Faculty of Manufacturing Engineering

PARAMETER OPTIMIZATION OF FUSED DEPOSITION MODELLING UNDER AMBIENT TEMPERATURE CONTROL

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DECLARATION

I declare that this thesis entitled “Parameter Optimization of Fused Deposition Modelling Under Ambient Temperature Control” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	…………………………………...
Name	:	…………………………………...
Date	:	…………………………………...

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature	:	…………………………………...
Supervisor Name	:	…………………………………...
Date	:	…………………………………...

DEDICATION

To my beloved parents, husband and son

ABSTRACT

Fused Deposition Modelling (FDM) is one of the most popular RP techniques available in the market. However, there is still limitation in terms of FDM performance such as surface roughness and dimensional accuracy. Creation of a part with good surface roughness and dimensional accuracy is critical as it can affect the part accuracy, post-processing cost and functionality of the parts. Based on the literature review, it was found that studies on the effect of ambient temperature in improving the surface roughness and dimensional accuracy of FDM built parts have been limited to certain extend. Environmental factors such as temperature and relative humidity have been believed to be the sources of error affecting surface finish and dimensional accuracy. Besides, temperature fluctuations during production also believed could lead to delamination and higher surface roughness. Therefore, this research study aims to investigate the effect of parameter variables such as ambient temperature, layer thickness and part angle to the samples fabricated by using FDM machine. The response surface methodology (RSM) was employed by using historical data in the experiment to determine the significant factors and their interactions on the FDM performance. Three levels manipulated factors namely ambient temperature (30℃, 45℃, 60℃), layer thickness (0.178 mm, 0.267 mm, 0.356 mm) and part angle (22.5°, 45°, 67,5°) have been studied. A total of 29 numbers of experiments had been conducted including two replications at center point. The results showed that all the parameter variables have significant effects on the part surface roughness and dimensional accuracy. Layer thickness are the most dominant factors affecting the surface roughness. Meanwhile, ambient temperature was the most dominant in determining part dimensional accuracy. The responses of various factors had been illustrated in diagnostic plot and interaction graph. Besides, the results also had been illustrated in further surface roughness and cross-sectional sample analysis. The optimum parameter required for minimum surface roughness and dimensional accuracy was at ambient temperature 30.01°C, layer thickness 0.18 mm and part angle 67.38°. The optimization has produced the maximum productivity with RaH 2.78 µm, RaV 12.38 µm and RaS 10.92 µm. Meanwhile, dimensional accuracy height 3.2%, length 2.1%, width 3.7% and angle 0.39°.

ABSTRAK

Permodelan Pemendapan Bersatu (FDM) adalah salah satu teknik RP paling popular yang terdapat di pasaran. Walau bagaimanapun, masih terdapat batasan dari segi prestasi FDM seperti kekasaran permukaan dan ketepatan dimensi. Penciptaan bahagian dengan kekasaran permukaan yang baik dan ketepatan dimensi adalah kritikal kerana ia boleh menjejaskan ketepatan bahagian, kos pasca pemprosesan dan fungsi bahagian. Berdasarkan kajian literatur, didapati kajian tentang kesan suhu ambien dalam meningkatkan kekasaran permukaan dan ketepatan dimensi bahagian-bahagian yang dibina oleh FDM telah terhad kepada beberapa jangkaan. Faktor alam sekitar seperti kelembapan suhu dan relatif dipercayai sebagai sumber kesilapan yang mempengaruhi kemasan permukaan dan ketepatan dimensi. Selain itu, turun naik suhu semasa pengeluaran juga dipercayai boleh mengakibatkan pengosongan dan kekasaran permukaan yang lebih tinggi. Oleh itu, kajian ini bertujuan untuk mengkaji kesan pembolehubah parameter seperti suhu ambien, ketebalan lapisan dan sudut bahagian kepada sampel yang dibuat dengan menggunakan mesin FDM. Kaedah permukaan respon (RSM) digunakan dengan menggunakan data sejarah dalam eksperimen untuk menentukan faktor-faktor penting dan interaksi mereka terhadap prestasi FDM. Tiga faktor yang dimanipulasi iaitu suhu ambien (30 ° C, 45 ° C, 60 ° C), ketebalan lapisan (0.178 mm, 0.267 mm, 0.356 mm) dan sudut bahagian (22.5 °, 45 °, 67,5 °) telah belajar. Sebanyak 29 bilangan eksperimen telah dijalankan termasuk dua replikasi dititik pusat. Keputusan menunjukkan bahawa semua pembolehubah parameter mempunyai kesan yang ketara pada kekasaran permukaan bahagian dan ketepatan dimensi. Ketebalan lapisan adalah faktor paling dominan yang mempengaruhi kekasaran permukaan. Sementara itu, suhu ambien adalah yang paling dominan dalam menentukan ketepatan bahagian dimensi. Respons pelbagai faktor telah digambarkan dalam plot diagnostik dan graf interaksi. Selain itu, hasilnya juga digambarkan dalam kekasaran permukaan dan analisis sampel keratan rentas. Parameter optimum yang diperlukan untuk kekasaran permukaan minimum adalah pada suhu ambien 30.01 ° C, ketebalan lapisan 0.18 mm dan sudut 67.38°. Pengoptimuman telah menghasilkan produktiviti maksimum dengan RaH 2.78 µm, RaV 12.38 µm dan RaS 10.92 µm. Sementara itu ketinggian ketepatan dimensi 3.2%, panjang 2.1%, lebar 3.7% dan sudut 0.39.

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LIST OF ABBREVIATIONS

3D	-	Three-dimensional
ABS	-	Acrylonitrile-butadiene-styrene
ANOVA	-	Analysis of variance
ANN	-	Artificial neural network
CAD	-	Computer-aided-design
CMM	-	Coordinate measuring machine
CT	-	Computerized tomography
DOE	-	Design of experiment
FDM	-	Fused deposition modelling
FEA	-	Finite element analysis
GTRE	-	Gas turbine research establishment
L	-	Sampling length
LOM	-	Laminated object manufacturing
MRI	-	Magnetic resonance imaging
PC	-	Polycarbonate
PLA	-	Polylactic acid
Ra	-	Roughness average
RaH	-	Horizontal surface roughness
RaS	-	Slanted surface roughness
RaV	-	Vertical surface roughness
RMS	-	Root mean square
Rmax	-	Maximum peak value
RP	-	Rapid prototyping
RPM	-	Revolutions per minute
RSM	-	Response surface manufacturing

SGC	-	Solid round curing
SLA	-	Stereo lithography
SLS	-	Selected laser sintering
STL	-	Standard triangulation language
S/N	-	Signal to noise
UV	-	Ultraviolet
Z(x)	-	The profile height function
µm	-	Micrometer

LIST OF PUBLICATIONS

1. Harun, N.H., Kasim, M.S., Abidin, M.Z.Z., Izamshah, R., Attan, H., and Ganesan, H.N., 2017. A Study On Surface Roughness During Fused Deposition Modelling: A Review. *Journal of Advanced Manufacturing Technology (JAMT)*, Volume 11 (Special Issue).

CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, industrial production has become increasingly challenging, the focus of industries has changed from conventional method to rapid fabrication techniques. The requirement for complex shape with rapid production has becomes a new challenge for the manufacturers. Aware of the growing demand of the new design, manufacturers require accelerating their product development and cycle time to meet the market demand without neglecting the product quality. The requirement of product quality with high accuracy and surface finish has become an important criterion in engineering application. Therefore, manufacturers need to conduct ongoing studies to meet the standard required. So, products would response based on the market demand earlier than their competitors.

Since 1999, the automotive industry has shown that rapid prototyping (RP) can be used to reduce the lead time in the development process (Wiedemann and Jantzen, 1999). RP or additive manufacturing is referred as a technology used to produce a physical model or a prototype directly from three-dimensional computer-aided-design (3D CAD) data in a very short time (Boejang et al., 2013). The potential of the technique is seemed to be widespread as the technique helps to optimize the product development cost and time to the market and creating complex parts with precise dimension.

Taking advantage of the flexibility, cost and time saving, RP has been extensively used by manufacturers from different industries such as automotive, consumer products, business machines, medical and aerospace industry to accelerate their product cycle to the market (Chua et al., 2003; Ivanova et al., 2013). The use of RP technology in a production is able to reduce the development time by 30-50 percent (Thrimurthulu et al., 2004) due to minimum human intervention including the use of traditional tool such as jigs and fixture (Boschetto and Bottini, 2015). Besides, the used of RP also able to minimize the used of wastage materials compared than subtractive method such as milling and lead (Peng et al., 2014).

The estimated breakdown of worldwide 3D printing has shown that motor vehicles and consumer products are the biggest contributor in the worldwide 3D printing use. Followed by business machines, medical, academic and aerospace industry (Vashishtha, 2011). RP has been applied in automotive and consumer product industry to manufacture multiple plastic parts via investment casting process. Since many years, investment casting has been used to produce complex shape with good surface finish such as producing intake manifold in automotive parts. However, the conventional investment casting process is time consuming and required higher cost as it involves the use of injection molding for pattern preparation (Singh and Singh, 2016). Besides, the used of wax in conventional investment casting process susceptible to shrinkage (Taşcioğlu and Akar, 2003). Injection molding has accuracy ups to 0.005 inches.

Therefore, the possibility of manufacturing plastic parts through fused deposition modelling (FDM) within minimum cost has opened a new field of rapid tooling (Pal and Ravi, 2007). FDM as a one of the most popular RP technique has provided an alternative method for producing investment casting patterns with lower cost within shorter time. FDM is selected due to cheaper and low maintenance cost compare than the other RP machine available in the market (Jain and Kuthe, 2013). Research study by Stratasys has shown that FDM process able to save up cost from 75 to 94% and the time taken can be enhanced in 98% faster than the conventional method (Stratasys, 2016b). Besides, the advantages of FDM such as easy material change, compact size and low temperature operation has make it more popular among the other RP machine (Galantucci et al., 2009).

1.2 Problem statement

Surface quality is a main problem facing in RP. The improvement of surface roughness and dimensional accuracy are key issues that need to be addressed for successful implementation of RP technology (Rosochowski and Matuszak, 2000; Hopkinson et al., 2006). As RP is moving towards rapid manufacturing there is an increasing demand on obtaining good quality parts with good surface roughness and accuracy. Rapid manufacturing is the process of using RP process to construct parts that directly used as a finished product or components. Therefore, creation of a part with good surface roughness and dimensional accuracy is critical as it can affect the part accuracy, post-processing costs and functionality of the parts (Vijay et al., 2012).

RP has been used as a master pattern for a broad range of manufacturing process. However, the application of RP as a master pattern is limited due to the bad surface roughness and dimensional accuracy. The surface roughness value for FDM by using ABS material is ranged between 9 µm and 40 µm (Campbell et al., 2002). Meanwhile, the percentage of accuracy for FDM is between 0.03 % to 2.21 % in length and 0.32 % to 5.86 % in width (Akande, 2015). The nature of investment casting will duplicates whatever kind of surface condition that the master pattern presents (Bakar et al., 2010). Therefore, the quality of RP as a master pattern need to be improved. Investment casting generally provides better accuracy with 0.127 mm with normal tolerances and surface finish of 3.125 µm compared than other casting process (Stratasys, 2016b).

Since the past few years, several studies have been made by numerous researches to improve the RP performance by using proper adjustment of parameters and post-processing technique. However, the used of post-processing technique is cost and time consuming as it adds more steps in the final process. Meanwhile, the parameters optimization is more flexible, less time consuming and cheaper compared to the post-processing technique. The technique involves the controlling various input parameters to the fabricated part and it is believed to have significant effect on the RP performance (Shojib Hossain et al., 2014).

Several parameters have been studied by previous researchers to improve the FDM performance. However, to the best of author's knowledge studies on the effect of ambient temperature in improving the surface roughness and dimensional accuracy of FDM built parts have been limited to certain extend. Environmental factors such as temperature and relative humidity have been believed to be the sources of error affecting surface finish and dimensional accuracy (Gajdoš and Slota, 2013; Mohamed et al., 2015). Besides, temperature fluctuations during production also believed could lead to delamination and higher surface roughness (Anitha et al., 2009; Galantucci et al., 2009). Therefore, this research wants to study and demonstrates how optimizing these parameters can improve FDM performance.

1.3 Research objectives

The objectives of the research are as follows:

a) To study the effect of layer thickness, ambient temperature and part angle on FDM performance such as surface roughness and dimensional accuracy.
b) To identify the optimum value parameter for layer thickness, part angle and ambient temperature as to obtain the lowest surface roughness and high dimensional accuracy.
c) To generate the mathematical prediction model on each part of the FDM performance studied.