UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THE INFLUENCE OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES OF FUSED DEPOSITION MODELING PARTS

This report is submitted in accordance with requirement of the University Technical Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Manufacturing Design) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Manufacturing Design) (Hons). The member of the supervisory committee are as follow:

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(Dr. Zulkeflee bin Abdullah)

ABSTRAK

Fused Deposition Modeling (FDM) adalah salah satu jenis proses additive pembuatan yang menggunakan pemanasan bahan polimer seperti acrylonitrile-butadiene-styrene (ABS) dari muncung mesin untuk menghasilkan produk berlapisan dari bawah ke atas. Bahagian FDM rapuh kerana keliangan yang tinggi yang disebabkan oleh udara terperangkap apabila model sedang dibina. Tujuan projek ini adalah untuk mengkaji pengaruh jenis-jenis parameter proses ke atas sifat-sifat mekanikal dari spesimen FDM. Parameter-parameter proses yang digunakan dalam projek ini adalah corak infill, peratusan infill, dan ketebalan lapisan dengan interaksi parameter disiasat. Tiga tahap parameter akan digunakan iaitu, corak infill barisan, sepusat dan sarang lebah; peratusan infill 10%, 30% dan 50%; ketebalan lapisan 0.2 mm, 0.3 mm dan 0.4 mm. Sifat-sifat mekanikal yang digunakan adalah kajian kekuatan tegangan dan kekuatan lenturan. Terdapat 27 kumpulan eksperiment dan telah disusun menggunakan kaedah reka bentuk (DOE). Kekuatan tegangan menghasilkan keputusan kekuatan mekanikal yang paling tinggi 31.22 MPa, iaitu corak infill sepusat, peratusan infill 50% dan ketebalan lapisan 0.2 mm. Manakala keputusan mekanikal yang paling tinggi (26.66 MPa) di kekuatan lenturan adalah corak infill sarang lebah, peratusan 50% dan ketebalan 0.2 mm. Ini adalah disebabkan oleh kaedah ujian yang berlainan untuk mematahkan spesimen. Analisis Varians (ANOVA) Minitab 2017 telah digunakan untuk mengetahui yang mana satu parameter dan interaksinya signifikant. Plot kesan dan Plot interaksi uga dihasilkan untuk mencari keputusan optimuman untuk kedua-dua sifat mekanikal. Hasil menunjukkan semua parameter dengan interaksinya adalah ketara.

ABSTRACT

Fused deposition modeling (FDM) is one of additive manufacturing process which used heated plastic materials such as acrylonitrile-butadiene-styrene (ABS) from the nozzle to produce parts layer by layer from bottom to top. FDM parts were brittle because of the high porosity which cause by the trapped air bubbles when models were built. The aim of this project is to study the influence of different types of process parameters on mechanical properties of FDM parts. Process parameters used in this project are infill pattern, infill percentage and layer thickness. In addition the interactions between process parameters were investigated. Three levels of each parameters were used in this project; infill pattern of line, concentric, and honeycomb; infill percentage of 10%, 30% and 50%; layer thickness of 0.2 mm, 0.3 mm and 0.4 mm. The mechanical properties used for testing were tensile and three-point flexural test. There are 27 experimental runs for each responses that were arranged using design of experiment (DOE) method. For the tensile, infill pattern of concentric, infill percentage of 50% and layer thickness of 0.2 mm shows the highest mechanical strength of 31.22 MPa. Compare with flexural, the result were mostly same but infill pattern of honeycomb and the flexural strength is 26.66 MPa. This is due to the different testing method to cause the specimens to break. Analysis of Variance (ANOVA) of Minitab 2017 is used to find which parameters or the interaction are significant. Main effect plot and interaction plot were also plotted to find the optimization result for both responses. The outcomes showed all the parameters including the combination of the parameters were statistically significant.

DEDICATION

Dedicated to
My beloved father, Tang Tat Seng
My appreciated mother, Law Siew Gaik
My siblings, Tang Mei Juan, Mei Ee, Mei Ay, Mei Le, Zheng Shian
For giving me moral support, money, cooperation, encouragement and also understandings

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive Manufacturing
ASTM	-	American Standard for Testing and Materials
ANOVA	-	Analysis of Variance
CAD	-	Computer Aided Design
CCD	-	Central Composite Design
DE	-	Differential Evolution
DFMA	-	Design for Manufacturing and Assembly
DOE	-	Design of Experiment
FDM	-	Fused Deposition Modelling
FYP	-	Final Year Project
GMDH	-	Group Method of Data Handling
MS	-	Mean Square
ISO	-	International Standard Operation
PC	-	Polycarbonate
PEEK	-	Polyether-Ether-Ketone
PLA	-	Polylactic Acid
PPSF	-	Polyphenylsulfone
SS	-	Sum of Square
STL	-	Stereolithographic
ULTEM	-	Polyetherimide

LIST OF SYMBOLS

mm	-	Milimeters
kN	-	Kilo Newton
%	-	Percentage
σ	-	Stress
MPa	-	Mega Pascal
N	-	Force
ε	-	Strain
°	-	Degree
˚C	-	Degree Celsius
mm/min	-	Milimeters per minutes

CHAPTER 1

INTRODUCTION AND GENERAL INFORMATION

1.1 Background of the Study

Additive manufacturing (AM) is a type of direct manufacturing which developed from rapid prototyping innovation in 1990 (Deon de Beer *et al*., 2016). AM famously known as 3D printing which a manufacturing technique that builds parts layer by layer using material as polymer, metals and composites. According to Bagsik and Schöoppner (2011), this technology started as a procedure for building model parts and recently it has discovered new using method in the manufacturing process and the production of manufacturing tools for end-use parts. AM provides adaptability to make complex part geometries that are hard to build using conventional method. It can be fabricate with design such as internal cavities and lattice structures that reduce parts weight without trading off the mechanical properties.

Fused deposition modeling (FDM), example of the Additive Manufacturing system which produces models from the material of plastic, for example like PLA or ABS by laying tracks of semi-liquefied plastic filament on the build platform in a layer by layer order from bottom to top. It is an additive manufacturing process in which the material used is selectively extruded through a nozzle or orifice. FDM 3D printer which is a thermoplastic filament that driven into the heated nozzle where the plastic reaches a molten state, and is dispensed through a small diameter hole tip, nozzle (Hossain *et al*., 2013). The process starts with a 3D part model in CAD or modeling software before converting to STL format file (Gardan *et al.*, 2016), which slice the file to thin cross-sectional layer. Besides, FDM technology is office-friendly and easy to use which supported production-grade thermoplastics that are environmentally stable (Surange and Gharat, 2016).

The FDM machine generally have restrictions and cannot build undermines without support material (Kun, 2016). Acrylonitrile Butadiene Styrene (ABS), one of a type of FDM material which used in a very large variations of applications in the industry recently. Normally, 3D printers are able to process ABS material with a hot-end, which means the plastic is melted before it forced through the nozzle. ABS is durable, flexible, machinery and could resist high temperature make it often a preferred plastic for engineers and professional applications (When *et al*., 2015). This makes ABS material products has a very wide space in most purposes such as easy to be sanded and painted for a matte appearance.

Every AM machines have different machine setup parameters which specific to machine or process. The process parameters could influence the strength and quality of a part that printed by the 3D printing, such as the infill percentage, deposition angle, infill pattern, build orientation and thickness of resolution layers effect the performance of part models built by FDM machine. Sood et al. (2012) stated that the ability to change infill dimensions and layer thicknesses of the parameters can significantly impact the mechanical properties. Parameter selection can result in inverse relationships such as minimal build time coupled with inferior part strength (Ali and Maharaj, 2014). However, as it is a relatively new AM technologies, the suitable levels of process parameters combined with different performance criteria still need a further investigation (Lee *et al.*, 2005).

Mostly, the process parameters set is according to the default settings of the 3D printing manufacturers or open source tooth-path generating software. Based on Baich and Manogharan (2015), CAD model contains no data concerning loading during usage, which can change in different parts and then require different mechanical properties. This indicates that CAD software modelling could not verify the suitable mechanical testing in various shape of parts.

1.2 Problem Statement

This report has come from an interest to investigate the area of 3D printing as part of the research strategy on emerging technologies under the Faculty of Manufacturing Engineering. In the Fused Deposition Modeling process, plastic material is melted and extruded via a nozzle or two nozzles to generated sections parts. There are many type of parameters depends on the 3D printing machine that could influence the strength and quality on the lattice structure when using 3D printers. Different scales of these process parameters could affect the mechanical performance and the quality of the printed part.

According to Bourell *et al.*, (2014) and Phil Lambert (2014), mechanical properties of the parts produce by Additive Manufacturing is low and brittle. This is because AM parts produce high porosity which cause by the trapped air bubbles (Chuang *et al.*, 2015). There are still lack of information on using suitable parameters scale because Additive Manufacturing technologies are still new in Malaysia and needed further investigations.

1.3 Objectives

There are few objectives that will be carried out through this project:

1. To study the process parameters of infill percentage, layer thickness and infill pattern on the mechanical properties of tensile and flexural strength.

2. To find out the significant parameters using Design of Experiment (DOE) method.

3. To analyze the results on part tensile and flexural strength.

1.4 Scope

This study is to exploratory in Fused Deposition Modeling (FDM) because it is still new and has not yet been fully explored in the industry applications. The aim of this research is to investigate the influence of the process parameters setting on the mechanical properties using ABS material. At the same time, the research can used as guidance for the new 3D printer users to create an ideal products. Parameters such as infill percentage, layer height and infill pattern of the FDM machine will be investigated throughout this project. The main body point of this research, a detailed description of the effect on these three types of process parameters on mechanical properties of tensile strength and flexural strength are investigated and provided in this report. Besides, software analysis such as Analysis of Variance (ANOVA) is used and arranged by Design of Experiment (DOE) with full factorial design to find out the optimum parameters when using the FDM machine. This research aid to the FDM 3D printing users produce the quality of the outcomes product.

1.5 Project Significance

With the regularly expanding interests in using 3D printing, it is important to identify which infill pattern, infill percentage or layer thickness will provide ideal strength for users in printing parts. This is a great significance because in FDM machine, there are still lack of information towards the combination of these three type parameters.

The work presented in this report will significantly study the relationship between infill patterns, infill percentage and layer thickness with mechanical strength of tensile and flexural testing. Although this study utilized an open source printer and build infill parameter combinations, the proposed techniques can be adjusted and extrapolated to other entry-level material extrusion frameworks and parameters. This investigation will help in the analysis of the correlation between three types of parameters with mechanical properties. The study will enable users to have a guidelines to make ideal and generating more predictable product based on the process parameters setting and manufacturing criteria of Fused Deposition Modeling 3D printing.

1.6 Summary

Additive manufacturing (AM) could reduce raw material usage, lead time for part production, and manufacturing cost while maintaining or improving the performance of the end item. The purpose of this report is to investigate the influence of three process parameters (infill pattern, infill percentage, and layer thickness) on the mechanical properties (tensile and flexural test) using FDM machine with ABS material. Testing and software analysis (DOE) will be done in this report to determine the accurate result. In the end of this report, the study will help the users formulate criteria of process parameters in future works.

CHAPTER 2

LITERATURE REVIEW

In this chapter, detail result data from the related research journal and article were carried out. An overview of parameters setting on the mechanical properties using Fused Deposition Modeling were presented and discussed in this session. The vast majority of the researches on FDM parameters setting have been guided to enhance the mechanical properties, surface finishing and dimensional accuracy for ABS material printed models (Mohamed *et al*., 2015). Therefore, types of process parameter that mostly used by the researcher and the mechanical properties such as tensile strength, compressive strength, flexural and hardness testing of the printed parts were also explained and reviewed. The current problem of the user encounters is the various types of process parameters in FDM machine which could affected the printed part produced. Hence, this project is carried out to investigate the influence of process parameters on the mechanical properties to solve the problems that might be faced by users on choosing the suitable parameter scales when using FDM machine.

2.1 Fused Deposition Modelling (FDM)

Fused Deposition Modeling (FDM) printers with low cost are now easily found in the market for the researchers and professionals to allow experimentation with an assortment of easily programmable mechanical parameters (Lužanin *et al.*, 2014). The printers will produces outline of a part then only filled the inside with filaments that were crossed with the next layer. Figure 2.1 shows the process and highlights on some key parts of FDM machine. FDM technology was anisotropic due to the material used and the way of part building (Szykiedans and Credo, 2016). FDM process was widely used in the industry, various perspectives such as material, process, build time, machine specification and etc. are mostly linked to the AM system. The details of advantages and disadvantages of FDM machine that had been researched by other researcher will be discussed in this subchapter.

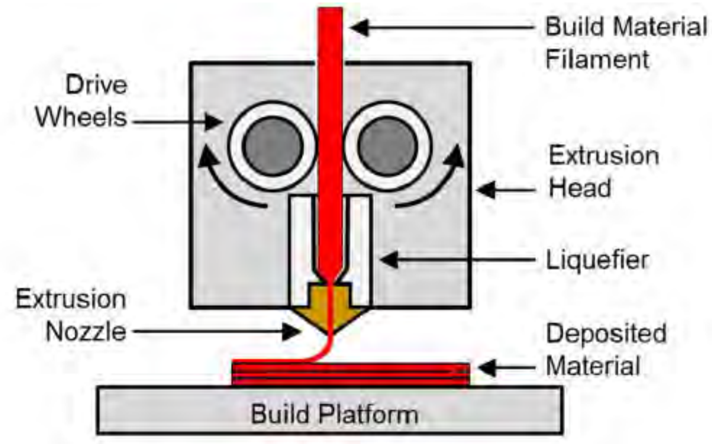

Figure 2.1: Schematic diagram of the standard FDM process (Cantrell *et al.*, 2011).

2.1.1 Advantages of FDM

FDM printers was a type of additive manufacturing process which could printed parts with high complexity, which the process was actually cost less to print a complex part instead of a simple cube of the same size. As stated by Chennakesava, (2014), high complexity parts can be built with better accuracy dimension and with low cost when compared to subtractive manufacturing process. FDM also offers a unique solutions that build the assemblies with only one-piece, which means the multi parts of the model can be built in one machine run (Grimm, 2002). Furthermore, moving parts such as hinges could printed directly into one parts which fulfil the DFMA method. The variety of the design could be changed immediately in the original CAD file and the changed product can be printed right away.

2.1.2 Disadvantages of FDM

There were also the limitation of the FDM machine which the surface finishing of the printed part might be lower quality than other manufacturing methods, rough surface will be formed due to the layer by layer of the printed format. Besides, the dimensional accuracy of the part produced does not match with the CAD model due to the shrinkage of the material (Bansal,