Implementation Of Analytic Hierarchy Process to Determine the Optimal FDM Process Parameters

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ABSTRACT: FDM has limitations such as the appearance of seam lines between layers leading to poor surface finish that could be resulted by incorrect process parameter selection. This research applied the Analytic Hierarchy Process (AHP) method to determine the best process parameter that enables optimum surface finish and dimensional accuracy. The AHP was conducted to calculate the weights of the surface roughness. The weights were verified by the consistency analysis and confirmed by referring to other studies. The layer thickness was the most important process parameter for both dimensional accuracy and surface finish. The results shows that AHP can be used to choose the optimum process parameters to achieve best surface finish and dimensional accuracy. of printed parts.

Keywords: *Fused Deposition Modeling (FDM), Analytic Hierarchy Process (AHP), Surface Roughness*

1. INTRODUCTION

Valerga et al., (2018) analyzed various PLA filament conditions to determine their effect on surface quality, along with the dimensional accuracy and tensile strength of the FDM printed component. Extrusion temperature, humidity, and pigmentation color were called factors. They concluded that lack of pigmentation and low extrusion temperature was superior to improved surface efficiency [2]. Pérez et al. (2018) using a cylindrical-shaped specimen instead of a cuboid-shaped specimen. The parameters examined were layer thickness, printing speed, extrusion temperature, and shell thickness in their analysis. The findings showed that low layer thickness favored strong surface finishing, but extrusion temperature and printing speed were negligible [3]. AHP is a systematic methodology to coordinate and analyze complicated judgments. It provides a comprehensive framework for quantifying the weights of decision-making parameters [4].

2. METHODOLOGY

In this research, the decision making process is address using the hierarchical structure method as in Figure 1.

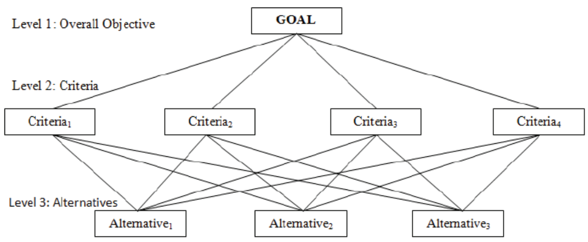

Figure 1 Three-level hierarchical decision process

2.1 AHP Analysis on Surface Roughness

From the literature review, best five criteria that have significant effect on the surface roughness parameter are listed as:

1-Layer Thickness (Extremely important = 9)
2-Build Orientation (Highly important = 7)
3-Raster Angel (moderately important = 5)
4-Raster Width (Low importance = 3)
5-Air Gap (Very low importance = 1)

Based on these rankings, a pairwise ratio comparison that forms the AHP matrix as in Table 1 was constructed.

Table 1 AHP matrix for the surface roughness parameter

	Layer thickness	Build Orientation	Raster Angel	Raster Width	Air Gap
Layer thickness	1	1.286	1.8	3	9
Build Orientation	0.778	1	1.4	2.333	7
Raster Angel	0.556	0.714	1	1.667	5
Raster Width	0.333	0.428	0.6	1	3
Air Gap	0.111	0.143	0.2	0.333	1

From Table 1, a normalized matrix was created. The average of each raw in the normalized matrix is then taken as a representation of the weight. This weight marks the importance of its corresponding criterion. The weights are shown in Table 2.

Table 2 Weights obtained from Table 1

Criteria	Weight
Layer thickness	0.359
Build Orientation	0.28
Raster Angel	0.2
Raster Width	0.12
Air Gap	0.039

2.2 Consistency Analysis

After the weights are calculated, the consistency analysis was carried out to make sure that the calculation is consistent. This is done by firstly calculating the weighted sum and the ratio of the weighted sum over the weight from Table 1. The AHP consistency analysis is shown in Table 3.

Table 3 Consistency Analysis

	Layer thickness	Build Orientation	Raster Angel	Raster Width	Air Gap	Weighted sum	Weighted sum/weight
Layer thickness	1(0.359)	1.286(0.28)	1.8(0.2)	3(0.12)	9(0.039)	1.79	4.986
Build Orientation	0.778(0.359)	1(0.28)	1.4(0.2)	2.333(0.12)	7(0.039)	1.39	4.964
Raster Angel	0.556(0.359)	0.714(0.28)	1(0.2)	1.667(0.12)	5(0.039)	0.99	4.95
Raster Width	0.333(0.359)	0.428(0.28)	0.6(0.2)	1(0.12)	3(0.039)	0.596	4.966
Air Gap	0.111(0.359)	0.143(0.28)	0.2(0.2)	0.333(0.12)	1(0.039)	0.199	5.1

The λ_{max} is then calculated by taking the average in of all the ratios calculated in Table 3. This is shown in Equation 1.

$$\lambda_{max} = \frac{4.986 + 4.964 + 4.95 + 4.966 + 5.1}{5} = 4.993 \quad (1)$$

The Consistency Index (CI) is calculated through equation 2. Where n is the number of the criteria.

$$CI = \left|\frac{\lambda_{max} - n}{n - 1}\right| = \left|\frac{4.993 - 5}{4}\right| = 0.00175 \quad (2)$$

The Consistency ratio is subsequently calculated by dividing the consistency index over random index (RI) which is restricted to the value of 1.12 because we are using 5 criteria. This is shown in equation 3.

$$Consistency\ ratio = \frac{CI}{RI} = \frac{0.00175}{1.12} = 0.00156 \quad (3)$$

Since consistency ratio < 0.1, the system is said to be consistent.

2.3 Finalized Weights

Since consistency ratio < 0.1, the system is consistent, and the weights are finalized as following. This consistency test is crucially important as it tests the correctness of the whole process too. In many cases, the process has to be repeated a number of times until it reaches an acceptable level of consistency to allow us to consider the values of the weights as reliable. The finalized weights are shown in Table 4.

Table 4: Finalized weights of the chosen criteria for the surface roughness parameter.

Criteria	Weight
Layer thickness	0.359
Build Orientation	0.28
Raster Angel	0.2
Raster Width	0.12
Air Gap	0.039

These weights mark the priorities that should be given in choosing the best surface roughness, in addition it will provide exact empirical values of the importance of each creation in the process. Next to, demonstrate how the process works, given the values in Table 5, the best value can be chosen in each criterion based on the correlations driven from the literature.

Table 5 The values for the surface roughness criteria in three different options.

ABS Material	Layer thickness (mm)	Build Orientation (degree)	Raster Angel (degree)	Raster Width (micrometer)	Air Gap (mm)
Option 1	0.05	1	1	100	0.2
Option 2	0.15	45	15	200	0.5
Option 3	0.25	90	30	300	1

Table 5 can be normalized by dividing each criterion over the highest value at the criterion and the ratio must be with respect to the relationship or the criterion with the surface roughness. Table 6 shows the normalized values.

Table 6 The normalized version of Table 5

ABS Material	Layer thickness (mm)	Build Orientation (degree)	Raster Angel (degree)	Raster Width (micrometer)	Air Gap (mm)
Option 1	0.05/0.25= 0.2	1/90 = 0.01	0	100/100= 1	0.2/1=0.2
Option 2	0.15/0.25= 0.6	45/90 = 0.5	0/15= 0	100/200 =0.5	0.5/1=0.5
Option 3	0.25/0.25 = 1	90/90 =1	0/30 = 0	100/300 = 0.33	1/1=1

This overall imaginative quality could be calculated by Equation 4. Where C is the criterion and w is its weight and i is the number of the criterion.

$$Overall(factor) = \sum C_i w_i \quad (4)$$

By using Equation 4 we get the following values:

1- Option 1: 0.22
2- Option 2: 0.43
3- Option 3: 0.718

Therefore, the best option is option 3 for the best surface finish.

3. CONCLUSION

AHP is used to choose the best process parameters for FDM to obtain best surface roughness and dimensional accuracy. Layer thickness is the most important parameters to both dimensional accuracy and surface finish. The extrusion temperature is the second rank of effectiveness to the dimensional accuracy while it did not have a considerable effect on the surface finish. The build orientation is the second most effective in surface finish while it is the third to the dimensional accuracy. The raster angle and raster width are the third and fourth effective criteria on the surface finish respectively and the raster orientation is ranked as the fourth creation among the dimensional accuracy criteria. This paper shows that AHP can be used to choose the best parameters without the need to conduct experiments and it saves time.

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REFERENCES

[1] H. Rahman, T. D. John, M. Sivadasan, and N. K. Singh, “Investigation on the Scale Factor applicable to ABS based FDM Additive Manufacturing,” *Mater. Today Proc.*, vol. 5, no. 1, pp. 1640–1648, 2018.

[2] A. P. Valerga, M. Batista, J. Salguero, & F. Girot, (2018). Influence of PLA filament Conditions On Characteristics Of FDM Parts. *Materials*, *11*(8).

[3] M., Pérez, G. Medina-Sánchez, A. García-Collado, M. Gupta, & D. Carou, (2018). Surface Quality Enhancement Of Fused Deposition Modeling (FDM) Printed Samples Based On The Selection Of Critical Printing Parameters. *Materials*, *11*(8).

[4] N. K. Mandavgade, V. N. Kalbande, R. R. Bilawane, M. T. Kanojiya, and C. U. Padole, “AHP for ranking effect of qualitative factors in uncertainty measurement of material testing,” *Mater. Today Proc.*, 2021.