Application of Taguchi Method in Investigating The Effect of Layer Thickness and Fill Angle on FDM Parts

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Abstract. This paper studies the effect of Layer Thickness and Fill Angle on tensile stress of Fused Deposition Modeling (FDM) parts for Acrylonitrile Butadiene Styrene (ABS) and Carbon Fiber Reinforced ABS (CFRABS) materials by using Taguchi Method, signal-to-noise (S/N) ratio analysis and Analysis of Variance (ANOVA). From the results, it was found that layer thickness contribute to the tensile stress performance of ABS and fill angle has significant effect on tensile stress of CFRABS. It can be concluded that the optimized parameter obtained in this study for both materials are 0.18mm layer thickness and 90° fill angle.

1. Introduction
Fused Deposition Modelling (FDM) is a popular Additive Manufacturing (AM) machine that able to manufacture parts with complex geometries easily in a minimal time compared to traditional machine [1]. Acrylonitrile butadiene styrene (ABS) has been used as a homopolymer FDM feedstock due to its properties which provides chemical resistance, heat stability, toughness, impact strength, rigidity and easiness of process ability [2]. Reference [3] stated that the range of the application of polymer can be extended further by the reinforcement of carbon fiber, ceramics, metals and fiber glass in polymer matrix. Reference [4] revealed that one of the possible ways to increase the strength of FDM printed thermoplastic parts is by adding reinforced materials such as carbon fibre into plastic materials to form thermoplastic matrix carbon fibre reinforced plastic (CFRP) composites. Nowadays, CFRP are applied in various industries. The examples of application are components in automotive and endoscopic surgery. Taguchi approach provides statistical method of analyzing is the best way to investigate the effect of FDM process parameters such as layer thickness and fill angle on tensile stress of FDM part for ABS and CFRABS where details of the experiment can be discussed accurately through S/N ratio and ANOVA analyses.

2. Methodology

2.1. Samples Preparation and Analysis
The geometrical model of Dog bone specimen ASTM D638 was produced by using CATIA V17 solid modelling software and saved as a stereolithographic file (STL). This .STL file then was loaded into the slicing software or interface platform namely ‘Flash Print’. The file was converted to G-file and uploaded into FDM Flashforge Dreamer modeller. The 3D model was sliced into layers at the required
thickness and fill angle. A molten Acrylonitrile Butadiene Styrene (ABS) thermoplastic and Carbon Fiber Reinforced ABS (CFRABS) with a diameter of 1.75mm were used as FDM feedstock and extruded by the heated nozzle which was deposited on the bed as the nozzle travels along the platform bed. 9 samples of ABS and CFRABS respectively were produced and detached from the heat bed upon completion. The statistical software of Minitab 17 and Microsoft Excel 2010 were utilized for the S/N ratio and ANOVA analysis.

2.2. Taguchi Method
Taguchi technique was applied in this project as it is a powerful statistical tool in simplifying experimental plan where number of experiments, time and cost can be reduced without giving effect to the product’s quality [5]. This approach proposes an experimental plan that consist series of L9 Orthogonal Array as in Table 1 which provides combination of process parameters and their level to the required performance quality of the product [5]. Hence, correlation between process parameters and their levels to the quality response can also be determined using this tool [6]. ‘The-larger-the-better’ objective function was implemented to meet the purpose of this project that is maximizing the tensile stress of FDM parts. Several steps in parameter design had been proposed by Günay and Yücel [7] to optimize the process parameters was implemented in this research as the following:

- Process parameters and performance characteristics were selected.
- The number of levels for the process parameters and possible interactions between the process parameters were determined.
- Appropriate orthogonal array and assignment of process parameters to the orthogonal array was selected.
- The experiments were carried out based on the arrangement of the orthogonal array.
- Total loss function and the S/N ratio were calculated.
- Experimental results using the S/N ratio and ANOVA were analyzed.
- Optimal levels of process parameters were selected.
- Optimal process parameters were verified through the confirmation experiment.

Table 1. L9 Orthogonal Array

| Experiment No | Process Parameters/Levels |
|---------------|---------------------------|
|               | A | B |
| 1             | 1 | 1 |
| 2             | 1 | 2 |
| 3             | 1 | 3 |
| 4             | 2 | 1 |
| 5             | 2 | 2 |
| 6             | 2 | 3 |
| 7             | 3 | 1 |
| 8             | 3 | 2 |
| 9             | 3 | 3 |

2.3. Selection of Process Parameters
In this experiment, layer thickness and fill angle parameters are variable process parameters while humidity and temperature were kept constant. Layer thickness indicates the height of deposited slice from FDM nozzle whereas fill angle is the method where roads can be deposited to fill the interior part. In this experiment, values of the layer thickness for level 1, level 2 and level 3 are 0.18mm, 0.25mm and 0.31mm respectively whereas 30°, 45° and 90° were used for each level of the fill angle respectively. This experiment used Taguchi method which proposed L9 Orthogonal Array of three rows and nine columns with three process parameters at three different levels.
2.4. Tensile Test Experiment
The research test in this project was tensile strength test. The tensile machine used in testing the Specimens of ABS and CFRABS was Universal Test Machine: INSTRON 8832. The dog bone of both specimens were clamped and stretched until fracture. The data of the tensile strength was recorded and display to the computer.

3. Result And Analysis

3.1. Signal-to-Noise Ratio
The signal-to-noise ratio is an effective tool in measuring sensitivity of the quality being investigated to the uncontrollable factors (error) in the experiment [8]. There are two categories to classify factors that affect system performance which are controllable factors and noise factors. Chamber temperature, humidity, and model temperature are the example of noise factors that cannot be controlled during manufacturing or fabricating process [9]. This indicates signal and the undesirable value (Standard Deviation from Mean) represents noise for the output characteristic [10]. In this experiment, the higher S/N ratio was used because it produced smaller product variance around the target value by means of minimizing the expected loss of function quality. The optimal level of the process parameters can be obtained by the level with the highest S/N ratio which keeps the response on target while making it insensitive to the variation of noise factors. The objective of this experimental plan is to gain the maximum tensile stress of FDM part. Hence, the larger the better quality characteristic was implemented in analysis for better accuracy [11].

\[
\eta = - \log \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)
\]

Where \( \eta \) is the sample size and \( y \) is the tensile stress in MPa.

Table 2. Obtained S/N Ratio Values Of The Tensile Stress Response

| Experiment No | Parameters | Responses |
|---------------|------------|-----------|
|               | Layer Thickness (mm) | Fill Angle (˚) | Tensile Stress (MPa) | SNRA for Tensile Stress |
| 1             | 0.18       | 30        | 29.643             | 29.4384 24.0460 |
| 2             | 0.18       | 45        | 30.478             | 29.6797 23.9759 |
| 3             | 0.18       | 90        | 32.526             | 30.2446 26.9676 |
| 4             | 0.25       | 30        | 25.851             | 28.2495 24.3397 |
| 5             | 0.25       | 45        | 25.815             | 28.2374 23.6409 |
| 6             | 0.25       | 90        | 29.002             | 29.2486 25.4808 |
| 7             | 0.31       | 30        | 21.043             | 26.4622 24.5237 |
| 8             | 0.31       | 45        | 17.090             | 24.6548 24.5402 |
| 9             | 0.31       | 90        | 22.404             | 27.0065 25.3157 |

Figure 1. Graph of S/N Effects of process parameter on Tensile Stress: (a) ABS (b) CRFABS
Table 2 shows that the highest level of S/N ratio for both materials is experiment 3 with 0.18mm layer thickness and 90° fill angle which produced S/N ratio of 30.2446 and 26.6967 respectively prior to their highest values of tensile stress.

As depicted in Fig.1 (a) and (b), the combination of parameters and their levels for ABS and CFRABS, 0.18mm layer thickness and 90° fill angle has produced maximum value of S/N ratio and it yields optimum quality characteristic with maximum variance of targeted value for tensile stress.

Table 3. S/N Ratio Values For Tensile Stress By Factor Level

| Level | Control Factors | Layer Thickness | Fill Angle |
|-------|----------------|----------------|------------|
|       |                | ABS CF-ABS     | ABS CF-ABS |
| 1     |                | 29.79 24.91    | 28.05 24.30 |
| 2     |                | 28.58 24.49    | 27.52 24.05 |
| 3     |                | 26.04 24.79    | 28.83 25.83 |
| Delta |                | 3.75 0.42      | 1.31 1.78   |
| Rank  |                | 1 2 2 1        |            |

Table 4. S/N Ratio Values For Tensile Stress By Factor Level

| Source          | Df | Adj SS   | Adj Ms   | F      | C%    |
|-----------------|----|----------|----------|--------|-------|
| Materials       |    |          |          |        |       |
| ABS             | 2  | 21.936   | 0.2821   | 21.936 | 0.2821|
| CF-ABS          | 2  | 10.9679  | 0.1410   | 10.9679| 0.1410|
| Layer Thickness |    | 21.936   | 0.2821   | 21.936 | 0.2821|
| Fill Angle      |    | 2.604    | 5.5615   | 2.604  | 5.5615|
| Error           |    | 1.443    | 1.3849   | 1.443  | 1.3849|
| Total           | 8  | 25.983   | 7.2285   |        |       |

Based on Table 3, tensile stress increases as the layer thickness value increases for ABS material and ranked number 1 compared to layer thickness for CFRABS is ranked as number 2 where its inconsistency of layer thickness performance could be seen. Meanwhile, fill angle ranked as number 1 for CFRABS and number 2 for fill angle of ABS material. The analysis of S/N ratio in Table 4 had shown that the layer thickness is the most significant parameter for ABS which influenced the tensile stress by 84.42% of contribution percentage and fill angle is the most significant for CFRABS which contributed about 76.94%.

3.2. Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is often used due to its capability in investigating parameters that significantly affect the output characteristic [8]. The ANOVA computations were tabulated based on procedure in Table 5. F-test was applied to study which parameters have significant effect on the build time response. F ratio is termed as ratio of the mean square error to the residual error [12]. Usually, when F > 4, it means that the change of the process parameter has significant effect on the quality characteristic [8].

As depicted in Table 5, results showed that layer thickness gave P-value less than 0.05 which is 0.001 for ABS material and fill angle indicated valid P-value result of 0.046 for CFRABS material. The results were also supported with F-test which both layer thickness and fill angle produced values greater than 4 for ABS. On the other hands, only fill angle for CFRABS that showed valid F-Test result. The contribution percentage of layer thickness marked the highest percentage for ABS which is 86.95% followed by fill angle with lesser contribution of 9.68%. Meanwhile, layer thickness gave least contribution to the output of CFRABS by 4.37% and fill angle showed largest contributions of 75.14%. Based on Table 5, fill angle is found to be negligible to the tensile response of ABS since the P-value is 0.066 and in contrast, layer thickness is found negligible for CFRABS as it produced P-value of 0.679. In this study, the effect of fill angle and interaction between fill angle with layer
thickness for ABS were found to be negligible effect and in comparison to CFRABS, the effect of layer thickness and interaction between layer thickness with fill angle were also found to be negligible.

Table 5. Anova Results For Effects Of Process Parameters On Tensile Stress

| Source           | DF | Seq SS  | F     | C%   | P-Value |
|------------------|----|---------|-------|------|---------|
| Materials        |    |         |       |      |         |
| ABS              | 2  | 175.534 | 51.71 | 86.95% | 0.001   |
| CF-ABS           | 2  | 1.387   | 0.43  | 4.37%  | 0.679   |
| Layer Thickness  | 2  | 19.546  | 5.76  | 9.68%  | 0.066   |
| Fill Angle       | 2  | 23.852  | 7.34  | 75.14% | 0.046   |
| Error            | 4  | 6.790   | 3.36% | 86.95% | 0.001   |
| Total            | 8  | 201.870 | 20.49%| 9.68%  | 0.046   |
| S                | 1.30285 | 1.27508     |       |       |         |
| R-sq             | 96.64% | 79.51%      |       |       |         |

3.3. Confirmation Test

Once the optimal combination and levels of the process parameter had been obtained, the final step was to verify the experimental result against theoretical value. Based on equation obtained from regression analysis, the average percentage error was 0.075% with the reliability of 99.92% for ABS and -0.02% percentage error and reliability of 100% for CFRABS. This verifies that experimental result is strongly correlated with the estimated result.

4. Conclusions

Utilizing Taguchi Approach proved that number of experiments can be simplified and reduced. Based on this method, 9 experiments were sufficient to analyse the results and it was found that layer thickness had a critical effect to the tensile stress of ABS and fill angle had significantly affect CFRABS performances. The effect of fill angle and interaction between fill angle with layer thickness for ABS were found to be negligible effect and in comparison to CFRABS, the effect of layer thickness and interaction between layer thickness with fill angle were also found to be negligible. Referring to ANOVA analysis for ABS, it was found that layer thickness had 86.95% contributions on tensile stress followed by least contribution of fill angle with 9.68%. Meanwhile, ANOVA for CFRABS showed that the effect of layer thickness and interaction between layer thickness with fill angle were also found to be negligible. According to S/N Ratio for both materials, the optimal process parameters and their levels were obtained at level 1 (0.18mm) of layer thickness, level 3 (90°) of fill angle.

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