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Shrinkage optimisation on the 3D printed part using Full Factorial Design (FFD) optimisation approach

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Abstract. Quality and productivity are both important in 3D printing products and processes. However, it is quite challenging to control the quality and productivity of each product due to several parameters involved in this additive manufacturing process. Most of the parameter settings depend on trial and error techniques which consume a lot of time and material waste. Therefore, in this study, the application of optimization approach which is Full Factorial Design (FFD) approach which has been employed on 3D printed housing part made from Polylactic Acid (PLA) which were printed using Fused Deposition Modelling (FDM) 3D printer to minimize shrinkage on the 3D printed parts. Based on the optimization work, the results showed the performance of FFD approach provides a good dimensional accuracy compared to the drawing specification for the printed part. Therefore, this research provides beneficial scientific knowledge and alternative solution for the additive manufacturing process in industries application to enhance the quality of the 3D printed parts produced using FDM 3D printer machine.

1. Introduction

Today, every sectors and industry has embraced industrial revolution 4.0 (IR 4.0) in their ecosystem. There are 9 pillars of IR 4.0 which are additive manufacturing, internet of things, system integration, simulation, augmented reality, big data, cloud computing, and autonomous system. The main idea was to improve business operation, reduce cost and increase of production. Additive manufacturing is one of the technologies that become an important part of the today manufacturing process. This technology has become the centre of attention for most of the industries today because their abilities and advantages to produce complex geometry part without the needs of tooling.

Additive manufacturing can be divided into three main categories which are Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS) and Stereolithography Apparatus (SLA). FDM 3D Printer is an additive manufacturing technology that has been the key to the manufacturing process revolution. Due to their low cost, easy to operate and less risk, many industries prefer to use this technology as a starting point in adapting the additive manufacturing in their production line. FDM 3D Printer works by feeding thermoplastic filament into the heated extruder to form physical object layer by layer. Figure 1 shows the schematic diagram of the FDM machine.

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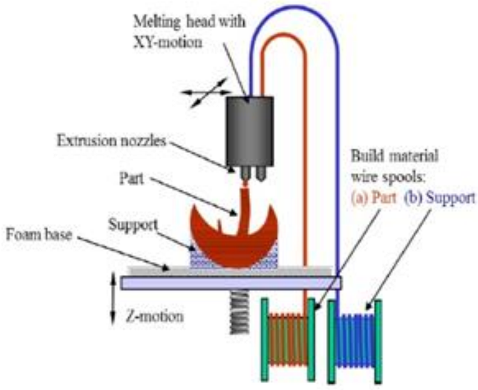

Figure 1. Schematic diagram of FDM [1].

Few issues and problems regarding FDM technology that the implementation of this technology for mass production slightly slower than expected. The issues are shrinkage and warping that influence part dimensional accuracy. Therefore, this study will present the application of several optimisations works to improve shrinkage on the 3D printed part. Based on the input of processing parameters, the design of experiment (DOE) approach will be used to screen the significant factor contribute to the shrinkage. Then, several samples will be printed by following each DOE run. Regression analysis will be performed to obtain the Analysis of Variance (ANOVA) and optimised result.

2. Full Factorial Design (FFD)

Full Factorial Design (FFD) is one of classical optimisation approach which using statistical manners. It used to demonstrate the relationship between variable parameters which influence the response by using the linear regression model. [2]. The necessary information to construct the response model was accumulated by the simulation analysis [3,4]. Figure 2 shows the flowchart of FFD used in this study.

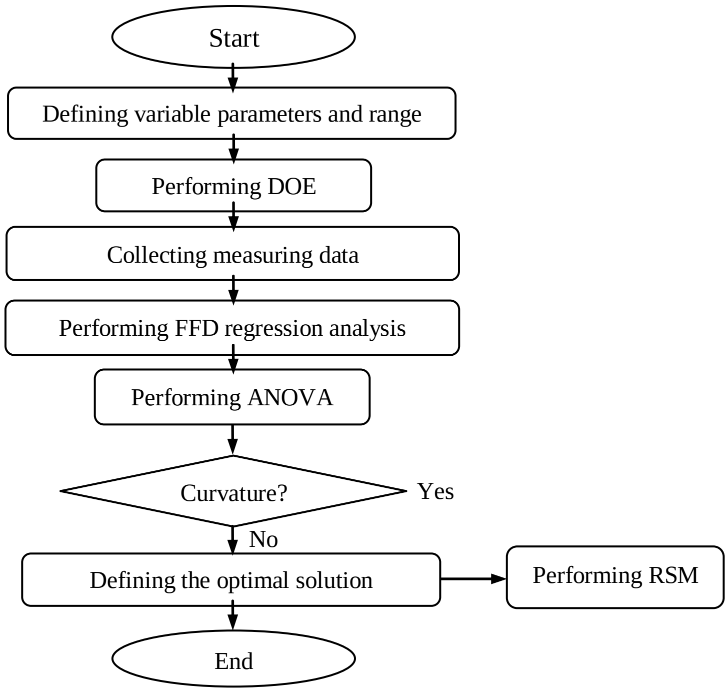

Figure 2. Full Factorial Design (FFD) flowchart.

2.1. Design of Experiment Setup

In this study, extruder temperature, platform temperature, printing speed and infill percentage have been selected as variable parameters due to significant effects on the shrinkage condition. The range of each parameter is shown in Table 1 based on material recommended processing parameter. Then, Full Factorial Design (FFD) with four centre points was selected as a screening process to evaluate the model and main parameter which contribute to the shrinkage by using Design Expert 7.0 software. Therefore, 20 runs of the specified condition have been generated and each run will be set in a 3D printing machine to evaluate the shrinkage condition of the printed part.

Table 1. Variable parameters and levels.

Factors	Level	
	Minimum	**Maximum**
Extruder temperature, A (°C)	190	220
Platform temperature, B (°C)	23	60
Printing speed, C (mm/s)	40	100
Infill percentage, D (%)	20	100

2.2. Specimen Setup

The specimens have 2.5mm of average thickness and this part has been donated by Continental Automotive Component, Malaysia as shown in Figure 3. The specimen has been printed by using Fused Deposition Modeling (FDM) printer (Vagler) and material used was (Polymax) Polylactic Acid (PLA).

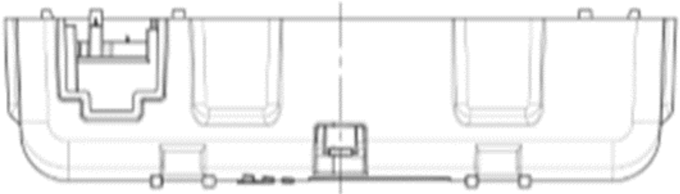

Figure 3. Specimen design

2.3. FFD Regression Analysis

The shrinkage results for each run which obtained from the measuring process using a coordinate measuring machine (CMM) will be used in the FFD regression analysis. By using Design Expert 7.0 software the regression analysis was performed to obtain the recommended parameter setting which will optimize the shrinkage results. The software will determine the relationship between variable parameters and response by using linear regression model in a statistical manner and the results will be verified with analysis of variance (ANOVA) to define either the regression models for both specimens were statistically significant or vice versa by defining the probability value.

3. Results and Discussion

3.1. Measurement Results

Results from measuring process using CMM for housing are shown in Table 2. The results tabulated the shrinkage values for each run of experiment with a specified variable parameters condition which obtained from the DOE. The dimensions that have been measured for 3D printed housing part were shown in Figure 4.

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Table 2. DOE results for the 3D printed housing part.

DOE run	Variable parameters for 3D Printing simulation				
	Extruder temperature (°C)	Platform temperature (°C)	Printing speed (mm/s)	Infill percentage (%)	Shrinkage (mm)
1	190	23	40	20	80.24
2	220	23	40	20	79.59
3	190	60	40	20	79.40
4	220	60	40	20	79.64
5	190	23	100	20	79.53
6	220	23	100	20	79.37
7	190	60	100	20	79.50
8	220	60	100	20	79.28
9	190	23	40	100	79.05
10	220	23	40	100	79.23
11	190	60	40	100	79.65
12	220	60	40	100	79.44
13	190	23	100	100	79.26
14	220	23	100	100	79.36
15	190	60	100	100	79.30
16	220	60	100	100	79.31
17	205	41.5	70	60	79.50
18	205	41.5	70	60	79.50
19	205	41.5	70	60	79.50
20	205	41.5	70	60	79.50

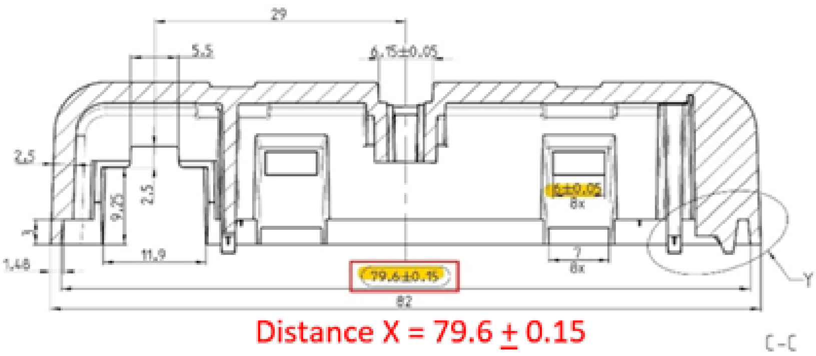

Figure 4. Dimensions measured.

3.2. Analysis of Variance Result

The results of the Analysis of Variance (ANOVA) were shown in Table 3. Based on the ANOVA results, DOE model was significant while curvature was shown insignificant. Therefore, the FFD optimisation approach was enough to get the recommended setting which optimised the shrinkage conditions.

Table 3. ANOVA Results for the 3D Printed Parts.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob >F
Model	0.24	1	0.24	4.91	0.0407
D-Infill	0.24	1	0.24	4.91	0.0407
Curvature	9.202E-003	1	9.202E-003	0.19	0.6672
Residual	0.82	17	0.048		
Lack of Fit	0.82	14	0.058		
Cor Total	1.06	19			

3.3. Optimised Result
To obtain the best condition in minimising shrinkage on the 3D printed part, the variable parameters of the 3D printer setting should be in optimal condition. By using the FFD optimisation approach, the lowest value of shrinkage was defined based on the linear model where the best combination of parameters setting resulted in the better value of shrinkage. The optimised results using FFD approach have been summarised as shown in Tables 4.

Table 4. Optimised results using FFD for 3D printed housing part.

Factors	Recommended simulation results	Predicted of dimension (mm)
Extruder temperature (°C)	213.02	79.57
Platform temperature (°C)	46.34	
Printing speed (mm/s)	59.02	
Infill percentage, (%)	20	

4. Conclusions
This study helps enhance the quality of the 3D printed part produced where the objective to optimise shrinkage of 3D printed housing part have been achieved. Based on the results, the optimised setting of the 3D printer has been obtained for the housing part by using Full Factorial Design (FFD) approach. However, the reliability of the results was dubious due to the insignificant DOE model for some responses as per ANOVA results. Some responses show insignificant models due to bad data distribution. This might be due to errors in the measurement process or some severe sample conditions. For a better result, an automatic CMM machine can be used to get consistency data distribution and the measuring process should be made 48 hours after the printing process.

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