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RESEARCH ARTICLE

ANALYSIS OF FAN COOLING SPEED, PRINTING SPEED AND LAYER HEIGHT ON PRODUCT GEOMETRY ACCURACY IN 3D PRINTING

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Abstract

Additive manufacturing is a technology that works by making a product from scratch, layer by layer until it becomes a complete product. An example of additive manufacturing is a 3D printer machine. The process sequence on a 3D Printer machine is the initial stage of creating design drawings in computer-aided design (CAD). Next, materialize the design image into a 3D printing machine. To get the best performance on a 3D printing machine, several parameters are set such as setting the product location during the printing process, setting parameters such as bed temperature and nozzle temperature. Polylactic Acid (PLA) is a filament that is widely used because it is easily decomposed so it is more environmentally friendly, because PLA is made from natural materials such as starch which is used for polymerization. The aim of this research is to determine the effect of variations in fan cooling speed, printing speed and layer height on the accuracy of product geometry in 3D printing using PLA material as well as parameter selection to obtain the most optimal results. The results of this research contained 2 significant factors, namely cooling fan speed and layer height and 1 factor that was not significant, namely printing speed. The percentage contribution of fan cooling speed is 39.52%, printing speed 2.99%, and layer height 11.98%. The optimal variables in this research are level 2 fan cooling speed, namely 100%, level 2 printing speed, namely 70 mm/s, and level 1 layer height, namely 0.1 mm.

Introduction:-

Technology in the industrial world experiences rapid progress every day, one of which is in the manufacturing sector and medical field (Liu et al., 2017; Lee et al., 2017; Shahrubuddin, et. al. 2019; Jain et al., 2022). In the past, the manufacturing process was carried out by cutting or reducing ingredients from products made using conventional methods so that quite a lot of ingredients were wasted. This results in reduced company profits in the material section (Kai, et. al. 2017). When there is material manufacturing technology with the concept of continuously adding material, it can reduce material waste. This technology is known as additive manufacturing (Shahrubuddin, et. al. 2019). An example of additive manufacturing is a 3D printing machine. A 3D printing machine is a machine that can print three-dimensional (3D) objects using the Fused Deposition Modeling (FDM)

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method, which is a product manufacturing method whose process begins by heating the filament to a certain melting point in the nozzle. The filament that has reached the melting point is ready to be printed on the build platform.

From the description above, the problem formulation can be found, namely how the cooling fan speed, print speed and layer height influence the level of product geometric accuracy and how to choose the best product geometric accuracy level parameters using the Taguchi method.

In research conducted by Loflin, et. al. (2018), it was found that the best layer height used for 3D printing machines was 0.1 mm. In research conducted by Cahyati and Marpaung (2022), the best variation for fan cooling speed is 100%. Meanwhile, in research conducted by Kamer et. al. (2022), variations in printing speed of 20, 40, 60, 80, 100, 120, and at a speed of 140 mm/s produce products with decreasing mechanical properties.

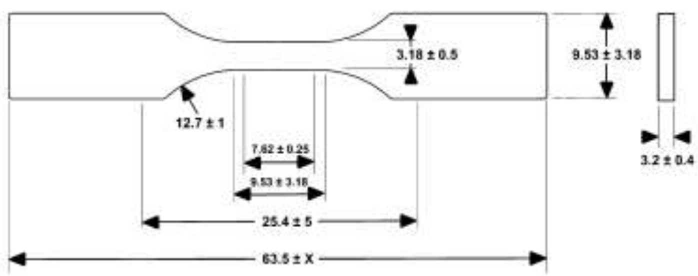
The aim of this research is to determine the effect of selecting fan cooling speed, printing speed and layer height on the level of accuracy of product geometric dimensions on a 3D printing machine and to determine the best parameters that can increase product geometric accuracy.

Research Methodology:-

The method used in this research is an experimental method to test the effect of selecting cooling fan speed, printing speed and layer height on product geometry on a 3D printing machine.

The design of this research is to first determine the independent and dependent variables. Next, look for the degrees of freedom and orthogonal matrices. The next stage is looking for the s/n ratio, optimal parameters, ANOVA, F test, percent contribution and response prediction.

The design used is the ASTM 638 type V standard tensile test specimen.



(Source: Perez, et. al. 2014)

The specifications of the equipment used are a brand 3D printer machine with specifications:
1. Print size: 220 x 220 x 250 mm
2. Layer thickness: 0.1 – 0.4 mm
3. Filament: PLA (1.75 mm)
4. File formats: STL, OBJ, AMF
5. Print speed: < 180 mm/s (standard is 30 – 60 mm/s)

The material used in this research is PLA type filament with the following specifications:
1. Diameter: 1.75 mm
2. Weight: 1 kg
3. Tolerance: ± 0.02 mm
4. Print temperature: 210-235°C
5. Bed temperature: > 50°C

This research uses the method used by Hasdiansah (2023), namely using the Taguchi Method. The Taguchi method in this study uses an L4(2^3) orthogonal matrix with randomization as shown in Table 1.

Table 1:- Research Control Parameters.

No Experiment	Control Parameters		
	Fan Cooling Speed (%)	Printing speed (mm/s)	Layer height (mm)
1	75	60	0,1
2	75	70	0,2
3	100	60	0,2
4	100	70	0,1

Collecting measurement data in this research uses a caliper to measure the size or dimensions of each product that has been made.

Calculation of the collected data is carried out using the equation:

1. S/N Ratio

$$S / N = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} = Y_i^2 \right)$$

2. Optimal parameters

The selection of optimal parameters in this research uses Minitab software with the smaller is better option, because the smaller the resulting dimension difference, the better.

3. ANOVA
   a. Degree of Freedom (DoF)
      (N – 1) = DoF total
   b. Error degrees of freedom
      (N – j) = DoF error
   c. Degrees of freedom for each factor (DoF_A)
      (n – 1) = DoF_A
   d. Sum of Square
      $$SS_T = \sum Y^2$$
   e. Sum of Mean Squares
      $$SS_M = N y^2$$
   f. Sum of Squares for Each Factor
      $$SS_A = \frac{[Total\ A1]^2}{n1} + \frac{[Total\ A2]^2}{n2} - \frac{[Total\ A]^2}{n1 + n2}$$
   g. Sum of squared errors
      $$SS_E = SS_T - (SS_M + SS_A + SS_B + SS_C)$$
   h. The mean square of each factor
      $$MS_A = \frac{SS_A}{DoF_A}$$
   i. Mean squared error
      $$MS_E = \frac{SS_E}{DoF_E}$$
   j. F ratio
      $$F_{ratio} = \frac{MS_A}{MS_E}$$
4. F Test

   The F test is carried out by comparing the F ratio with the F table.
5. Contribution Percent

   $$\rho_A = \frac{SS_A}{S_{Total}} x\ 100\%$$
6. Prediksi Respon

   Average predicted response

   $$\mu = \bar{y} + (y_1 - \bar{y}) + (y_2 - \bar{y}) + y_3 - \bar{y}$$
7. Average confidence interval

   $$\text{Neff} = \frac{\text{Total Eksperiments}}{(1 + \text{Degree of Freedom})}$$

$$CI = \sqrt{\pm\frac{F0{,}05:3:8 \cdot MSE}{Neff}}$$

Then the confidence interval can be written as follows:

μ - CI $\leq$ μ prediksi $\leq$ μ + CI

Results And Discussion:-

The following are the results of 3D Printing products with 4 trials and 3 replications (Figure 1).

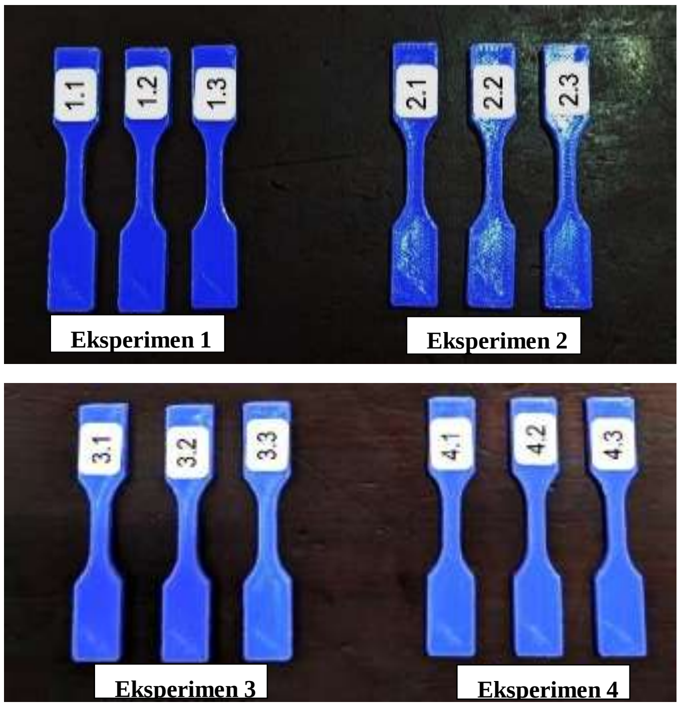


Fig. 1:- Results of 3D Printing Products.

The following are the results of measuring the difference in dimensions of 3D printing products compared to the design drawings created (Table 2).

Table 2:- The Results Of Measuring The Difference In Dimensions Of 3d Printing Products Compared To The Design Drawings Created.

Experiment	Measurement	Nth replication (mm)			Average (mm)
		1	2	3	
1	Length	0,08	0,05	0,05	0,060
	Width	0,41	0,4	0,37	0,393
	Thickness	0,02	0,02	0	0,013
	Center Width	0,54	0,59	0,4	0,510
2	Length	0,12	0,08	0,02	0,073
	Width	0,45	0,39	0,43	0,423
	Thickness	0	0,02	0,02	0,013
	Center Width	0,52	0,54	0,45	0,503
3	Length	0,02	0,08	0	0,033
	Width	0,42	0,37	0,35	0,380
	Thickness	0,01	0	0,02	0,010
	Center Width	0,49	0,5	0,49	0,493

4	Length	0,1	0,1	0,13	0,110
	Width	0,24	0,3	0,28	0,273
	Thickness	0,01	0,01	0,02	0,017
	Center Width	0,41	0,4	0,42	0,407

Next, the average difference in dimensions from each replication was calculated (Table 3).

Table 3:- The Average Difference In Dimensions From Each Replication.

No	Independent variable			Average Difference (mm)			
	Fan Cooling Speed (%)	Printing Speed (mm/s)	Layer Height (mm)	Rep.1	Rep.2	Rep.3	Average
1	75	60	0,1	0,263	0,265	0,205	0,244
2	75	70	0,2	0,273	0,258	0,230	0,253
3	100	60	0,2	0,235	0,238	0,215	0,229
4	100	70	0,1	0,190	0,203	0,213	0,202

After obtaining the average difference from each replication, the calculation is then carried out:

S/N Rasio

The following are the results of the S/N Ratio calculation, dimensional accuracy from the research carried out, which can be seen in the table below (Table 4).

Table 4:- The Results of The S/N Ratio.

Eksp.	Control Factors			S/N Ratio
	Fan Cooling Speed (%)	Printing Speed (mm/s)	Layer Height (mm)	
1	75	60	0,1	12,182
2	75	70	0,2	11,891
3	100	60	0,2	12,782
4	100	70	0,1	13,883
		Min =		11,891
		Maks =		13,883

Optimal Parameters

For optimal parameters, the S/N ratio of smaller is better can be seen in the Table 5.

Table 5:- Optimal Parameters.

Level	**Fan Cooling Speed**	**Printing Speed**	**Layer Height**
1	12,37	12,54	12,81
2	13,06	12,90	12,62
Delta	0,69	0,36	0,19
Rank	1	2	3

For more details, see the following S/N Ratio graphic image in Figure 2.

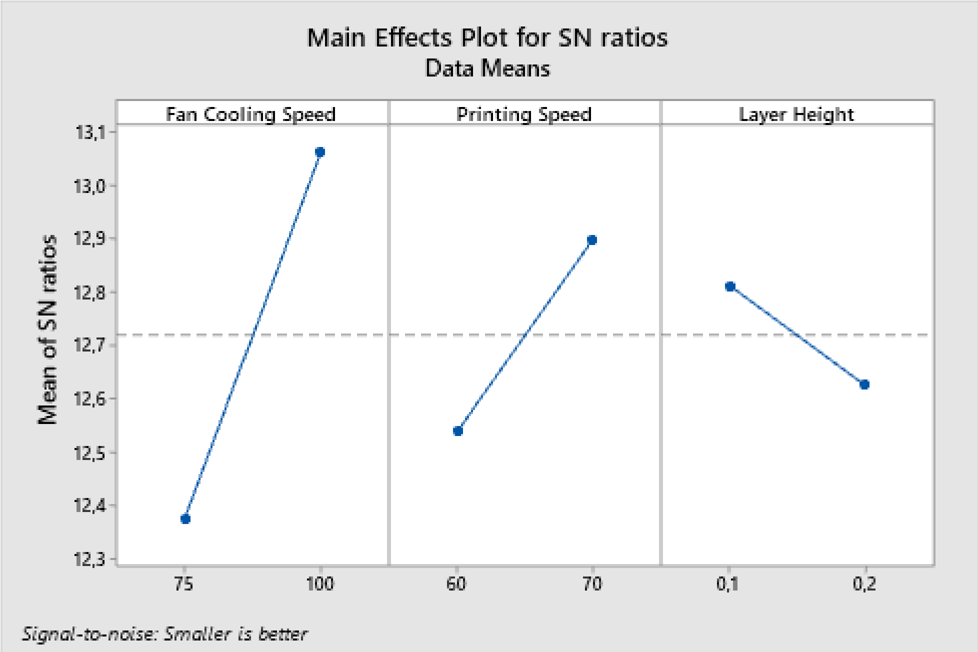


Fig. 2:- S/N Ratio Graphic.

From this graph, the optimal parameters are obtained as seen in the Table 6.
Table 6:- Optimal Parameters.

Control Factors	Level	Value
Fan Cooling Speed	2	100%
Printing Speed	2	70 mm/s
Layer Height	1	0,1 mm

1. ANOVA

The ANOVA calculation is obtained as follows.

a. Total Degree of freedom (DoF)

Total DoF = (N – 1)
Total DoF = (12 – 1)
Total DoF = 11

b. Error degrees of freedom

DoF error = (N – j)
DoF error = (12 – 4)
DoF error = 8

c. Degrees of freedom for each factor

DoF_A = (n – 1)
DoF_A = (2 – 1)
DoF_A = 1

In the same way, the DoF_B and DoF_C calculation results are obtained with values of 1 and 1 respectively.

d. Total Sum of Square

$SS_T = \sum Y^2$

$SS_T =$ 0,2632 + 0,2652 + 0,2052 + 0,2732 + 0,2582 + 0,2302 + 0,2352 + 0,2382 + 0,2152 + 0,1902 + 0,2032 + 0,2132

SS_T = 0,656

e. Sum of Mean Squares

$SS_M = N\, y^2$

$SS_M = 12\ x\ (0{,}232)2$
$SS_M = 0{,}646$

f. Sum of Squares for Each Factor

$$SS_A = \frac{[Total\ A1]^2}{n1} + \frac{[Total\ A2]^2}{n2} - \frac{[Total\ A]^2}{n1+n2}$$
$$SS_A = \frac{0{,}733^2}{6} + \frac{0{,}688^2}{6} - \frac{1{,}421^2}{12}$$
$$SS_A = 0{,}0033$$

In the same way, the SS_B and SS_C calculation results are obtained with values of 0.00025 and 0.0010 respectively.

g. Sum of squared errors

$$SS_E = SS_T - (SS_M + SS_A + SS_B + SS_C)$$
$$SS_E = 0{,}656 - (0{,}646 + 0{,}0033 + 0{,}00025 + 0{,}0010)$$
$$SS_E = 0{,}0038$$

h. The mean square of each factor

$$MS_A = \frac{SS_A}{DoF_A}$$
$$MS_A = \frac{0{,}0033}{1}$$
$$MS_A = 0{,}0033$$

In the same way, the MS_B and MS_C calculation results are obtained with values of 0.00025 and 0.0010 respectively.

i. Mean squared error

$$MS_E = \frac{SS_E}{DoF_E}$$
$$MS_E = \frac{0{,}0038}{8}$$
$$MS_E = 0{,}00048$$

j. F Ratio (A Factor: Fan Cooling Speed)

$$F_{ratio} = \frac{MS_A}{MS_E}$$
$$F_{ratio} = \frac{0{,}0033}{0{,}00048}$$
$$F_{ratio} = 7{,}033$$

In the same way, the F ratio calculation results obtained for factor B and factor C are 0.532 and 2.127 respectively.
The following is the ANOVA table from the calculations above (Table 7).

Table 7:- ANOVA.

Control Factors	DoF	SS	MS	F ratio
Fan Cooling Speed	1	0,0033	0,0033	7,033
Printing Speed	1	0,00025	0,00025	0,532
Layer Height	1	0,0010	0,0010	2,127
Error	8	0,0038	0,00048	1
S_{Total}	11	0,00835	0,00503	10,692

2. F Test

The F test is carried out by comparing the calculated F or F ratio with the F table. This comparison can be seen in the Table 8.

Table 8:- F Test.

Source	F ratio	F tabel	P
Fan Cooling Speed	7,033	4,07	Significant
Printing Speed	0,532	4,07	Not Significant
Layer Height	2,127	4,07	Significant

3. Contribution Percent

The calculation of the contribution percentage is obtained as follows:

$$\rho_A = \frac{0,0033}{0,00835}\ x\ 100\%$$

$$\rho_A = \frac{0,0033}{0,00835}\ x\ 100\%$$

$$\rho_A = 39.52$$

In the same way, the calculation results are obtained and each is as in the Table 9.

Table 9:- Contribution Pencent.

Control Factors	Contribution Percent
Fan Cooling Speed	39,52 %
Printing Speed	2,99 %
Layer Height	11.98 %
Error	45,51 %
Total	100 %

4. Response Prediction

From the optimal parameters that have been obtained, the response prediction can be calculated as follows:

$$\mu = \overline{y} + (y_1 - \overline{y}) + (y_2 - \overline{y}) + y_3 - \overline{y}$$

$$\mu = 0{,}232 + \left(\frac{0{,}235 + 0{,}238 + 0{,}215 + 0{,}190 + 0{,}203 + 0{,}213}{6} - 0{,}232\right) + \left(\frac{0{,}273 + 0{,}258 + 0{,}230 + 0{,}190 + 0.203 + 0.213}{6} - 0{,}232\right) + \left(\frac{0{,}263 + 0{,}265 + 0{,}205 + 0{,}190 + 0.203 + 0.213}{6} - 0{,}232\right)$$

$$\mu = 0{,}232 + (0{,}216 - 0{,}232) + (0{,}228 - 0{,}232) + (0{,}223 - 0{,}232)$$

$$\mu = 0{,}203\ \mathrm{mm}$$

$$\mathrm{Neff} = \frac{\text{Total Eksperiments}}{(1 + \text{Degree of Freedom})}$$

$$\mathrm{Neff} = \frac{12}{1 + (1 + 1 + 1)}$$

$$\mathrm{Neff} = \frac{12}{4}$$

$$\mathrm{Neff} = 3$$

Noted that : $F_{0,05:3:8}$= 4,07 and MSE = 0,00048, then

$$\mathrm{CI} = \pm\sqrt{\frac{F0{,}05{:}\,3{:}\,8 \cdot MSE}{Neff}}$$

$$CI = \pm\sqrt{\frac{4{,}07 \cdot 0{,}00048}{3}}$$

$$CI = \pm\ 0{,}037$$

Conclusions:-

1. Each factor affects the level of accuracy. Fan cooling speed has a significant influence, with the largest percent contribution. Printing speed has an insignificant influence because the comparison results of the F ratio are smaller than the F table, and the percent contribution is the smallest. Layer height has a significant influence, with a fairly large percent contribution, after fan cooling speed.
2. The combination of parameters that provides the most optimal results regarding the level of product geometric accuracy is fan cooling speed 100%, printing speed 70 mm/s, and layer height 0.1 mm. With this combination, you will get the most optimal geometric accuracy results from 3D printing products.

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