PARAMETERS OPTIMIZATION FOR 3D PRINTER BY USING STATISTICAL TECHNIQUE

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SUPERVISOR'S DECLARATION

I declare that this project report entitled "Parameters Optimization for 3D Printer by Using Statistical Technique" is the result of my own work except as cited in the references

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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ABSTRACT

3D printer is widely used in producing and manufacturing prototypes as well as functional parts due to its ability to make three dimensional object by layering technique and also its various options of materials. It is found that mechanical properties of 3D printed part are affected by the values of the process parameters used in the 3D printing process. In this project, the process parameter of layer thickness, raster orientation and infill density are set as the manipulated variables while tensile strength of the 3D printed part is set as the responding variable. This project aims to identify the relationship between the input process parameters and the tensile strength of FDM printed part, the correlation among the input process parameters, the significance of input parameters towards the responding variable and also the optimized value of the input process parameters to maximize the tensile strength of the FDM printed part. Taguchi orthogonal array is used to determine the total number of experiment runs and combination of levels of each input process parameters that are needed to be executed. Multiple regression model analysis, analysis of variance and Taguchi signal-to-noise ratio are statistical methods that are used to identify the relationship, correlation, significance and optimum values of the input process parameters in maximizing the tensile strength of the FDM printed part. It is obtained that the tensile strength of the FDM printed part is inceasing with the increasing value of the layer thickness, raster orientation as well as infill density. There is no correlation between the input process parameters. Raster orientation is significant in maximizing the tensile strength of the FDM printed part. The optimum value of each input process parameters in maximizing the tensile strength of the FDM printed part is 0.28mm, 90° and 40%.

ABSTRAK

Pencetak 3D digunakan secara meluas dalam menghasilkan dan mengeluarkan prototaip serta bahagian berfungsi kerana keupayaannya untuk membuat objek tiga dimensi dengan teknik lapisan dan juga pelbagai pilihan bahan yang boleh digunakan. Didapati sifat mekanikal bahagian cetakan 3D dipengaruhi oleh nilai parameter proses yang digunakan dalam proses cetakan 3D. Dalam projek ini, parameter proses ketebalan lapisan, orientasi raster dan ketumpatan isian ditetapkan sebagai pembolehubah yang dimanipulasi manakala kekuatan tegangan hasil cetakan 3D ditetapkan sebagai pembolehubah bergerak balas. Projek ini bertujuan untuk mengenal pasti hubungan antara parameter proses input dan kekuatan tegangan bahagian cetakan FDM, korelasi antara parameter proses input, parameter proses input yg penting dan juga nilai optimum parameter proses input untuk memaksimumkan kekuatan tegangan hasil cetakan FDM. Tatasusunan ortogonal Taguchi digunakan untuk menentukan jumlah bilangan larian percubaan dan gabungan tahap setiap parameter proses input yang diperlukan untuk dilaksanakan. Analisis model regresi berbilang, analisis varians dan nisbah isyarat-kepada-bunyi Taguchi adalah kaedah statistik yang digunakan untuk mengenal pasti hubungan, korelasi, kepentingan dan nilai optimum parameter proses input dalam memaksimumkan kekuatan tegangan bahagian cetakan FDM. Didapati bahawa kekuatan tegangan bahagian cetakan FDM semakin meningkat dengan peningkatan nilai ketebalan lapisan, orientasi raster serta ketumpatan isian. Tiada korelasi antara parameter proses input. Orientasi raster adalah penting dalam memaksimumkan kekuatan tegangan hasil cetakan FDM. Nilai optimum bagi setiap parameter proses input dalam memaksimumkan kekuatan tegangan hasil cetakan FDM ialah 0.28mm, 90° dan 40%.

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LIST OF ABBREVIATIONS

3D	Three Dimensional
PETG	Polyethylene Terephthalate Glycol
ANOVA	Analysis of Variance
CAD	Computer Aided Design
STL	Stereo-lithography
FDM	Fused Deposition Modelling
S/N	Signal-to-Noise
UTM	Universal Testing Machine
SS	Sum of Square

CHAPTER 1

INTRODUCTION

1.1 Background

3D printing is categorized as additive manufacturing or layer manufacturing technology. It could use various types and forms of materials to build a three dimensional object. It has been developing progressively in improving and widening its functionality. It has been used for manufacturing prototypes, tools and functional end products. There are several existing technologies regarding 3D printing which are selective laser sintering/ melting, laser-cutting of sheet material, electron beam melting, laser-photo resin curing, fusing of melted filament material and many others. Although these technologies are commercially available, there are a wide range of qualities and built parts of the machines that needed to be considered (Tontowi et al., 2017).

Fusing of melted filament material or known as FDM is different from conventional technique of injection moulding product formation as there is no usage of any moulding or housing to form the product in FDM process. It only extrudes heated material on a flat surface platform called as building platform which is made of material such as glass or steel layer by layer until a complete 3D model of the product is formed (Nazan et al., 2017).

There are few steps involved in generating a FDM part using a 3D printer. The first step is to create a three dimensional solid model using any available CAD software such as Solidworks or CATIA software. The three dimensional model is then exported to the FDM software in STL format. This format tessellating the model and reduce it into a set of triangles. The model in STL format is horizontally sliced into many thin sections that will be generated layer by layer in FDM process. These thin sections are in a form of two dimensional contours which resemble three dimensional model when they are stacked up together. The FDM software will then generate a process plan for the FDM machine's hardware to operate based on the information (Montero et al., n.d.).

The concept used in FDM machine hardware is that a filament is fed through a heating element. The filament is heated into a semi-molten state. Then, the filament goes through a nozzle and deposited onto the constructing part. Since the material which is the filament is extruded in semi molten state, it will fuse with any material around it that has already been deposited. The nozzle head moves along the X-Y plane depositing the material according to the part in STL file and then moves vertically along Z plane to deposit a new layer of two dimensional contour. These will be repeated until a full physical representation of the original CAD model have been deposited (Montero et al., n.d.).

1.2 Problem Statement

Additive manufacturing has become an integral part in engineering process. There are more parts that are printed with 3D printer are being used for functional purposes rather than for being prototypes (Hernandez et al., 2016). Mechanical properties of 3D printed parts is important in evaluating and determining the printing quality (Wu et al., 2015). Characteristics and efficiency of FDM printed parts are affected by its process parameters (Dey & Yodo, 2019). Different setting of the process parameters could lead to different values of mechanical properties such as tensile strength of FDM printed part. Selecting an optimum combination of the process parameters will produce a FDM printed part with desired qualities (Dey & Yodo, 2019). The examples of process parameters for 3D printer are raster width, raster orientation, layer thickness, air gap, build orientation, extrusion temperature, infill pattern and density. The description for the process parameters are as in Table 1.2.1.

Table 1. 2. 1: Process Parameters

Process Parameters	Definitions
Layer thickness	The height of deposited layers along Z axis which is the vertical axis of 3D printer
Raster orientation	The angle between the direction of deposited bead and the X axis of the building platform of 3D printer
Air gap	The gap between two adjacent deposited beads on the building platform of 3D printer for each layer
Raster width	The width of deposited bead
Build orientation	The orientation of a part being produced on building platform
Infill density	The percentage of infill volume filled with material
Infill pattern	The pattern of internal structure
Extrusion temperature	The temperature set to heat the filament during FDM process

There are a lot of researchers have been analyzing and optimizing various process parameters to achieve desirable properties of FDM printed part. Tensile strength is one of the important desirable mechanical properties for FDM printed parts. Hernandez et al. (2016) studied to determine the optimum mechanical properties in terms of tensile, compressive and flexural of 3D printed parts with varying build orientation. Ismail and Rukiya (2014) tested

FDM printed parts for their tensile strength, flexural strength and surface roughness by setting five different raster orientations and three different build orientation.

Letcher (2017) studied the correlation between process parameters and mechanical properties of FDM printed part. The process parameters are number of layers, layer thickness and raster orientation while the mechanical properties tested are ultimate tensile strength, modulus of elasticity, maximum force and maximum elongation. Wu et al. (2015) studied the influence of layer thickness and raster angle on the mechanical properties such as tensile, compressive and bending strength of 3D printed part. Montero et al. (n.d) investigated the effects of varying process parameters of FDM such as raster orientation, air gap, raster width, color and model temperature on the tensile strength of 3d printed parts.

1.3 Objective

The objectives of this project are:

1. To determine the relationship between input process parameters and the tensile strength of FDM printed part.
2. To identify if there is a correlation between the input process parameters.
3. To determine whether the input process parameters are significant in maximizing the tensile strength of FDM printed part.
4. To obtain the level of contribution for each input process parameters in maximizing tensile strength of FDM printed part.
5. To determine the optimum values of input process parameters in maximizing tensile strength of FDM printed part.

1.4 Scope

The scopes of this project are:

1. An experiment is designed using Taguchi orthogonal array. The input process parameters for FDM printing are layer thickness (0.16mm, 0.20mm and 0.28mm), raster orientation (0°, 45° and 90°) and infill density (20%, 30% and 40%). The orthogonal array shows the amount of experiment runs that needed to be executed. Each experiment runs will have different combinations levels of layer thickness, raster orientation and infill density.
2. Specimens with measurements of ASTM D638 Type I standard are printed using a FDM printer. PETG filament is used as the printing material. The settings of layer thickness, raster orientation and infill density for the printing will be based on the combination levels of each factors in the experiment runs. The other process parameters are set constant based on the standard printing setting in Ultimaker Cura software. The printing settings used are line infill pattern, 220°C printing temperature, 80°C build plate temperature, 50mm/s printing speed, 100% fan speed, skirt build plate adhesion, 1.6mm wall thickness and four wall line count.
3. The FDM printed parts are tested using a universal testing machine to determine their maximum tensile strength before fracture.
4. The tensile strength of FDM printed specimens are analysed using statistical method such as multiple regression analysis, analysis of variance and Taguchi signal-to-noise ratio. The multiple regression analysis is used to obtain a regression equation and to determine the correlation between each input process parameters. The analysis of variance is used to identify whether the input process parameters are significant in maximizing the tensile strength of the FDM printed specimen. The signal-to-noise

ratio is used to determine the level of contribution and optimum values for each input process parameters in maximizing the tensile strength of FDM printed specimen.

CHAPTER 2

LITERATURE REVIEW

Several articles that are related with this project has been reviewed and summarized according to several sub-topics. A table has been made to highlight the main points of the literature review as in Table 2.0.1. It shows the details of the studies that are carried out by other researchers that are important as the reference for this project.

2.1 Test Specimen

Shape and dimensions of a specimen are made according to the type of standard used in mechanical testing of the specimen. Each mechanical testing use different kind of standards. As the example, Hernandez et al. (2016) used ASTM D638 Type I which is a dog bone shaped specimen in testing tensile strength while ASTM D695 for compression test. The type of standard used also depends on the type of material used to manufacture the specimen. Thermoplastic is a common material used in FDM process, therefore researchers used standard that is suitable for testing mechanical properties of thermoplastic in their studies on FDM process. As the example, Hernandez et al. (2016) used ASTM D638 Type I which is a dog bone shaped specimen in testing tensile strength. It has total length of 165 mm, total width of 19 mm, depth of 7 mm, narrow width of 13 mm, narrow length of 57 mm, radius fillet of 76 mm and gage length of 50 mm. Croccolo et al. (2013) used specimen according to ASTM D638-10 but with modified fillet radius which is from 76mm to 244mm to avoid unacceptable ruptures at the fillet region. Durgun and Ertan (2014) used ISO 527:1997 standard for tensile specimen. Liu et al. (2017) designed its specimen according to GB/T 1040.2-2006 which is suitable for tensile testing. Panda et al. (2014) made specimen based on ISO 604-1973 standard for testing the tensile of the specimen.

2.2 Material

There are various materials that can be used in FDM process. Dey and Yodo (2019) have listed several materials of filaments that can be used in FDM process which are:

1. Acrylonitrile butadiene styrene (ABS)
2. Polylactic acid (PLA)
3. Polycarbonates (PCs)
4. Polyether ether ketone (PEEK)
5. Polyetherimide (PEI)
6. Nylon

ABS and PLA are two common materials that are widely used in FDM process (Dey & Yodo, 2019). These filament materials are used based on their properties. Durgun and Ertan (2014) and Hernandez et al. (2016) used Acrylonitrile Butadiene Styrene (ABS) P430 as the material of their test specimen because it has high mechanical strength and convenient for FDM process. Croccolo et al. (2013) used specimen of ABS M30 which is a common material used in FDM process. Panda et al. (2014) used ABS P400 as the material for FDM process. Liu et al (2017) used Poly-lactic Acid (PLA) as the material of the filament for FDM process.

2.3 Machine/Equipment

3D printer is needed to carry out FDM process. There are many 3D printers available in the market which comes with various properties and characteristics. There are also various types of universal testing machine for testing tensile strengths. Hernandez et al. (2016) used uPrint SE Plus 3D printer which has fixed settings of process parameters and MTS 810 Material Test System Load Unit as testing machine. Durgun and Ertan (2014) printed their specimen using a Dimension 3D Printer machine and tested tensile strength using a Zwick/Roell test system. Liu et al. (2017) fabricated specimens using Desktop 3D Printer MakerBot Replicator 2 and measuring ultimate load for calculating tensile strength using microcomputer-controlled electronic universal testing machine (WDW-10). Panda et al. (2014) carried out the FDM process using Stratasys Fortus 400mc machine.

2.4 Process Parameters

Properties of specimen printed by FDM process are influenced by the setting of its process parameters. Various settings will produce different properties of the FDM printed part. There are many examples of process parameters in FDM process stated under problem statement of this paper. There are many studies have been made to determine the best settings of FDM process parameters to obtain the required or optimal mechanical properties of FDM printed part. As the example, Hernandez et al. (2016) studied the effects of different build orientations on the tensile, compression and 4-point flexure on the part printed with five different build orientations which are 0° in xy plane, 45° and 90° in xy and z plane.

The result shows that the part printed in 90° in xy plane has the highest tensile strength than other build orientations but only with small different. Croccolo et al. (2013) developed an analytical model to estimate the mechanical properties of FDM printed part which are strength and stiffness properties based on the setting of number of contour, build orientation, bead width, raster angle, air gap and layer thickness. Durgun and Ertan (2014) printed FDM parts with raster orientation of 0°, 30°, 45°, 60° and 90° and build orientation of horizontal, vertical and perpendicular to test on the surface roughness, tensile strength and flexural strength of FDM part. They found that build orientation has more significant effect to the mechanical properties than the raster orientation. Liu et al. (2017) studied on layer thickness, deposition style, deposition orientation, raster gap and width as the factors in contributing to the tensile strength, flexural strength and impact strength of FDM part. Panda et al (2014) studied the relationship between layer thickness, raster angle and width with air gap on the tensile strength of FDM printed part.

2.5 Statistical Method

Statistical methods are mainly used for two purposes which are to design the experiment and also to find the optimum combination of process parameters in producing FDM part with desired properties. Liu et al. (2017) used Taguchi method in designing experiment and Analysis of Variance (ANOVA) to study the influences of layer thickness, deposition style, deposition orientation, raster gap and raster width on the tensile strength, flexural strength and impact strength of FDM part. Liu et al. (2017) also determined the optimal combination of the process parameter based on grey relational analysis. Panda et al. (2014) applied Particle Swarm Optimization (PSO) to find combination of layer thickness, raster angle, raster width and air gap that results in good strength.

Genetic programming is also used by Panda et al. (2014) to approximate the relationship between the process parameters with tensile strength of FDM printed part. Differential evolution also used in this paper to estimate the accuracy and convergence characteristic (Panda et al., 2014).

Table 2. 0. 1: Summary of Studies on Tensile Strength of FDM Printed Part

Reference	Machine/Equipment	Material / Model	Statistical Method	Process Parameters	Result
(Hernandez et al., 2016)	FDM • uPrint SE Plus 3D printer (has fixed setting of parameters) Tensile Testing • MTS 810 Material Test System Load Unit	Material • ABS P430 Model • ASTM D638 Type I for tensile testing	-	Build orientation; • 0°, 45° and 90° in xy plane • 45° and 90° in z plane	Part printed in 90° in xy plane has the highest tensile strength
(Croccolo et al., 2013)	Only FDM machine and Tensile test machine are mentioned. The model name are not specified.	Material • ABS M30 Model • ASTM D638-10 with modified fillet radius to prevent unacceptable rupture at fillet region.	-	Number of contour, build orientation, bead width, raster angle, air gap and layer thickness	-

(Durgun & Ertan, 2014)	FDM • Dimension 3D Printer Tensile Testing • Zwick/Roell test system	Material • ABS P430 Model • ISO 527:1997	-	Build orientation • Horizontal, vertical and perpendicular Raster angle • 0°, 30°, 45°, 60° and 90°	Build orientation has higher effect to the mechanical properties than the raster angle
(Liu et al., 2017)	FDM • Desktop 3D Printer MakerBot Replicator 2 Tensile Testing • microcomputer-controlled electronic universal testing machine (WDW-10)	Material • Polylactic Acid (PLA) Model • GB/T 1040.2-2006	• Taguchi Method • Analysis of Variance (ANNOVA) • Grey Relational Analysis	Deposition orientation, layer thickness and deposition style, raster width, and raster gap	-
(Panda et al., 2014)	FDM • Stratasys Fortus 400mc machine	Material • ABS P400 Model • ISO 604-1973	• Particle Swarm Optimization (PSO) • Genetic Programming (GP) • Differential Evolution (DE)	Layer thickness, raster angle, raster width and air gap	-