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APPLICATION OF ANALYTIC HIERARCHY PROCESS TO DETERMINE AND OPTIMIZE FDM PRINTING PROCESS PARAMETERS FOR TENSILE STRENGTH

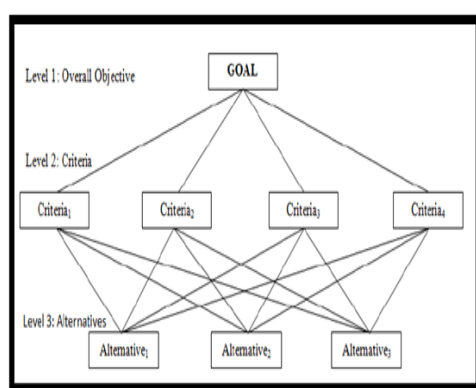Shajahan Maidin*, Amira Atiqah Sah Azmi, Norilani Md Nor hayati, Haroun Albaluoosh

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Graphical abstract

Abstract

This paper investigates the application of the analytic hierarchy process (AHP) to optimize Fused Deposition Modeling (FDM) printing process parameters to obtain the best tensile strength from several test specimens. To proceed with applying the AHP, the data to list the most effective process parameters that affect the tensile strength was collected from various journals. After obtaining the best option from the AHP analysis, a tensile strength test was conducted to validate the data. Standard ASTM specimen with a gauge length of 57 mm and a gauge width of 13mm and the material specimen of Polylactic Acid (PLA) was printed using an open-source FDM printer. The result shows that from the AHP, option 3 has the highest score of 0.7723, and the best process parameter for tensile strength of the FDM process is layer thickness of 0.3mm, infill density of 80%, build orientation of 0^0, and raster angle of 60^0. Finally, to validate the result from the AHP, the tensile strength test of option 3 was done, and it shows that option 3 has the highest tensile strength, which is 2556 N/m² compared to the other two options. This study is significant because it shows that AHP is feasible to obtain the optimum proses parameters that influence the mechanical properties of the printed test specimens.

Keywords: AHP, FDM, PLA, Tensile strength, Process Parameters

Abstrak

Makalah ini menyelidiki penerapan proses hierarki analitik (AHP) untuk mengoptimumkan parameter proses pencetakan pemodelan pemendapan fusi (FDM) untuk mendapatkan kekuatan tegangan terbaik dari sejumlah spesimen ujian. Data untuk menyenaraikan parameter proses yang paling berkesan yang mempengaruhi kekuatan tegangan yang diperlukan dikumpulkan dari pelbagai jurnal. Setelah mendapat pilihan terbaik dari analisis AHP, ujian kekuatan tegangan dilakukan untuk mengesahkan data. Spesimen standard ASTM dengan panjang 57 mm dan lebar 13 mm, dan spesimen bahan Asid Polylactic (PLA) dicetak menggunakan pencetak FDM sumber terbuka. Hasilnya menunjukkan bahawa dari AHP, pilihan no 3 mempunyai skor tertinggi 0.7723 dan parameter proses terbaik untuk kekuatan tegangan proses FDM adalah ketebalan lapisan 0.3mm, ketumpatan pengisian 80%, orientasi binaan 0^0, dan sudut raster 60^0. Akhirnya, untuk mengesahkan hasil dari AHP, ujian kekuatan tegangan pilihan no 3 telah dilakukan, dan ini menunjukkan bahawa pilihan no 3 mempunyai kekuatan tegangan tertinggi, iaitu 2556N/m² berbanding dua pilihan yang lain. Kajian ini penting kerana ia menunjukkan AHP boleh dilaksanakan untuk mendapatkan parameter proses optimum yang mempengaruhi sifat mekanikal spesimen yang dicetak.

Katakunci: AHP, FDM, PLA, Kekuatan tegangan, Parameter Proses

1.0 INTRODUCTION

Additive manufacturing (AM) is one of the technologies used to construct a 3D part. Additive processes involve successive deposition of material layers by layers. The printed objects can be of almost any shape or geometry and are created from 3D CAD data or any digital source. AM has been extended to include a broad range of methods entirely based on processes such as extrusion and sintering [1].

AM has a lot of benefits that can reduce the time and the cost of product development to directly manufacture finished components [2]. Other than that, AM can reduce material waste and energy because it may need to do the finishing, such as to file off burrs or supports that hold the part, but overall waste is minimal [3]. The applications of AM vary and are widely used as end used parts or as functional prototypes [4]. AM also has gotten into the medical industry with biomedical applications and produced medical tools to ease the visualization of specific anatomy [5].

One of the most used approaches in the selection process is the Analytical Hierarchy Process (AHP) methodology. The goal is to measure the relative priority of the given value according to the acceptable value scale. Typically, the selection is based solely on the interpretation of the person who makes the final decision and decides the goals, demonstrating the importance of continuity and the correlation of the choices as opposed to the overall decision-making process. The AHP approach is flexible since it offers a convenient way to find the relation between standards and alternatives. In the form of complex problems with multiple criteria and a sufficient set of alternatives, this approach assesses the validity of the criteria in the real world to determine the relationship between the criteria. By applying AHP, complex problems could be decomposed into precise hierarchies, such that the assessment would consist of quantitative and qualitative components of the issue. All hierarchical ranges are linked by AHP. This helps us see how one criterion's alternative influences the other criteria and alternatives [6].

There are three basic steps in the implementation of the AHP. First is the creation of a hierarchical model of decision-making problems. The model starts with the goal at the top level. The criteria are defined at the lower level, and the possibilities are listed at the bottom of the model. Secondly, the elements contrast with each other in pairs on each level of the hierarchical structure. The selector preferences are expressed through the Saaty Relative Scale of Importance, which has five main levels and four intermediate levels of verbally defined intensities and corresponding numerical values within the 1-9 range. Thirdly, it is possible to derive the use of a mathematical model from estimating the relative value of variables from an acceptable level of hierarchical structure, weight criteria, and local selection priorities, which can be outlined later in the alternative's overall priorities. You can determine the overall priority of an alternative by summarizing the local priorities multiplied by the weight of the criterion [7].

This paper studies the application of the analytic hierarchy process (AHP) to optimize FDM printing process parameters to obtain the best tensile strength from several PLA material test specimens. A literature review was conducted to investigate the most effective process parameters that affect tensile strength from various journals. After obtaining the best option from the AHP analysis, a tensile strength test was conducted to validate the data. Standard ASTM specimen with a gauge length of 57 mm and a gauge width of 13mm and the material specimen of Polylactic Acid (PLA) was printed using an open-source FDM printer.

2.0 METHODOLOGY

2.1 Data Collection

A detailed literature survey was conducted to determine the tensile strength's relative importance. The studies were constructed based on the hierarchy tree to allow pairwise comparisons of all the selection criteria at each level of the tree. As a result of the pairwise comparison process, a group's strength can be determined. Furthermore, all studies used to decide on the rankings were carefully and critically selected.

2.2 AHP Method

2.2.1 Hierarchal Structure

The structure of the AHP hierarchically introduces the issue and purpose of decision-making to the scene of the relevant decision elements at the first level. Decision-making elements are decision signals and decisions by creating a hierarchy following Figure 1 that must represent the problem of understudy [8]. A complex decision is to be arranged in a hierarchy descending to more than a few criteria from a general target, sub-criteria until the lowest level. At the top level of the hierarchy, the general purpose of the decision is portrayed. At intermediate levels, the criteria and sub-criteria which contribute to the decision are represented. Finally, the alternatives to the decision are laid down at the final hierarchical level. According to [22], with the help of creative thinking, imagination, and using people's perspectives, a hierarchy can be created. Figure 1 shows the AHP structure.
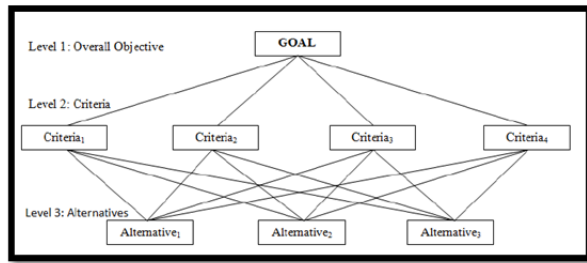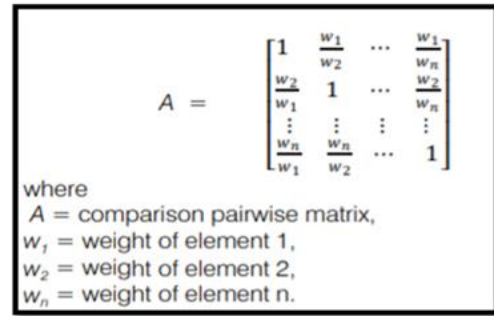
Figure 1 AHP Structure

2.2.2   *Pairwise Comparison Matrix*

Comparison is made at all levels of hierarchy in pairs of structure variables, where the decision-priority makers are articulated using the Saaty scale of relative significance levels. The scale consists of 5 levels and 4 sub-levels that define the intensity verbally, with numerical values in the range of 1 to 9 corresponding to each other [2]. The scale ranges from 1 to 9 where one implies that the two elements are identical or are equally important. On the other hand, range 9 implies that one element is extraordinarily more important than the different one in a pairwise matrix. The pairwise scale and the importance value attributed to every number are illustrated [8]. Figure 2 shows the score for the important variable.

Figure 2 score for the Important Variable

According to [9], to determine the relative preferences for two elements of the hierarchy in matrix A, an underlying semantically scale is employed with values from 1 to 9 to rate. For every factor of the hierarchy structure, all the related elements in low hierarchy are compared in pairwise contrast matrices as follows in Figure 3.

Figure 3 Pairwise Comparison Matrix

2.2.3   *Estimating the Relative Weights*

According to [9], some strategies like the eigenvalue technique are used to calculate the relative weights of elements in each pairwise comparison matrix. The relative weight (W) of matrix A is obtained from the following Equation 1.

$$(A - \lambda_{max} I) \times W = 0 \qquad (1)$$

Where λ_{max} = The biggest eigenvalue of matrix A,
I = Unit matrix

From the point of view of engineering applications, own-value problems are among the most important matrix-related problem. Let $A = [a_{jk}]$ be a given nXn matrix and consider the vector equation that shows from Equation 2.

$$A = \lambda x \qquad (2)$$

Here, x is an unidentified vector, and λ is an unknown scalar. Clearly, for any value of λ, the zero-vector x=0 is the solution of equation (3). It is of no fair interest. A value of λ that has a response of x≠0 is the matrix A's value or characteristic value (or latent root). The corresponding options x to 0 of equation (3) are referred to as proprietary vectors, or A vector attributes corresponding to the proprietary value λ. The spectrum of A is called the set of Eigenvalues. The largest of the absolute values of A's values is defined as A's spectral radius.

2.2.4   *Consistency of the Comparison Matrix*

Equations 3 and 4 show the maximum eigenvalue is a sum of y1, y2, ... yn and denoted via λ*max*, CI= $\lambda_{max-n/n-1}$, where n is the total number of elements being compared, *CR=CI/RI*, where *RI* is a random consistency number of equal matrix size. RI is the consistency index of a randomly generated pairwise comparison matrix which is the value of *RI* varies with several elements to be in contrast. The *CR* provides a measure of the likelihood that the matrix was once filled in simply at random; it is an evaluation between

the current matrix and, in simple terms, random answering of questions. The acceptability of CR is ≤ 0.1. In some cases, it can be tolerated up to 0.2, however in no way extra than that [22]. If CR is not suitable, revise the judgments via additional cautious analysis [10].

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad (3)$$

$$CR = \frac{CI}{RI} \qquad (4)$$

2.2.5   Obtaining the Overall Rating

Equation 5 shows the obtaining relative weight of the decision that the rankings of preference are mixed with the criterion weights in a closing step to produce an overall score for each choice. Following the relative importance of the criterion, the extent to which the alternatives satisfy the criteria is weighted. This can be done via simple weighted summation. Finally, when all of the elements and objectives on the hierarchy have been determined, the fewer essential factors may be eliminated from consideration. The targets may then be recalculated throughout, whether with or without changing the decisions.

$$(Overall\ factor) = \sum C_i W_i \qquad (5)$$

2.3   Tensile Strength Test

2.3.1   Modeling ASTM D638 Type 1 Specimen

The first step was to design the specimens. Due to the mechanical property test such as tensile testing, compressive testing, and hardness testing, the specimens constructed by FDM are according to ASTM specifications. These are the standard dog bone structure specimen for tensile, and standard block form specimens for compressive testing and hardness testing. This gripping head is 32.86 mm in size and 19 mm in height. The test specimen has a gauge length of 57 mm and a gauge width of 13 mm. The experiment started by specimen drawn in CATIA CAD software with the exact length of the as shown in Figure 4. The dimension of the specimen is 165 mm × 19 mm × 3.2 mm.
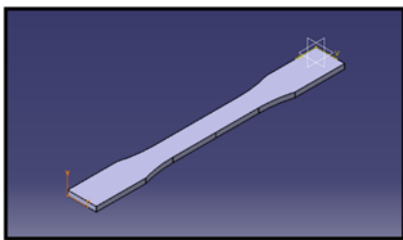

Figure 4 ASTM D638 Type 1 Specimen

2.3.2   Slicing

After the specimen is drawn, the file has to be saved in an STL file format. The slicing software that was used for this project is Ultimaker Cura software, shown in Figure 5. From this software, the specimen was sliced with three different types of layer height, which are 0.1 mm, 0.2 mm, and 0.3 mm, with constant infill density, build orientation, and raster angle.
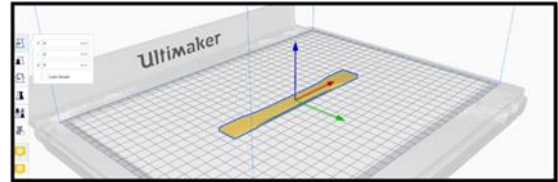

Figure 5 Ultimaker Cura Slicing Software

2.3.3   Specimen Printing

After the specimen had been sliced, the specimen was printed by using Ender 3 V2 FDM printer. Three specimens, as shown in Figure 6 was printed to proceed with the tensile strength test.

Figure 6 ASTM D638 Type 1 Specimens

2.3.4   Test Specimen

After specimens were printed, the tensile strength test was done. The tensile strength machine will have to grip the specimens. When aligning the specimens at the z-axis with the grips, precaution has to be taken not to overtighten grips. They should be tight enough to prevent slippage but not too tight that the specimen is crushed. Then the speed of testing has to be set to a proper rate which is 5 mm/min. After the test is run, the data was collected. The data collected was the force required to break the specimen due to the tensile strength formula, which is tensile strength is equal to the force divided with the cross-sectional area of the specimens.

3.0 RESULTS AND DISCUSSION

3.1 Data Collection

Table 1 shows various studies on process parameter that influence the tensile strength of printed specimen that was collected from literature review. This information is vital in order to progress to the next steps of the process of utilising AHP.

Table 1 Identification of process parameters

References	Content
[11]	The highest tensile strength is obtained for 0.3 mm layer height, 0° orientation, and 80% infill density
[12]	Three process parameters, build orientation (on-edge), nozzle diameter (0.5), and infill density (100%), were statistically significant and significantly impacted the final product's strength
[13]	The effect of layer height on ABS and PLA filaments and discovered that the influence of layer height on ABS is negligible, whereas the effect of layer height on PLA is considerable
[14]	The 0.4mm layer thickness and 30°/60° raster angle were found to have the maximum tensile strength in PLA specimens
[15]	High infill percentage specimens and increased layer height and extrusion temperature are required to increase mechanical qualities, as well as the correct construction direction
[16]	Tensile strength improves as layer thickness increases from 0.05 to 0.1 mm in the horizontal direction
[17]	Tensile and yield strength both rise when density increases from 10 to 90%. With 90% of the infill, maximum strength is achieved
[18]	Building in the X0° Y0° orientation a study has found that as the Y-component of build orientation grows, PLA parts mechanical behavior degrades
[19]	Results of the Taguchi L27 design experiment demonstrated that the best orientation for FDM pieces was 0°
[20]	The specimen's strength increases due to an increase in layer thickness interlayer and intralayer bonding could be a factor. Tensile strength is best at 30°/60° raster angle and 0.4mm layer thickness
[21]	The build orientation contributed 44.68% to the final product, while raster orientation contributed only 0.46% to the final product. Statistically significant was just three parameters in the ANOVA table: build orientation, nozzle diameter, and infill densities

3.2 AHP Analysis

3.2.1 Developing Hierarchical Structure

The first step is to develop a hierarchical structure with a goal at the top level, criteria at the second level, and alternatives at the third level. Each alternative has its value associated with them. Figure 7 shows that the goal at the top level is to evaluate the capability of the FDM process parameters in the AHP. Next for the criteria at the second level is the layer thickness, infill density, build orientation, and raster angle. The last level, which is the alternative, shows that it has three options which are option 1, option 2, and option 3.
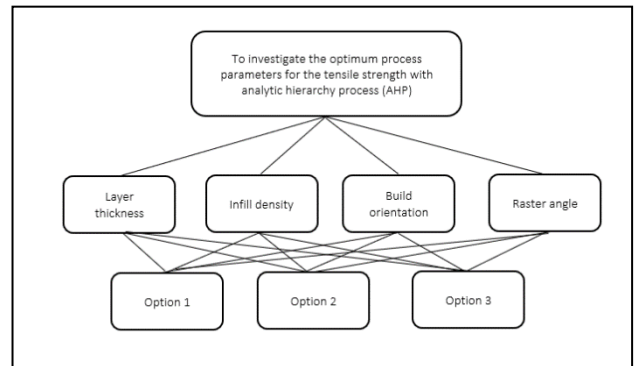
Figure 7 Hierarchical Structure

3.2.2 Pairwise Comparison Matrix

From the literature review, the best 4 criteria that affect tensile strength have been chosen. The ranking of the chosen criteria is listed below:

1. Layer thickness
2. Infill Density
3. Build Orientation
4. Raster Angle

The second step is to create a pairwise comparison matrix. The pairwise comparison matrix gives the relative importance of various attributes concerning the goal. It shows how important each criterion is to get the best tensile strength. This pairwise comparison matrix is created with the help of a scale of relative importance. The length of the pairwise matrix is equivalent to the number of criteria used in the decision-making process.

Literature review showed that high tensile strength can be accomplished by high layer thickness, high infill density, the lowest degree of build orientation, and the suitable raster angle. Scale of number 1 equally important and 9 is extremely important was given. Table 2 shows a 4X4 matrix has four criteria which are layer thickness, infill density, build orientation, and raster angle. The value in the pairwise matrix depends upon the decision based on the literature review that has been referred. It started with how important is layer thickness to infill density for a good tensile strength of the FDM printed product. The literature review shows that layer thickness is very important than infill density. Infill density is given x value then, the layer thickness is given 5x value which shows layer thickness has strong importance based on the score of the important variable. Next, divide the row element by the column element. The sum of each value is also calculated, as shown in Table 2.

Table 2 Pairwise Comparison Matrix

	Layer thickness	Infill density	Build orientation	Raster angle
Layer thickness	1	5	4	7
Infill density	1/5 = 0.200	1	1/2= 0.500	3
Build orientation	1/4= 0.250	2	1	3
Raster angle	1/7 = 0.143	1/3 = 0.333	1/3= 0.333	1
Sum	1.593	8.333	5.833	14

The normalized pairwise matrix was calculated. All elements of the column are divided by the sum of the column. After that, calculate the criteria weights. The weighted calculated by averaging all the elements in the row that need to be added all the elements and dividing it with the number of criteria, which will give the criteria weight shown in Table 3.

Table 3 The Normalized Pairwise Matrix

	Layer thickness	Infill density	Build orientation	Raster angle	Criteria weight
Layer thickness	$\frac{1}{1.593}$ = 0.628	$\frac{5}{8.333}$ = 0.600	$\frac{4}{5.833}$ = 0.686	$\frac{7}{14}$ = 0.500	0.6035
Infill density	$\frac{0.2}{1.593}$ = 0.126	$\frac{1}{8.333}$ = 0.120	$\frac{0.5}{5.833}$ = 0.086	$\frac{3}{14}$ = 0.214	0.1365
Build orientation	$\frac{0.25}{1.593}$ = 0.157	$\frac{2}{8.333}$ = 0.240	$\frac{1}{5.833}$ = 0.171	$\frac{3}{14}$ = 0.214	0.1955

3.2.3 Finalized Weights

A consistency ratio of less than 0.1 indicates that there is consistency in the system. The finalized weights are listed in Table 4. This consistency test is critical as it also verifies that the entire procedure is correct. Additionally, these weights indicate which parameters should be prioritized when selecting the optimum tensile strength, and they provide exact numbers that represent the relative importance of each creation in

the process. Table 4 shows that layer thickness has the highest criteria weight.

Table 4 Finalized Weights

Criteria	Weight
Layer thickness	0.6035
Infill density	0.1365
Build Orientation	0.1955
Raster angle	0.0645

3.2.4 Consistency Analysis

The third step was made to validate the consistency of the calculation. This step needs to take the same pairwise comparison matrix, which is not normalized to multiply each value in the column with the criteria value. After the matrix is obtained, the weighted sum value is calculated by taking the sum of each value in the row shown in Table 5.

Table 5 Consistency Analysis

	Layer thickness	Infill density	Build orientation	Raster angle	Weighted Sum Value
Layer thickness	1(0.6035) = 0.6035	5(0.1365) = 0.6825	4(0.1955) = 0.782	7(0.0645) = 0.452	2.5200
Infill density	0.2(0.6035) = 0.1207	1(0.1365) = 0.1365	0.5(0.1955) = 0.0978	3(0.0645) = 0.1935	0.5485
Build orientation	0.25(0.6035) = 0.1509	2(0.1365) = 0.2730	1(0.1955) = 0.1955	3(0.0645) = 0.1935	0.8129
Raster angle	0.143(0.6035) = 0.0863	0.333(0.1365) = 0.0455	0.333(0.1955) =0.0651	1(0.0645) = 0.0645	0.2614

Next, calculate the ratio of weighted sum value and criteria weight. This is to get the lambda value as shown in Table 6.

Table 6 Lambda Value

Weighted Sum Value	Criteria weight	Lambda value
2.5200	0.6035	2.5200/0.6035 = 4.1756
0.5485	0.1365	0.5485/0.1365 =4.0183
0.8129	0.1955	0.8129/0.1955 = 4.1581
0.2614	0.0645	0.2614/0.0645 = 4.0527

The λ_{max} is calculated by taking the average of all these values. The λ_{max} is calculated by dividing the weighted summation value in Table 6 by the number of criteria. This is shown in Equation 6 below.

$$\lambda_{max} = \frac{4.1756+4.0183+4.1581+4.0527}{4} = 4.1012 \qquad (6)$$

Next, the consistency index *(CI)* is calculated, which is given by the formula minus n upon n minus 1 as in Equation 7 below.

$$Consistency\ Index\ (CI) = \frac{4.1012-4}{4-1} = 0.0337 \quad (7)$$

Then, the consistency ratio is calculated which is given by dividing the consistency index *(CI)* with random index *(RI)* shown in Equation 8. The random index is the consistency index of the randomly generated pairwise matrix.

$$Consistency\ ratio = \frac{CI}{RI} = \frac{0.0337}{0.90} = 0.0374 < 0.10 \quad (8)$$

The proportion of inconsistency consistency ratio is less than 0.10, which is standard can assume that the matrix is reasonably consistent, so may continue with the process of decision making by using AHP.

3.2.5   *Obtaining the Overall Rating*

From the experiments and investigation of the impact process parameters on the tensile strength by [6], the authors have used the following criteria to choose the best tensile strength. After they experimented, it was concluded that the highest tensile strength is obtained for 0.3 mm layer height, 0° orientation, and 80% infill. This shows that layer thickness and infill density significantly affect the tensile strength shown in Table 7.

To make all criteria comparable, normalization needs to be done. Beneficial criteria have to divide the performance value in the individual cell with the maximum value. Similarly, non-beneficial criteria need to take the minimum value and divide it with the performance value of each cell. There is a difference in both beneficial and non-beneficial which are the maximum value takes the denominator, and in non-beneficial, the minimum value takes the numerator. This will get a normalized decision matrix shown in Table 8.

The next step is to assign weight criteria. The sum of weight criteria is always 100%. Multiply the weight assigned to each criterion with its normalized. On solving, get the weighted normalized decision matrix. Then, add all weighted normalized performance values of each alternative to get the ranking. Ranks can be allocated to which option based on the performance score. Based on the weight assigned to each criterion, option 3 is the best alternative among all other alternatives as it has rank number 1 shown in Table 9.

Table 7 The Value for Tensile Strength Criteria in Three Different PLA Print Setting

PLA material	Layer thickness (mm)	Infill density (%)	Build orientation (°)	Raster angle (°)
Option 1	0.1	50	30	30
Option 2	0.2	20	60	45
Option 3	0.3	80	0	60

Table 8 The Normalized Version

PLA material	Layer thickness (mm)	Infill density (%)	Build orientation (°)	Raster angle (°)
Option 1	$\frac{0.1}{0.3}=0.3$	$\frac{50}{80}=0.6$	$\frac{30}{60}=0.5$	$\frac{30}{30}=1$
Option 2	$\frac{0.2}{0.3}=0.7$	$\frac{20}{80}=0.3$	$\frac{60}{60}=1$	$\frac{30}{45}=0.7$
Option 3	$\frac{0.3}{0.3}=1$	$\frac{80}{80}=1$	$\frac{0}{60}=0$	$\frac{30}{60}=0.5$

Table 9 The Ranking of the Options

Weight-age	0.6035	0.1365	0.1955	0.0603		
PLA material	Layer thickness (mm)	Infill density (%)	Build orientation (°)	Raster angle (°)	Performance score	Rank
Option 1	0.3(0.6035) = 0.1811	0.6(0.1365) = 0.0819	0.5(0.1955) = 0.0978	1(0.0645) = 0.0645	0.4253	3
Option 2	0.7(0.6035) = 0.4225	0.3(0.1365) = 0.0410	1(0.1955) = 0.1955	0.7(0.0645) = 0.0452	0.7042	2
Option 3	1(0.6035) = 0.6035	1(0.1365) = 0.1365	0(0.1955) = 0	0.5(0.0645) = 0.0323	0.7723	1

$$Overall\ (factor) = \sum C_i W_i \quad (9)$$

By using Equation 9 above in Table 9, the values that have been calculated are:

1.   Option 1 = 0.4253
2.   Option 2 = 0.7042
3.   Option 3 = 0.7723

Therefore, the best option is option 3, which is the best process parameter to optimize the tensile strength.

3.3   Tensile Strength Test

A tensile strength test was done to validate the data from the AHP analysis. The AHP analysis shows that option 3 has the best process parameter to optimize the tensile strength. Layer thickness has the most significant weight score. When selecting the ideal tensile strength, these weights suggest which characteristics should be given the highest priority. They also provide exact values that show the relative importance of each creation in the process. The highest layer thickness with a high amount of infill density, the right build orientation, and the suitable raster angle will give the highest tensile strength for printed PLA products. This paper decided to validate whether the increasing layer thickness will affect the tensile strength from the AHP analysis.

With the help of the slicing software, the specimen was sliced into three different layer heights of 0.1mm, 0.2mm, and 0.3mm, while maintaining constant infill density, which is 100%, 0⁰ build orientation, and

60° raster angle. After that, the tensile strength test was conducted. By using an imaginary line to connect the grips to the machine to align the specimen long axis with the grips. To prevent slippage, they should be snug enough to prevent the specimen from being crushed. Then set the testing speed to 5mm/min. A tensile strength formula based on force divided by cross-sectional area is used to determine how much force is required for a specimen to break. After the test has been run, data will be collected to determine how much force is required for the specimen to break.

Table 10 Tensile Strength Based on Layer Thickness

Layer thickness, mm	Tensile strength, N/m^2
0.1	2400
0.2	2412
0.3	2556

Data in Table 10 shows proves that option 3, with the highest layer thickness, which is 0.3mm, with infill density which is 80%, 0° build orientation, and 60° raster angle has the highest tensile strength compared to 0.1 mm and 0.2mm. This is because the layer thickness increases overall strength. Increasing the layer thickness would also increase the mechanical properties. The three process parameters were statistically significant and significantly impacted the final specimen strength.

4.0 CONCLUSION

In conclusion, the literature shows various process parameters that could affect the tensile strength that was proceeded to the AHP analysis. As for the criteria, the layer thickness has the top impact factor to tensile strength. After analyzing the consistency of the weight criteria, an overall rating was obtained to know which option is the best FDM process parameter for tensile strength. The result shows option 3 (0.7723), which has the highest layer thickness, 80% infill density, 0^0 of build orientation, and 60^0 of raster angle. Finally, to validate the result from AHP, the tensile strength of the FDM specimen by using the tensile strength test was made. It tests the increasing and decreasing of the layer thickness with the same infill density, build orientation, and raster angle. The result proved that option 3 has the highest tensile strength of 2556 N/m^2.

Acknowledgment

References

[1] V. G. S and P. V Gharat. 2016. 3D Printing Process Using Fused Deposition Modeling. *International. Research Journal of Engineering Technology*. 3(3): 1403-1406.

[2] M. Attaran. 2017. The Rise of 3D Printing: The Advantages of Additive Manufacturing Over Traditional Manufacturing. *Bus. Horiz.* 60(5): 677-688.

[3] M. Gayette. 2019. 5 Major Benefits of Additive Manufacturing You Should Consider. https://www.cmtc.com/blog/benefits-of-additive-manufacturing (accessed Oct. 27, 2020).

[4] D. B. Patel. 2016. Additive Manufacturing – Process, Applications and Challenges. *IJARIIE*. 2(5): 883-889.

[5] W. Stephen. 2015. Additive Manufacturing as an Enabling Technology for Green Hybrid Spacecraft Propulsion. *7th International Conference on Recent Advances in Space Technologies (RAST), IEEE*. 1-6.

[6] T. A. Pachemska, M. Lapevski, and R. Timovski. 2014. Analytical Hierarchical Process (AHP) Method Application in the Process of Selection and Evaluation. *Proceedings. Gabrovo Internatinal Sci. Conference. 21-22 November 2014*. 373-380.

[7] I. Peko, N. Gjeldum, and B. Bilić. 2018. Application of AHP, Fuzzy AHP and Promethee Method in Solving Additive Manufacturing Process Selection Problem. *Tehnički vjesnik*. 25(2): 453-461.

[8] H. Taherdoost. 2018. Decision Making Using the Analytic Hierarchy Process (AHP); A Step by Step Approach. *International Journal of Economic. Management System*. (January 2017): 244-246.

[9] A. T. Ibraheem and N. S. Atia. 2017. Applying Decision Making with Analytic Hierarchy Process (AHP) for Maintenance Strategy Selection of Flexible Pavement. *Global Journal of Research*. 16(5).

[10] Brunelli, M. 2014. *Introduction to the Analytic Hierarchy Process*. Springer.

[11] S. Bardiya, J. Jerald, and V. Satheeshkumar. 2020. The Impact of Process Parameters on the Tensile Strength, Flexural Strength and the Manufacturing Time of Fused Filament Fabricated (FFF) Parts. *Mater. Today Proc*. 39: 1362-1366.

[12] M. Hikmat, S. Rostam, and Y. M. Ahmed. 2021. Investigation of Tensile Property-based Taguchi Method of PLA Parts Fabricated by FDM 3D Printing Technology. *Results Eng*. 100264.

[13] A. Rodríguez-Panes, J. Claver, and A. M. Camacho. 2018. The Influence of Manufacturing Parameters on the Mechanical Behavior of PLA and ABS Pieces Manufactured by FDM: A Comparative Analysis. *Materials (Basel)*.11(8).

[14] Z., Abdullah, H. Y., Ting, M. A. M., Ali, M. H. F. M., Fauadi, M. S., Kasim, Hambali, A., Ghazaly, M. M., and F. Handoko. 2017. The Effect of Layer Thickness and Raster Angles on Tensile Strength and Flexural Strength for Fused Deposition Modeling (FDM) Parts. *Journal of Advanced Manufacturing Technology*. 147-158.

[15] Alafaghani, A., Qattawi, A., Alrawi, B., and Guzman, A. 2017. Experimental Optimization of Fused Deposition Modelling Processing Parameters: A Design-for-Manufacturing Approach. *Procedia Manufacturing*.10: 791-803.

[16] DeHoff, P. H., Anusavice, K. J. and Wang, Z. 1995. Three-dimensional Finite Element Analysis of the Shear Bond Test. *Dental Materials*. 126-131.

[17] A. Pandzic, D. Hodzic, and A. Milovanovic. 2019. Effect of Infill Type and Density on Tensile Properties of PLA Material for FDM Process. *Ann. DAAAM Proc. Int. DAAAM Symp*. 30(1): 545-554.

[18] A. M. Abdelrhman, W. Wei Gan, and D. Kurniawan. 2019. Effect of Part Orientation on Dimensional Accuracy, Part Strength, and Surface Quality of Three-dimensional Printed Part. *IOP Conf. Ser. Mater. Sci. Eng*. 694(1): 012048.

[19] D. Syrlybayev, B. Zharylkassyn, A. Seisekulova, M. Akhmetov, A. Perveen, and D. Talamona. 2021.

Optimisation of Strength Properties of FDM Printed Parts-A Critical Review. *Polymers (Basel)*. 13(10).

[20] J. M. Chacon, M. A. Caminero, Garcfa-Plaza E., & P. J. Nunez. 2017. Additive Manufacturing of PLA Structures using Fused Deposition Modelling: Effect of Process Parameters on Mechanical Properties and Their Optimal Selection. *Materials & Design*. 124: 143-157.

[21] S. B. Basturk, C.E. Dancer, and T. McNally. 2021. Fabrication and Characterization of Composites of a Perovskite and Polymers with High Dielectric Permittivity. *Materials Research Bulletin.* 135: 11126.

[22] M. Hussain, M. Ajmal, M. Khan and H. Saber. 2015. Competitive Priorities and Knowledge Management: An Empirical Investigation of Manufacturing Companies in UAE. *Journal of Manufacturing Technology Management.* 26(6): 791-806.