



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**INVESTIGATION OF THE EFFECT OF BUILD ORIENTATION
ON MECHANICAL PROPERTIES OF FUSED DEPOSITION
MODELING PART**

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

by

CHOO JIA HUANG

B051210004

920922-14-6463

FACULTY OF MANUFACTURING ENGINEERING

2016



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: Investigation of The Effect of Build Orientation On Mechanical Properties of Fused Deposition Modeling Part

SESI PENGAJIAN: 2015/16 Semester 2

Saya CHOO JIA HUANG

mengaku membenarkan Laporan 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 Malaysia sebagaimana yang Termaktub dalam AKTA RAHSIA RASMI 1972)

TERHAD

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

TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:

15, Jalan Songlai, 27/42, Seksyen 27

40400 Shah Alam,

Selangor

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 “Investigation of The Effect of Build Orientation On Mechanical Properties of Fused Deposition Modeling Part” is the results of my own research except as cited in references.

Signature :

Author's Name : CHOO JIA HUANG

Date : 25 JUNE 2016

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) (Hons.). The member of the supervisory is as follow:

.....

(DR. SHAJAHAN BIN MAIDIN)

ABSTRAK

Tujuan projek ini adalah untuk mengenalpasti kesan orientasi pembinaan kepada sifat-sifat mekanikal bahagian FDM. Orientasi pembinaan yang digunakan di projek ini adalah rata, mendatar dan menegak. Specimen ujian telah direka dengan menggunakan UP 3D Printer dengan fail STL yang diwujudkan pada perisian SolidWorks. Dua bahan iaitu PLA dan ABS digunakan untuk mereka specimen ujian. Ujian yang digunakan untuk menentukan sifat-sifat mekanikal ialah ujian tegangan dan ujian mampatan. Sifat-sifat yang dianalisis adalah kekuatan tegangan, modulus keanjalan dan daya maksimum yang boleh ditahan oleh spesimen ujian. Spesimen ujian dengan orientasi mendatar mempunyai kekuatan tegangan yang tinggi, modulus keanjalan dan daya maksimum berbanding dengan orientasi yang lain, iaitu 45.5 MPa, 8.53 MPa dan 5.01 kN masing-masing bagi bahan PLA. Untuk bahan ABS, Kekuatan tegangan, modulus keanjalan dan daya maksimum untuk orientasi mendatar 35 MPa, 7.03 MPa dan 4.99 kN masing-masing. Sebaliknya, orientasi menegak mempunyai kekuatan tegangan, modulus keanjalan dan daya maksimum yang paling rendah, iaitu, 37.1 MPa, 7.7 MPa dan 3.73 kN masing-masing untuk bahan PLA. Manakala bagi bahan ABS, kekuatan tegangan, modulus keanjalan dan daya maksimum ialah 21.8MPa, 6.57 MPa dan 3.71 kN masing-masing.. Selain itu, perbandingan antara bahan menunjukkan bahawa bahan PLA mempunyai kekuatan yang lebih baik dalam semua aspek berbanding bahan ABS. Selain itu, permukaan patah juga dianalisis oleh mikroskop stereo untuk mendapatkan corak patah. Spesimen menegak mempunyai permukaan licin pada permukaan patah manakala orientasi mendatar dan rata mempunyai permukaan patah yang tidak sekata.

ABSTRACT

The aim of this project is to determine the effect of built orientation on the mechanical properties of the FDM part. The built orientation that consider in this project is flat, horizontal and vertical orientation. Test specimen are fabricated using UP 3D printer with the STL file created on SolidWorks software. Two material which are PLA and ABS are used to fabricate the test specimens. Test to be carry out to determine the mechanical properties are tensile test and compression test. The properties to be analyze are tensile strength, modulus of elasticity and maximum force that can withstand by the test specimen. Test specimen with horizontal orientation has the highest tensile strength, modulus of elasticity and maximum force compare to other orientation which are 45.5 MPa, 8.53 MPa and 5.01 kN respectively for PLA material. For ABS material, the tensile strength, modulus of elasticity and maximum force for horizontal orientation are 35 MPa, 7.03 MPa and 4.99 kN respectively. In contrast, vertical orientation has the lowest tensile strength, modulus of elasticity and maximum force which are 37.1 MPa, 7.7 MPa and 3.73 kN respectively for PLA material. While for ABS material, the tensile strength, modulus of elasticity and maximum force are 21.8MPa, 6.57 MPa and 3.71 kN respectively. Besides, comparison between material shows that PLA material has better strength in all aspect compared to ABS material. Besides, the surface of fracture also being analyzed by stereo microscope to detain out the pattern of the fracture. Vertical specimen has the smooth surface of fracture while horizontal and flat orientation has uneven surface of fracture.

DEDICATION

I would like to dedicate this work to my

Beloved parents

Honorable supervisor and lecturers

Supportive friends and mates

ACKNOWLEDGEMENT

I would like to express my gratitude to everyone that support and guide me throughout the completion of my Final Year Project. I also thankful for their advice during carry out this project.

Besides, I would like to thanks my supervisor, Dr. Shajahan bin Maidin for the guidance and advice for every single part on this project. I also would like to thanks to my family members and my friends as well for support me along the progress of this Final Year Project report.

TABLE OF CONTENT

Abstrak	i
Abstract	ii
Dedication	iii
Acknowledgement	iv
Table of content	v
List of Figures	x
List of Tables	xiii
List of Abbreviations, Symbols and Nomenclatures	xiv
CHAPTER 1: INTRODUCTION	1
1.1 Introduction	1
1.2 Problem statement	2
1.3 Objective	3
1.4 Scope	3
CHAPTER 2: LITERATURE REVIEW	5
2.1 Definition of additive manufacturing	5
2.2 Additive Manufacturing System	6
2.2.1 Selective Laser Sintering (SLS)	6

2.2.1.1	Advantages of SLS	7
2.2.1.2	Disadvantages of SLS	8
2.2.1.3	Application	8
2.2.2	Fused deposition modelling (FDM)	8
2.2.2.1	Advantages of FDM	10
2.2.2.2	Disadvantages of FDM	10
2.2.2.3	Application	10
2.2.3	Stereolithography (SLA)	11
2.2.3.1	Advantages of SLA	12
2.2.3.2	Disadvantages of SLA	12
2.2.3.3	Application	13
2.3	Application of AM	13
2.4	Advantages and Disadvantages of AM	14
2.4.1	Advantages	14
2.4.2	Disadvantages	15
2.5	Working principle of FDM	16
2.6	Parameters affecting mechanical property of FDM parts	18
2.6.1	Definition of FDM parameters	19
2.6.2	Built orientation	20
2.6.3	Layer thickness	22
2.6.4	Air gap	22
2.6.5	Raster angle	23

2.6.6	Raster width	24
2.7	Effect of built orientation on the FDM part	24
2.7.1	Build time	24
2.7.2	Support structure	25
2.7.3	Dimensional accuracy	26
2.7.4	Surface finish	26
2.8	FDM materials	27
2.8.1	ABS	28
2.8.2	PLA	28
2.9	General definitions of mechanical properties	29
2.10	Tensile test	31
2.10.1	Properties from tensile test (stress-strain graph)	33
2.11	Compression test	36
2.11.1	Compression stress strain graph	39
2.12	Anisotropic material	39
2.13	Progressive mechanism of thermoplastic	41
CHAPTER 3: METHODOLOGY		43
3.1	Introduction	43
3.2	Project planning flowchart	44
3.3	Project implementation	46
3.3.1	Planning	46

3.3.2	Standard Operating Procedure (SOP)	47
3.3.2.1	Universal Testing Machine	47
3.3.2.2	FDM machine	49
3.3.2.3	Stereo microscope	50
3.3.3	Specimen design	52
3.3.3.1	Tensile test specimen	52
3.3.3.2	Compression test specimen	53
3.3.4	Production of specimen	54
3.3.5	Testing	56
3.3.5.1	Tensile test	56
3.3.5.2	Compression test	59
3.3.6	Result and analysis	61
3.3.7	Conclusion and final report preparation	61
CHAPTER 4: RESULTS AND DISCUSSION		62
4.1	Fracture of test specimen	62
4.2	Tensile Test	68
4.2.1	Tensile strength	68
4.2.2	Modulus of Elasticity	72
4.2.3	Stress strain graph of tensile test	76
4.3	Compression test	78
4.3.1	Maximum force	78

4.3.2	Stress strain graph of compression test	82
4.4	Sustainability	83
4.4.1	Reduce	83
4.4.2	Recycle	83
CHAPTER 5: CONCLUSION AND RECOMMENDATION		84
5.1	Conclusion	84
5.2	Recommendation	86
REFERENCES		87
Appendix A Gantt Chart for PSM I		
Appendix B Gantt Chart for PSM II		
Appendix C Result for tensile test		
Appendix D Result for compression test		

LIST OF FIGURES

2.1 SLS process	7
2.2 FDM technique	9
2.3 SLA process	11
2.4 Process of FDM	16
2.5 FDM tool path parameter	19
2.6 Definition of raster angle (left) and layer thickness (right) in built orientation or built direction	21
2.7 Effect of built orientation on the support structure requirement	25
2.8 Stair stepping effect	27
2.9 Direction of force applied to a material in tension	31
2.10 Stress strain curve	32
2.11 Toughness for different type of plastic	34
2.12 Tensile stress curve for several categories for plastic material	35
2.13 Way to determine the modulus of elasticity	35
2.14 Comparison of elastic behavior of three materials with different modulus of elasticity	36
2.15 Compression test using a universal testing machine	37
2.16 Direction of force applied to a material in compression	37
2.17 Stress-strain curve of compression test	39

2.18	Test specimen machined at different orientations from a single “parent” block	40
2.19	A thin unidirectional composite panel (left) and two specimens machined from the unidirectional panel (right).	40
2.20	Illustration of fatigue damage development until the final failure.	41
3.1	Flow chart of the project	45
3.2	Universal Testing machine (UTM)	48
3.3	UP Plus 3D printer	49
3.4	Meiji stereo microscope	51
3.5	Dimension of test specimen for tensile test	52
3.6	Dimension of test specimen for compression test	53
3.7	Tensile test piece made form ABS (red) and PLA (light blue)	55
3.8	Compression test piece made form ABS(red) and PLA (light blue)	55
3.9	Improper (left, center) and proper (right) alignment of the specimen in the grips	56
3.10	Flowchart of tensile testing	58
3.11	Flowchart for compression testing	60
4.1	Separation of dog bone in flat orientation	63
4.2	Separation of dog bone in horizontal orientation	63
4.3	Separation of dog bone in vertical orientation	64

4.4	Test specimen in horizontal orientation after compression test	64
4.5	Test specimen in vertical orientation after compression test	65
4.6	Fracture on the horizontal orientation dog bone for PLA (left) and ABS (right)	65
4.7	Fracture on the vertical orientation dog bone PLA (left) and ABS (right)	66
4.8	Fracture on the flat orientation dog bone PLA (left) and ABS (right)	66
4.9	Chart of Tensile Strength Versus Build Orientation	71
4.10	Chart of Modulus of Elasticity Versus Build Orientation	75
4.11	Stress strain graph of tensile test	77
4.12	Chart of maximum force versus build orientation	80
4.13	Orientation of raster angle in compression test specimen	81
4.14	Stress strain graph of compression test	82

LIST OF TABLES

1.1	Parameters with its description	4
2.1	Technical attributes for ABS	28
2.2	Technical attributes for PLA	29
2.3	Description of mechanical properties	30
3.1	List of parameters with its value	47
3.2	Specification of UP Plus 3D printer	49
4.1	Tabulation of data for tensile strength for flat specimen	68
4.2	Tabulation of data for tensile strength for horizontal specimen	69
4.3	Tabulation of data for tensile strength for vertical specimen	69
4.4	Tabulation of data for tensile strength for each orientation	70
4.5	Tabulation of data for modulus of elasticity for flat specimen	73
4.6	Tabulation of data for modulus of elasticity for horizontal specimen	73
4.7	Tabulation of data for modulus of elasticity for vertical specimen	74
4.8	Tabulation of data for modulus of elasticity for each orientation	74
4.9	Tabulation of data for maximum force for horizontal specimen	78
4.10	Tabulation of data for maximum force for vertical specimen	79
4.11	Tabulation of data for maximum force for each orientation	79

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive Manufacturing
ASTM	-	American Society for Testing and Materials
CAD	-	Computer Aided Design
2D	-	2 Dimension
3D	-	3 Dimension
EL	-	Elongation
FDM	-	Fused Deposition Modelling
FKP	-	Fakulti Kejuruteraan Pembuatan
FTMK	-	Fakulti Teknologi Maklumat dan Komunikasi
PLA	-	Polylactic acid
PSM	-	Project Sarjana Muda
SLA	-	Stereolithography
SLS	-	Selective Laser Sintering
SOP	-	Standard Operating Procedure
UTeM	-	Universiti Teknikal Malaysia Malaka
UTS	-	Ultimate Tensile Strength
UTM	-	Universal Testing Machine

CHAPTER 1

INTRODUCTION

This chapter introduces the project and briefly discuss the problem statement, objectives and also the scopes.

1.1 Introduction

Additive manufacturing (AM) is an advance manufacturing used to fabricate parts layer by layer. Domino-Espin *et al.* (2015) wrote that the ability of creating complex three-dimensional (3D) parts from AM technology results in production of complex part with lower cycle time and cost compared to the traditional manufacturing process. Omar *et al.* (2015) explained that AM technology is widely used in many fields in engineering and industry nowadays due to the increasing in competition of products. Designer and product engineer able to produce a product in shorter time to fulfil the customer requirements and as well as achieve competitive edge.

Fused deposition modelling (FDM) is an extrusion-based additive manufacturing process. It has the same working principle with other rapid prototyping system which

is layer by layer principle. It is one of the most used additive manufacturing processes to produce prototypes and end use parts due to its capabilities of producing parts neatly and safely in office friendly environment.

Proper selection of process parameters has to be done in order to produce high quality product to meet the customer requirement and satisfactions. The process parameter includes built orientation, layer thickness, raster width and more. The mechanical properties of a part vary with the process parameters.

In this project, process parameter of built orientation will be emphasized. Build orientation refers to the way in which the part is oriented in the machine build platform with respect to X, Y, Z axes. The built orientation of the FDM parts is important as it will affect the mechanical properties of the parts. Other than that, built orientation will affect some other characteristics such as part building time, amount of supports required, part quality and cost as well.

1.2 Problem statement

The quality of a part is important as it determines the lifetime of the products. Omar *et al.* (2015) stated that in order to gain satisfaction of the customer, the process condition for AM must be established for each application. Determination of optimum process condition is important to ensure the quality of product. A prototype part built that does not consider the effect of built orientation may result in mechanical failure. A same part will deform differently with the difference of the built orientation of the part. Thus, to enhance the quality of the part, the process parameter such as build orientation should be optimized. There are few build orientations such as flat, horizontal and vertical oriented. Bagsik *et al.* (2011) concluded that different builds orientation will give different results on the strength which is also the mechanical properties of the part.

Thus, to maximize the strength, the effect of proper builds orientation on mechanical properties of Fused Deposition Modelling (FDM) part should be determined.

1.3 Objective

- i. To produce the CAD drawing of test specimens and to build it with different built orientations by using the FDM machine.
- ii. To test the test-specimen with different mechanical tests such as tensile test and compression test.
- iii. To investigate the effect of the build orientation on mechanical properties of FDM test specimen.

1.4 Scope

There are many process parameters that affect the part quality in FDM parts. In this project, the process parameter is limited to build orientation of FDM. Besides, acrylonitrile-butadiene-styrene (ABS) and Polylactic Acid (PLA) are the materials used to produce the test specimen. Besides, the mechanical properties of FDM produced parts considered in this study are tensile strength, modulus of elasticity and maximum force that can withstand by the compression test piece. To get these mechanical properties, Universal Testing Machine (UTM) which located in material engineering lab, FKP block B is used to perform all two tests which are tensile test and compression test. In addition, microscopic inspection on the fracture surface of the

test specimen is performed by using stereo microscope that located in the metrology lab in FKP block B.

The CAD software used in this research is SolidWork. The parameter for the production of the test specimen is as shown in Table 1.1.

Table 1.1: Parameters with its description

Parameters	Description
Build orientation	Flat, horizontal, vertical
Layer thickness (mm)	0.15
Raster angle (⁰)	45
Air gap	Level 1

CHAPTER 2

LITERATURE REVIEW

This chapter will discuss some of the related knowledge on the additive manufacturing as well as its effect of parameters to the mechanical properties. Some mechanical properties also discussed in this chapter.

2.1. Definition of additive manufacturing

American Society for Testing and Materials (ASTM) defines Additive Manufacturing (AM) as a joining process of material, layer by layer, to make objects from 3D model data. Besides, Gibson *et al.* (2010) states that AM used widely in industry to describe the process of rapidly creating a system or part representation before its release into the market.

Anil *et al.* (2014) define AM process is unlike subtractive or forming process such as milling and grinding which the shape of the part is formed by material removal or plastic deformation. AM belongs to generative (or additive) production processes where the part is formed by deposition of layers contoured in a (x-y) plane. The third

dimension, which is Z direction, is resulting from stacking of layers on top of each other but not as a continuous Z coordinate. Thus, the prototype is very exact on x-y plane and may have stepped effect in z-direction.

2.2 Additive Manufacturing System

2.2.1 Selective Laser Sintering (SLS)

Castoro (2013) defines selective laser sintering (SLS) as a process used to create 3D object from a plastic, metal or ceramic powder. As other AM system, the part is built layer by layer from the bottom and able to produce complex part. Usually the part is produced from digital CAD data. The main components of the SLS machine are roller, powder container, part bed and laser.

In SLS process, the laser traces the cross section of a part on a thin layer of powder, sintering the top layer of powder to the one below it. After the layer is finished, powder swept across the built area to form a new layer. This operation is done by the roller in the SLS machine where the roller moves across the powder container and sweeps thin layer of powder across part bed. The process is continuing until the part has completely sintered. Figure 2.1 shows the SLS system and the component in the process.