the three process parameters are selected named as Layer Thickness, Infill Percentage and Print speed. We solely addressed size variation in roundness of component for the convenience. Size variation is very vital when fitting component parts together since size has a direct impact on clearance conditions.

2. Experimental Setup

The details of experimental setup are given in Table 1 along with the specifications.

To assess effects of parameters on roundness of FDM printed parts three process parameters each of them having three levels are selected. These process parameters and their levels are given in table 2.

Taguchi L_9 array is created using 3 factors at 3 levels for selected process parameters in free trial

Table 1
Details of experimental work.

Item	Details
3D Printing technology	Fused Deposition Modelling
3D Printer	Flashforge Finder 3D printer (140 mm^3)
Filament Diameter	1.75 mm
Nozzle Diameter	0.4 mm
Slicing Software	Flashprint
File Type	STL
Nozzle Temperature	220^{o}C
Infill Pattern	Line
Shell Thickness	0.80 mm
Material	Polylactic Acid (PLA)
Specimen Specifications	Cylindrical Block (r= 10 mm, l=40 mm)
Roundness Measurement	Baker Type 302A dial gauge

Table 2
Process parameters and their levels.

Process Parameters	L1	L2	L3
Layer height (mm)	0.12	0.14	0.16
Infill Density (%)	80	85	90
Print Speed (mm/sec)	50	55	60

version of Minitab software. Table 3 shows the Taguchi L_9 array.

Table 3
Taguchi L_9 Array for selected parameters.

Sr. No	Layer Height (mm)	Infill % (%)	Print Speed (mm/ sec.)	Roundness Value (mm)
1	0.12	80	50	0.12
2	0.12	85	55	0.15
3	0.12	90	60	0.11
4	0.14	80	55	0.14
5	0.14	85	60	0.15
6	0.14	90	50	0.13
7	0.16	80	60	0.18
8	0.16	85	50	0.14
9	0.16	90	55	0.15

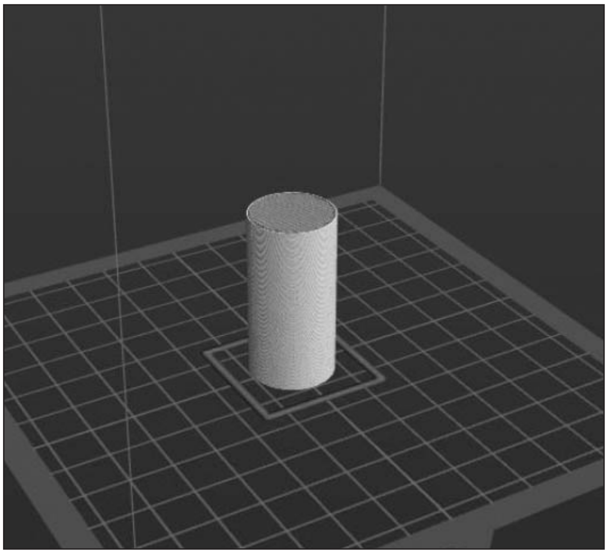
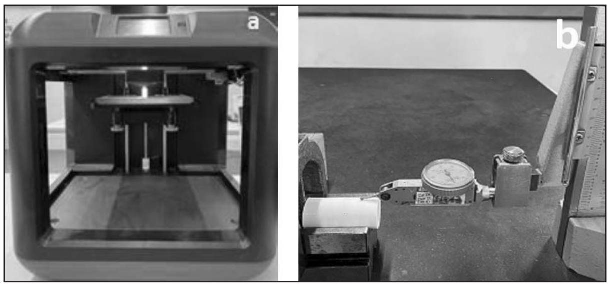


Fig. 2. Slicing of component.



a. 3D printing set up

b. Testing of Fabricated Parts

Fig. 3. Set up of printer and testing of specimen.

The CAD based 3 D model of cyclindrical body of Length 40mm and Diameter 20mm of test specimen is sliced in Flashprint software using set of process parameters Layer Height, Infill Percentage and Print speed which is defined in Taguchi L9 array. Fig. 2 shows the slicing of cylindrical component in Flashprint version 5.

After printing of 9 components (as shown in Fig.3. a) surface roundness measurement is carried out using Baker Type 302A dial gauge portable roundness tester. Measurements (as shown in Fig.3.b) are carried out at 3 different points for every component and mean of those values is considered as final Roundness value for analysis.

3. Results and Discussion

For analysis, Mean Effect Plot for Roundness values are shown in Fig.4, the mean of roundness is 0.127 mm at 0.12 mm layer thickness, 0.140 mm at 0.14 mm layer thickness and 0.157 mm at 0.16 mm layer thickness. Therefore, the minimum mean roundness is found at 0.12 mm layer thickness. The percentage increase in roundness at 0.14 mm layer thickness is 10.5% as compared to 0.12 mm layer thickness. Similarly, the percentage increase in roundness at 0.16 mm layer thickness is 23.6% as compared to 0.12 mm layer thickness. This indicates that smaller layer thickness results in better roundness. So smaller layer height produces nearly circular surface.

The mean of roundness at 80% infill density is 0.147 mm, at 85% infill density is 0.147 and at 90% infill density is 0.13 mm. Therefore, the minimum mean roundness is found at 90% infill density. The roundness at 80% and 85% infill density remains constant, where at 90% it decreases by 11.36% with respect to 80% and 85% infill density.

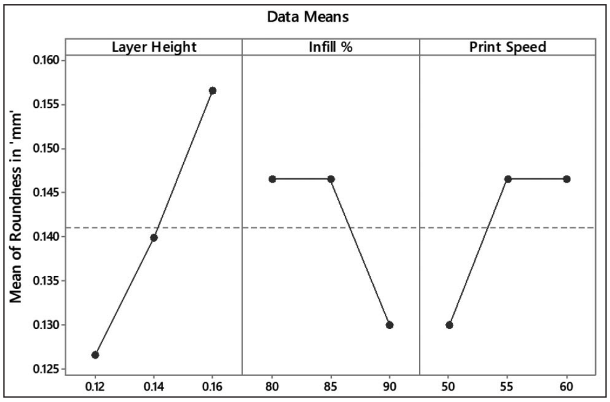


Fig. 4. Mean effect plot of roundness value.

From mean effect plot, it can be observed that the mean of roundness value at print speed of 50 mm/s is 0.13 mm, at print speed of 55 mm/s is 0.147 mm and at print speed of 60 mm/s is 0.147 mm. Therefore, the minimum mean roundness is found at 50 mm/s print speed and remains constant at 55 mm/s and 60 mm/s print speed. The percentage increase in roundness at 55 mm/s print speed is 12.8% as compared to 50 mm/s print speed.

From Response Table 4 for Means, it has been observed that the delta value which is calculated from difference between maximum and minimum mean roundness is 0.0300 for Layer Height followed by 0.0167 for other two parameters (Infill Percentage and Print Speed). Depending on the consequences their significant ranks are also given. From delta value it can be concluded that Layer height has highest delta value therefore it has 1st Rank. Print Speed and Infill percentage has same delta value having Rank 2nd and 3rd respectively. This indicates that Layer height is most manipulating parameter for as far as roundness is concerned.

Table 4

Response table for means.

Level	Layer Height	Infill %	Print Speed
1	0.1267	0.1467	0.1300
2	0.1400	0.1467	0.1467
3	0.1567	0.1300	0.1467
Delta	0.0300	0.0167	0.0167
Rank	1	3	2

The regression equation is an algebraic representation of the regression line and interprets relationship between the response and predictor parameters. The general regression equation can be given as Response = constant + (coefficient * parameter) + ... + (coefficient * parameter). For Roundness the Regression Equation for selected parameters is:

$$\text{Roundness} = 0.086 + 0.750 \times LH - 0.00167 \times IP + 0.00167 \times PS$$

From Regression equation expected roundness values are calculated and compared with actual

Table 5

Percentage error between actual and calculated roundness.

Layer Height	Infill %	Print Speed	Actual Roundness Values	Roundness Values from Regression Eq.	Percentage Error
0.12	80	50	0.12	0.1259	4.69%
0.12	85	55	0.15	0.1259	19.14%
0.12	90	60	0.11	0.1259	12.63%
0.14	80	55	0.14	0.14925	6.20%
0.14	85	60	0.15	0.14925	0.50%
0.14	90	50	0.13	0.1242	4.67%
0.16	80	60	0.18	0.1726	4.29%
0.16	85	50	0.14	0.14755	5.12%
0.16	90	55	0.15	0.14755	1.66%

Table 6

Analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	p-Value
Layer Height	1	0.001350	0.001350	6.11	0.056
Infill %	1	0.000417	0.000417	1.88	0.228
Print Speed	1	0.000417	0.000417	1.88	0.228
Error	5	0.001106	0.000221		
Total	8	0.003289			

roundness values. The percentage error along with actual values and predicted values is shown in Table 5, it has been observed that the percentage error between expected value and actual value ranges between 0.50% to 19.14%. With Layer thickness 0.12 mm and Infill density 85% along with print speed of 55 mm/s has maximum Percentages Error of 19.14%. Moreover, the minimum percentage error is 0.50% with corresponding Layer Thickness 0.14, Infill Density 85% and Print Speed 60.

In above Table DF is degree of Freedom, Adj SS is Adjusted Sum of Squares, Adj MS is Adjusted Mean Squares The p value is a probability, while the f ratio is a test statistic.

To get clarification of the effect of selected process parameters on roundness Analysis of Variance : ANOVA is shown in Table 6. For investigation of process parameters, p-value having confidence level 95% (0.05) is used. Therefore a parameter for whom p value is equal of less than 0.05 is significant parameter. From Table 6, it can be seen that the value for Layer height is 0.056 which implies that layer height is most significant parameter which affects roundness. The other two selected parameters do not show any desirable effect on roundness as their respective p-value for infill percentage and print speed is same which is 0.228.

4. Conclusion

Examination and Analysis of Effect of Printing Parameters on Roundness of Fused Deposition Modeling (FDM) Parts is proposed in this work. Following are some of the conclusions out of this work.

1. Smaller layer thickness results in better roundness. As a result, minimum layer thickness leads to produce circular surface.
2. Analysis of Variance: ANOVA confirms the importance of layer thickness on roundness as p-value for layer thickness is 0.056.
3. From mean effect plot it can be concluded that mean value of roundness for layer thickness 0.12 mm to 0.16 mm ranges from 0.125 mm to 0.160 mm. Mean value of roundness for 0.12 mm layer thickness is 0.127 mm which is minimum as compared to 0.14 mm and 0.16 mm layer thickness.

Acknowledgement

Authors want to acknowledge Inquest: Mechanical Engineering Student Research Forum of D.Y. Patil College of Engineering and Technology for guidance to frame this research article.

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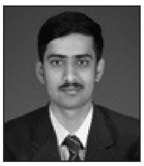

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