



**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

TANG MEI SHICK

B051310114

930722-01-5150

FACULTY OF MANUFACTURING ENGINEERING

2017

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

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

Sesi Pengajian: **2016/2017 Semester II**

Saya **TANG MEI SHICK (930722-01-5150)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA RAHSIA RASMI)

TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:
06, Jln Perdana 2/2
Tmn Sri Pulau Perdana 2,
81300 Skudai, Johor

Cop Rasmi:

Tarikh: _____

Tarikh: _____

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “The Influence of Process Parameters on Mechanical Properties of Fused Deposition Modeling Parts” is the result of my own research except as cited in references.

Signature :

Author's Name : TANG MEI SHICK

Date : 08 JUNE 2017

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:

.....
(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 eksperimen 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 signifikan. Plot kesan dan Plot interaksi juga dihasilkan untuk mencari keputusan optimum 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*

ACKNOWLEDGEMENT

In performing this final year project, I had receive the help and guideline from some respected persons, who deserve my greatest gratitude. I would like to express the deep gratitude to Dr. Zulkeflee bin Abdullah, my respected supervisors, for his great mentoring, patient guidance, enthusiastic, encouragement and useful critiques throughout this project. His willingness to give his time so generously has been very much appreciated.

In addition, I also grateful to Dr. Mohd Sukor Bin Salleh, coordinator of this Final Year Project. Thankful and indebted to him for sharing expertise, and sincere and valuable guidance and encouragement extended to us. Besides, I would like to give a special thanks to John Wong, master student of our manufacturing design course, for his guidance on using the machine as well as sharing me with meaningful experiences throughout the study.

Finally, I would like to thanks to my housemates, course mates and everybody who was important to this FYP report. Thanks to all the people for their directly and indirectly help for me to complete my project as well as expressing my apology that I could not mention personally to each of you.

TABLE OF CONTENTS

Abstrak	i
Abstract	ii
Dedication	iii
Acknowledgement	iv
Table of Contents	v
List of Tables	viii
List of Figures	ix
List of Abbreviations	xiii
List of Symbols	xiii

CHAPTER 1: INTRODUCTION AND GENERAL INFORMATION

1.1	Background of the Study	1
1.2	Problem Statement	3
1.3	Objectives	3
1.4	Scope	4
1.5	Project Significance	4
1.6	Summary	5

CHAPTER 2: LITERATURE REVIEW

2.1	Fused Deposition Modelling (FDM)	6
2.1.1	Advantages of FDM	7
2.1.2	Disadvantages of FDM	7
2.2	Material	8
2.2.1	Acrylonitrile Butadiene Styrene (ABS)	8
2.2.2	Polylactic Acid (PLA)	9

2.2.3	Research Findings on Material Behaviour	9
2.3	Process Parameters	11
2.3.1	Infill Pattern	11
2.3.2	Infill Percentage	12
2.3.3	Layer Thickness	13
2.3.4	Raster Angle	13
2.3.5	Build Orientation	14
2.3.6	Air Gap	15
2.4	Research Findings on Mechanical Properties	15
2.4.1	Tensile Strength	15
2.4.2	Flexural Strength	18
2.4.3	Compressive Strength	20
2.4.4	Other Testing	24
2.4.5	Summary of the findings of Mechanical Properties	25
2.5	Summary	27

CHAPTER 3: METHODOLOGY

3.1	Project Flow Chart	28
3.2	Sample Design	30
3.3	Fabrication	31
3.3.1	FDM Process Flow	31
3.3.2	FDM Machine Specification	33
3.4	Design of Experiment (DOE)	37
3.5	Mechanical Testing	40
3.5.1	Tensile Test	40
3.5.2	Flexural Test	43
3.6	Data Analysis	44

3.7	Summary	45
CHAPTER 4: RESULT AND DISCUSSION		
4.1	Data Collection of Tensile Strength	46
4.1.1	Analysis of Tensile Strength	48
4.1.2	Analysis of Variance (ANOVA) of Tensile Strength	54
4.2	Data Collection of Flexural Strength	60
4.2.1	Analysis of Flexural Strength	62
4.2.2	Analysis of ANOVA of Flexural Strength	70
4.3	Summary	73
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS		
5.1	Conclusions	74
5.2	Recommendations	75
5.3	Sustainability	76
REFERENCES		78
APPENDICES		
A	Drawing of Specimens	84
B	Full ANOVA results	87
C	Gantt Chart	98

LIST OF TABLES

2.1	Comparison of the untreated and treated specimens with the compressive strength	21
2.2	Summary of work on Mechanical Properties	25
3.1	Variable Parameters, Symbols and Level Settings	38
3.2	Full Factorial Design (3^3) includes 27 experimentation runs with the combination of process parameters.	39
3.3	ASTM standard of mechanical testing	40
3.4	Tensile test specimen Type IV (ASTM D638)	41
4.1	Experimental runs of Tensile Properties	47
4.2	Experimental runs of Flexural Properties	59

LIST OF FIGURES

2.1	Schematic diagram of the standard FDM process	7
2.2	Properties and characteristics of acrylonitrile, butadiene, and styrene	8
2.3	Characteristic stress strain curves of FDM samples	9
2.4	Comparison of the Main Properties of ABS and PLA	10
2.5	The Infill Pattern used in 3D Printing	12
2.6	Pores Size Variations by Infill Percentage Changes	12
2.7	The examples of each type of Layer Thickness	13
2.8	The Raster Angle of 3D Printing	14
2.9	Build Orientation for Specimen Tensile Test	14
2.10	Air gap application	15
2.11	3D Sample structure types and dimensions	16
2.12	A comparison of the stress-strain curves between each of the eight prototyping methods investigated	17
2.13	Measured and predicted tensile strength response	18
2.14	Loading scheme used in experiment Journal	19
2.15	Flexural behaviour of ABS composite 0.2 mm layer thickness	19
2.16	Convergence curve	20
2.17	FDM Build Styles (a) solid-build (D4), (b) sparse-build (D1 and D2), and (c) sparse-double dense build (D3)	22
2.18	Printing Time (min) vs. Infill Designs (left), Total Cost vs. Density (right)	22
2.19	Four different raster orientations investigated.	23
2.20	Interval plot of impact test results	23
2.21	Stress-strain curves of Tensile, Compressive and Bending in ABS and PEEK	24
3.1	Flowchart of overall methodology	29
3.2	Dog-bone size sample	30
3.3	Sample design of Flexural Test	31
3.4	The hierarchical steps involved in the FDM process	32

3.5	FDM Folger Technologies LLC machine	33
3.6	Repetier-Host V1.6.2 software	34
3.7	Layer and parameters settings of Folger Tech Software	34
3.8	Infill settings of Folger Tech Software	35
3.9	Fill pattern used in the study	35
3.10	The percentage of fill density.	36
3.11	The time estimation before build.	36
3.12	Manual Control Settings of the Repetier-Host Software	37
3.13	Typical tensile specimen, showing a reduced gage section and enlarged shoulders	40
3.14	Universal Testing Machine	41
3.15	Allowable Range of Loading Nose and Support Radii	43
3.16	Five steps of Full Factorial Design	45
4.1	Specimens tested by Tensile Strength	46
4.2	Tensile Test of Specimens	47
4.3	The average value of stress for 27 runs (Tensile Strength)	48
4.4	Maximum stress versus Layer Thickness of Tensile Strength	49
4.5	Layer Thickness versus maximum stress according to infill pattern of Tensile Strength	50
4.6	Line Pattern of Specimens, (a) 10%; (b) 30%; (c) 50%	50
4.7	Printed and Lading Direction of the Specimens	51
4.8	Stress-strain curves for (a) Run 3; (b) Run 6; (c) Run 9 for sample 1 (Tensile Test)	52
4.9	Diagnostic diagram, (a) Normal Probability Plot; (b) Residual Versus Fit (Tensile)	54
4.10	Factor Information and Analysis of Variance of Tensile Strength	54
4.11	Main Effect Plot for Tensile Strength	56
4.12	Interaction Plot for Tensile Strength	57
4.13	Specimens tested by Flexural Strength	58
4.14	Flexural Test of Specimens	58
4.15	The average value of stress for 27 runs (Flexural Strength)	60
4.16	Maximum stress versus Layer Thickness of Flexural Strength	61
4.17	Layer Thickness versus maximum stress according to infill pattern	62

	of Flexural Strength	
4.18	Specimens with same percentage but different layer thickness	62
4.19	Delamination happened in Flexural Specimens of Run 12	63
4.20	(a) Open source Folger-Tech FDM machine; (b) Other FDM machine	64
4.21	Stress-strain curve of (a) Run 12; (b) Run 15 (Flexural test)	66
4.22	Stress-strain curve for (a) Run 19; (b) Run 22; (c) Run 25 of sample 1 (Flexural test)	67
4.23	Diagnostic diagram, (a) Normal Probability Plot; (b) Residual Versus Fit (Flexural)	68
4.24	Factor Information and Analysis of Variance of Flexural Strength	60
4.25	Main Effect Plot for Flexural Strength	70
4.26	Interaction Plot for Flexural Strength	70

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 Schöppner (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 generate sections parts. There are many types of parameters that depend on the 3D printing machine that could influence the strength and quality of 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 produced by Additive Manufacturing are low and brittle. This is because AM parts produce high porosity which is caused by trapped air bubbles (Chuang *et al.*, 2015). There is still a lack of information on using suitable parameter scales because Additive Manufacturing technologies are still new in Malaysia and need 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.

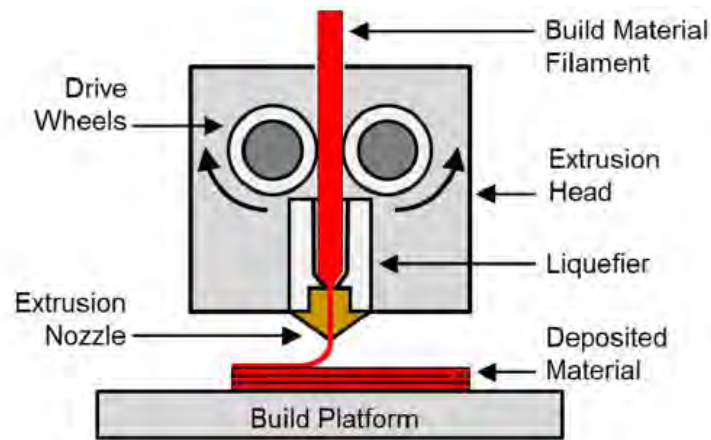


Figure 2.1: Schematic diagram of the standard FDM process (Cantrell *et al.*, 2011).

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,