MECHANICAL PROPERTIES INVESTIGATION ON PLA AND ABS MATERIALS FOR GEOSPATIAL TOPOLOGY PRODUCT PRINTED BY RAPID PROTOTYPING METHOD

ZARIF HASIF BIN TERMITI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MECHANICAL PROPERTIES INVESTIGATION ON PLA AND ABS MATERIALS FOR GEOSPATIAL TOPOLOGY PRODUCT PRINTED BY RAPID PROTOTYPING METHOD

ZARIF HASIF BIN TERMITI

This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

"I hereby declare that this project report entitled "Mechanical Properties Investigation on PLA and ABS Materials for Geospatial Topology Product Printed by Rapid Prototyping Method" is the result of my own work except as cited in the references"

Signature : ……………………….……………

Student Name: ………………………………...............

Date : ………………………………………

SUPERVISOR DECLARATION

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.

Signature	: ……………………………………………
Supervisor's Name	: ……………………………………………
Date	: ……………………………………………

DEDICATION

I would like to dedicate my project to my beloved parents, Mr. Termiti Bin Sidon and Mrs.Siti Azanah Binti Husin, family, my supervisor Dr.Mohd.Azli Bin Salim, lecturers and friends who gave me never ending affection, love, encouragement and pray of day and night throughout this Final Year Project of Bachelor's degree of Mechanical Engineering.

ABSTRACT

Mechanical properties of material is important aspect in designing and producing a high quality product and reliable to user. Geospatial technology is an advance technology that used by human which act as modern tools that provide the geographic mapping and analysis of the earth and human societies. The application of GIS under the geospatial technology is a system that processing and retrieving geospatial reference data which contain geographic attribute information. Rapid prototyping is one of element in the essence of the industrial revolution 4.0 which changes or revolutionize manufacturing industry pattern from mass production to mass customization. For instance, the used of rapid prototyping method have been implemented in the current development of geospatial product from various type of material. Recently, the FDM 3D printing had been widely used including in the development of geospatial product, unfortunately the performance of material after printed is still unknown. This research was done focusing on evaluating the material properties (tensile, flexural, and impact) for ABS and PLA filament for geospatial topology product produce by FDM 3D printing. The previous studies show that the variation or changes in parameter of FDM 3D printing would affect the material properties performance of printed material and product appearance. Other than that, the thesis had fulfilled its objective to investigate the relationship between tensile, flexural and impact data on ABS and PLA filament. The study involving the fabrication of specimen by FDM 3D printing method using same printing parameter of 3D printing geospatial product and finding suitable standard of testing that can be use based on the previous studies. The ASTM standards is used for all testing to study the material properties. For tensile test, ASTM D638 is used as standards guideline which required fabrication of type IV specimen size and 5mm/min testing speed. Meanwhile, ASTM D790 is chosen as guideline in conducting flexural testing that involving specimen preparation of molded type with 51.2mm span length and 1.367mm/min test speed. Impact testing which used izod impact testing method has following ASTM D256 which involving testing the specimen by using 2.75J pendulum energy. The finding of the studies shows that by using proper standard of testing, the material properties of the material used for geospatial product which are ABS and PLA material. For tensile testing, the tensile strength for ABS and PLA material are 3.48 MPa and 37.45 MPa respectively. Meanwhile, the flexural strength of ABS material is 53.15 MPa and 68.52 MPa for PLA material in flexural testing. Last but not least, the result of impact test gives value of impact strength for ABS and PLA material which are 3.33 MPa and 11.63 MPa respectively. The geospatial product which made by PLA material has the ability to withstand high tensile and flexural loading but poor in resisting impact loading compare with ABS material if producing according the reference parameter based on the result in this study.

ABSTRAK

Sifat mekanikal bahan adalah aspek penting dalam merekabentuk dan menghasilkan produk berkualiti tinggi dan boleh dipercayai kepada pengguna. Teknologi geospatial adalah teknologi maju yang digunakan oleh manusia yang bertindak sebagai alat moden yang menyediakan pemetaan dan analisis geografi bumi dan masyarakat. Aplikasi GIS di bawah teknologi geospatial adalah sistem yang memproses dan mengambil data rujukan geospasial yang mengandungi maklumat sifat geografi. Prototaip pantas merupakan element dalam intipati revolusi industri 4.0 yang mengubah atau merevolusikan corak industri pembuatan dari pengeluaran besar-besaran ke penyesuaian besar-besaran. Sebagai contoh, penggunaan kaedah prototaip pantas digunakan dalam pembangunan produk geospatial menggunakan pelbagai jenis bahan. Pada masa kini, percetakan 3D FDM telah digunakan secara meluas termasuk dalam pembangunan produk geospatial, malangnya prestasi bahan selepas dicetak masih tidak diketahui. Kajian ini dilakukan dengan berfokus kepada penilaian sifat bahan (tegangan, lenturan, dan impak) untuk filamen ABS dan PLA untuk menghasilkan produk topologi geospatial menggunakan percetakan FDM 3D. Kajian terdahulu menunjukkan bahawa variasi atau perubahan dalam parameter percetakan FDM 3D akan mempengaruhi prestasi sifat mekanikal bahan dan penampilan produk. Selain itu, tesis in telah memenuhi objektifnya untuk menyiasat hubungan antara data tegangan, lenturan dan impak pada filamen ABS dan PLA. Kajian yang melibatkan fabrikasi spesimen menggunakan kaedah percetakan 3D FDM menggunakan parameter percetakan yang sama dengan produk geospatial percetakan 3D dan mencari standard ujian yang sesuai yang boleh digunakan berdasarkan kajian terdahulu. Piawaian ASTM digunakan untuk semua ujian untuk mengkaji sifat bahan. Untuk ujian tegangan, ASTM D638 digunakan sebagai panduan piawaian yang memerlukan fabrikasi saiz spesimen jenis IV dan kelajuan ujian 5mm / min. Sementara itu, ASTM D790 dipilih sebagai garis panduan dalam menjalankan ujian lenturan yang melibatkan penyediaan spesimen berjangka dengan panjang span 51.2mm dan kelajuan ujian 1.367mm / min. Ujian impak yang menggunakan kaedah ujian impak izod telah mengikuti ASTM D256 yang melibatkan ujian spesimen dengan menggunakan tenaga pendulum 2.75J. Kajian menunjukkan bahawa dengan standard ujian yang tepat, sifat bahan bahan yang digunakan untuk produk geospatial yang merupakan bahan ABS dan PLA dikenal pasti. Untuk ujian tegangan, kekuatan tegangan untuk bahan ABS dan PLA masing-masing ialah 3.48 MPa dan 37.45 MPa. Sementara itu, kekuatan lenturan bahan ABS ialah 53.15 MPa dan 68.52 MPa untuk bahan PLA dalam ujian lenturan. Akhir sekali, keputusan ujian impak memberikan nilai kekuatan impak bagi bahan ABS dan PLA iaitu masing-masing 3.33 MPa dan 11.63 MPa. Produk geospatial yang dibuat oleh bahan PLA mempunyai keupayaan untuk menahan pemuatan tegangan dan lenturan yang tinggi tetapi miskin untuk menahan impak beban berbanding dengan bahan ABS jika menghasilkan mengikut parameter rujukan berdasarkan hasil kajian ini.

ACKNOWLEDGEMENT

Praise to Allah SWT almighty for giving me the opportunity and strength to finish up my project. I am grateful and would like to express my sincere appreciation to my supervisor Dr.Mohd Azli Bin Salim from the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka for providing tremendous technical guidance, advices, continuous encouragement, constructive criticisms, suggestions and glorious knowledge throughout the completion of this project. Sincerely, a great appreciation indicates to Dr. Mohd Nur Azmi Bin Nordin And En. Wan Mohd Farid Bin Wan Mohamad for evaluating my final year project

I would also like to express my greatest gratitude to my mentor for this project, Adhwa Atira Binti Zainal Abidin which help me in accomplishing my project especially in laboratory work. I also want to thank to laboratory assistant engineer En.Faizol Bin Kamarul Zahari and Azizul Ikhwan Bin Mohd. which assist and guide me through all the laboratory work.

A special thank for my loving mother, Siti Azanah Binti Husin and my father, Termiti Bin Sidon for never endless support and stunning advice. I also would like to express my special thanks of gratitude to thank my friends and classmates who involve helping me a lot finalizing this project successfully.

TABLE OF CONTENTS

CHAPTER	CONTENT		PAGE
	DECLARATION		
	SUPERVISOR DECLARATION		
	DEDICATION		
	ABSTRACT		i
	ACKNOWLEDGEMENTS		iii
	TABLE OF CONTENTS		iv
	LIST OF TABLES		viii
	LIST OF FIGURES		x
	LIST OF ABBREVIATIONS		xiv
	LIST OF SYMBOLS		xv
	LIST OF APPENDICES		xvi
CHAPTER 1	**INTRODUCTION**		**1**
	1.1	Overview	1
	1.2	Background of Study	1
	1.3	Problem Statement	4
	1.4	Objectives	5
	1.5	Scope of Project	5
	1.6	General Methodology	6
CHAPTER 2	**LITERATURE REVIEW**		**8**
	2.1	Overview	8
	2.2	Geospatial Technology	8
	2.3	Geographic Information System (GIS)	9

2.4 GIS Application 11
2.5 3D Printing Technology 14
2.6 Working Principle of 3D Printing 16
2.7 Type of 3D Printings 19
2.7.1 Stereolithography 20
2.7.2 Digital Light Processing 21
2.7.3 Fused Deposition Modelling 22
2.7.4 Selective Laser Sintering 23
2.7.5 Selective Laser Melting 24
2.7.6 Electronic Beam Melting 25
2.7.7 Laminated Object Manufacturing 26
2.7.8 Binder Jetting 27
2.7.9 Material Jetting 28
2.8 Material for 3D Printing 29
2.8.1 Polylactic-Acid 29
2.8.2 Acrylonitrile Butadiene Styrene 30
2.9 Geospatial Technology in 3D Printing Aspects 30
2.10 Printing Geospatial Using 3D Printing Method 33
2.11 Factor Affecting Mechanical Properties 3D Printing Product 35
2.11.1 Layer Thickness 35
2.11.2 Printing Speed 37
2.11.3 Printing and Build Orientation 38
2.11.4 Infill 39
2.12 Testing Method 39
2.13 American Society for Testing and Material (ASTM) 40
2.14 Surface Roughness of FDM Additive Manufacturing Product 41
2.15 Previous Researcher 43

CHAPTER 3	**METHODOLOGY**		**45**
	3.1	Overview	45
	3.2	Manufacturing Process	47
		3.2.1 UP Mini	47
		3.2.2 PRUSA I4	49
	3.3	Specimen Preparation	50
		3.3.1 Tensile Test Specimen	51
		3.3.2 Impact Test Specimen	54
		3.3.3 Flexural Testing Specimen	56
	3.4	Standard for Testing	57
	3.5	Testing	58
		3.5.1 Tensile Test	59
		3.5.2 Impact Test	63
		3.5.3 Flexural Test	67
	3.6	Sample of Data	72
		3.6.1 Tensile Test Result Data	73
		3.6.2 Flexural Test Result Data	73
		3.6.3 Impact Test Result Data	74
CHAPTER 4	**RESULT AND DISCUSSION**		**75**
	4.1	Overview	75
	4.2	Tensile Testing	75
		4.2.1 Tensile Test Fundamental	78
		4.2.2 ABS Material Tensile Test Result	80
		4.2.3 PLA Material Tensile Test Result	82
		4.2.4 Comparison ABS and PLA Material	83
	4.3	Impact Testing	87
		4.3.1 Impact Test Fundamental	90
		4.3.2 ABS Material Impact Test Result	92
		4.3.3 PLA Material Impact Test Result	93
		4.3.4 Comparison ABS and PLA Material	95
	4.4	Flexural Testing	98
		4.4.1 Flexural Test Fundamental	101

	4.4.2	ABS Material Flexural Test Result	103
	4.4.3	PLA Material Flexural Test Result	104
	4.4.4	Comparison ABS and PLA Material	105
	4.5	Mechanical Properties of Geospatial Product Material	110
CHAPTER 5		**CONCLUSION & RECOMMENDATION**	**113**
	5.1	Overview	113
	5.2	Conclusion	113
	5.3	Recommendation	116
		REFERENCES	**117**
		APPENDIX	**122**

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	List of previous research	43
3.1	Specification for UP Mini 3D printer	48
3.2	Specification for PRUSA i4 3D printer	50
3.3	Specification for specimen printing	51
3.4	ASTM D638 type I dimension for tensile test	52
3.5	ASTM D638 type IV dimension for tensile test	53
3.6	ISO 527 type 1A dimension for tensile test	53
3.7	ISO 527 type 5A dimension for tensile test	54
3.8	ASTM 256 dimension for izod impact test	55
3.9	ISO 180 dimension for izod impact test	56
3.10	ASTM D790 dimension for flexural test	57
3.11	ISO 178 dimension for flexural test	57
4.1	Data and result for tensile test	77
4.2	Data and result for tensile test of material properties	83
4.3	Data and result for impact test	89
4.4	Impact test result for ABS material	92
4.5	Impact test result for PLA material	93
4.6	Data and result for flexural test	100
4.7	Data and result for flexural test of material properties	106
4.8	Material properties of geospatial product material	111
4.9	Material properties comparison of data between experiment ABS and reference ABS.	111

4.10 Material properties comparison of data between experiment PLA and reference PLA. 112

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Flow chart of the general methodology	7
2.1	GIS topographic mapping	12
2.2	Detection of suspected mine area in Republic Srpska using GIS	13
2.3	General usage of GIS Application in urban planning	14
2.4	Usage of AM technology in industries	16
2.5	3D Data digital model	17
2.6	3D Printing process	18
2.7	Part finishing process	19
2.8	Stereolithography	20
2.9	Digital light processing	21
2.10	Fused deposition modelling	22
2.11	Selective laser sintering	23
2.12	Selective laser melting	24
2.13	Electronic beam melting	25
2.14	Laminated object manufacturing	26
2.15	Binder jetting	27
2.16	Material jetting	28
2.17	Development process of spatial data visualization enhancement	31
2.18	3D print geospatial model	32
2.19	Procedure for printing 3D geospatial model from GIS data.	33
2.20	Obtaining geospatial information from USGS	34

2.21	Sample of Impact Test at Layer a) Thickness 0.20mm b) Thickness 0.25mm c) Thickness 0.3mm	36
2.22	Test specimen different build orientation	38
2.23	Test specimen different printing orientation	38
2.24	Stair step effect: a) CAD surface profile, b) Layer slices, c) Additive Manufactured profile	42
2.25	Chordal effect	42
3.1	Flow chart of the research's methodology	46
3.2	UP Mini 3D printer	48
3.3	PRUSA i4 3D printer	49
3.4	Schematic diagram of the specimen for tensile test ASTM D638 (Type I)	52
3.5	Schematic diagram of the specimen for tensile test ASTM D638 (Type IV)	52
3.6	Schematic diagram of the specimen for tensile test ISO 527 (Type 1A)	53
3.7	Schematic diagram of the specimen for tensile test ISO 527 (Type 5A)	54
3.8	Schematic diagram of the specimen for izod impact test ASTM 256	55
3.9	Schematic diagram of the specimen for izod impact test ISO 180	55
3.10	Schematic diagram of the specimen for flexural test ASTM D790	56
3.11	Schematic diagram of the specimen for flexural test ISO 178	57
3.12	SHIMADZU Universal Testing Machine	60
3.13	Schematic of the tensile test	61
3.14	Electronic impact testing machine	65
3.15	Schematic of the izod impact test	66

3.16	INSTRON 5585	68
3.17	Schematic of the flexural test	69
4.1	Tensile test specimen for ABS material	76
4.2	Tensile test specimen for PLA material	76
4.3	ABS specimen after tensile test	76
4.4	PLA specimen after tensile test	77
4.5	Theoretical stress strain diagram for tensile test	79
4.6	Tensile stress versus strain graph for fifteen specimen of ABS material	80
4.7	Tensile stress versus strain graph for fifteen specimen of PLA material	82
4.8	Stress versus strain diagram specimen of ABS and PLA material for tensile test	83
4.9	Specimen versus yield strain and yield stress of tensile test	84
4.10	Specimen versus tensile strain and tensile strength of tensile test	85
4.11	Modulus elasticity versus specimen of tensile Test	86
4.12	Specimen versus failure strain and failure stress of tensile test	87
4.13	Impact test specimen for ABS material	88
4.14	Impact test specimen for PLA material	88
4.15	ABS specimen after impact test	88
4.16	PLA specimen after impact test	89
4.17	Theoretical diagram of ductile and brittle material	90
4.18	Type of fracture ABS material	93
4.19	Type of fracture PLA material	94
4.20	Comparison of impact test result between ABS and PLA material	95
4.21	Specimen versus energy of impact and impact strength of impact test	95
4.22	Comparison first layer of build between ABS and PLA material	97
4.23	PLA material after impact test	98

4.24 Flexural test specimen for ABS material 99
4.25 Flexural test specimen for PLA material 99
4.26 ABS specimen after flexural test 99
4.27 PLA specimen after flexural test 99
4.28 Theory of flexure or bending 101
4.29 Stress versus strain graph for fifteen specimen of ABS material in flexural testing 103
4.30 Stress versus strain graph for fifteen specimen of PLA material in flexural testing 104
4.31 Stress versus strain diagram specimen of ABS and PLA material for flexural test 105
4.32 Modulus elasticity versus specimen of flexural test 107
4.33 Specimen versus yield strain and yield stress of flexural test 108
4.34 Specimen versus flexural strain and flexural strength of flexural test 109
4.35 Specimen versus failure strain and failure stress of flexural test 110

LIST OF ABBEREVATIONS

ABS	Acrylonitrile butadiene styrene
AM	Additive Manufacturing
ASTM	American Society for Testing and Materials
BS	British Standard
CAC	Computer Assisted Cartography
CAD	Computer Aided Design
DEM	Digital Elevation Model
DLP	Digital Light Processing
EBM	Electron Beam Melting
FDM	Fused Deposition Modelling
GIS	Geographic Information System
GPS	Global Positioning System
ISO	International Organization for Standardization
LOM	Laminated Object Manufacturing
LCD	Liquid Crystal Display
PLA	Polylactic Acid
RP	Rapid Prototyping
SLA	Stereolithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
STL	Standard Triangulation Language
USGS	National Mapping Website
UTM	Universal Testing Machine
VR	Visual Reality
VRML	Virtual Reality Modeling Language

LIST OF SYMBOL

σ_T	=	Tensile Stress
F_t	=	Tensile Force
E	=	Modulus Elasticity
ε	=	Strain
Gc	=	Impact Strength of Material
Uc	=	Energy of Impact
Ac	=	Cross-Sectional Area of the Specimen
R	=	Rate of Crosshead Motion
L	=	Length of Support Span
Z	=	Rate Of Straining Outer Fibre
D	=	Mid-Span Deflection
σ_f	=	Flexural Stress, MPa
P	=	Force, N
E_f	=	Modulus Elasticity in Bending, MPa
m	=	Slope of The Tangent Curve

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Material Testing Result Table	122
B	Tensile Test Specimen	125
C	Impact Test Specimen	134
D	Flexural Test Specimen	142

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter will brief the introduction of the research that include background information about relationship between geospatial technology and additive manufacturing 3D printing. In addition, the mechanical properties of 3D printing material use in 3D printing will be brief which focusing on tensile, flexural and impact loading. This chapter also cover the problem statement, objective and scopes of the research.

1.2 Background Study

Geospatial technology is a technology that related to the collection or processing of data that is associated with location. It also can be describe as the range of modern tools contributing to the geographic mapping and analysis of the earth and human societies. This technology has existed since the first maps were drawn in the early age, and it have been evolving to other form of technologies which is related to geographic or positioning information. The collection of modern geographic data information has begun since 19th century. It begins when this technology collaborated with aerial photography technology to collect the data by using camera which use balloons and pigeons as aerial transportation medium. In 20th century, the collection of data becomes more reliable when the aerial vehicle which is airplanes used in process of collecting geospatial data. The science and art of photographic interpretation and map making was increased rapidly during the Second World War and during the Cold War it took on new upgrades with the advent of satellites and computers. Nowadays, the geospatial technology has been widely used in our daily life such as Global Positioning System (GPS), Geographic Information System (GIS) and Remote Sensing. GIS is a system which has been designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data. The aspect of GIS which important in term of geospatial is GIS has capability to gather and manage geospatial data into layered set of maps. This layers enable the geospatial data which contains various spatial information that includes information regarding precise location on the earth surface to be analysed and shared to audiences.

Additive manufacturing technology has become a phenomenon that contribute in industrial revolution recently. This manufacturing technology is declared as focused area of element in the 4th industrial revolution focus area. For the past few years, the development of AM technology has been rapidly increase which change and revolutionized the industrial fabrication process towards efficient product or part making. AM technology use the method of building parts layer-by-layer through depositing the build material such as thermoplastic, metal, and concrete. Basically, AM required three basics things to operate which are build material, machine and 3D file format such as STL and VRML. The 3D file format can be generated by using Computer Aided Design (CAD) software and image scanning. When the 3D file format is link with the machine, it will start deposit or lay down successive layer of build material in layer by layer pattern to generate the 3D model. The term of AM is related with Rapid Prototyping (RP) and 3D printing. In other words, AM and 3D printing are the process, and rapid prototyping is the end result of the AM and 3D printing. Rapid prototyping can be classified as one of many applications under the 3D printing and additive manufacturing process.

Currently, the 3D geospatial model is used for the visualization purpose such as for project presentation tool and public display. It enhances the human understanding on physical environment which consist of many spatial aspects. The traditional method to produce the 3D geospatial model require a lot of effort and time to produce a model that has accurate parameter and exactly same as the real geospatial image. The implementation of 3D printing AM for producing a 3D geospatial model has overcome the problem and limitation to produce a precise 3D model exactly as the real geospatial image. The 3D printing process of geospatial model require a GIS data that contain all the geospatial image parameter. The data can be access from the valid mapping source and need to be convert into 3D file format for the 3D printer to generate the G-Code for the fabrication process. This printing method can provide a better visualisation due to the model is generated according to the GIS data compared to the traditional method that inaccurate which can cause measuring and estimation error such as distance and contour height measurement.

A good product or services can be define as a product or services that made or invented for fulling the requirement and needs of the customer. The important aspect which become the priority and concern by the customer is the quality aspects. The aspects of producing goods which has high quality is essential for the manufacturer to ensure reliability of the product that manufactured for customer use. For every manufacturing process, mechanical properties of the material become the essential of making high quality goods. The properties are referring to the ability of the material to get through any stress or deflection which can affect the product physically. Every material that undergo manufacturing process which exposed too many types of parameter such as temperature and pressure, indirectly the material properties of the material will be altered. The alteration of the mechanical properties will affect the product ability to withstand any forces due to mechanical effect that cause by the user or the environment of the product. Quality of the 3D printing product also depends on the mechanical properties of the material. Printing parameter need to be control to ensure the product can effectively withstand and resist mechanical effect that has potential physically damage the product.

1.3 Problem Statement

The application of 3D printing AM technology is widely use nowadays which not only use for industrial purposes but also for personal use. There are many type of 3D printing process that can be used to produce 3D model or parts. One of the process is Fused Deposition Modelling (FDM) which is the most affordable 3D printing process compare to other type. Commonly FDM used filament of thermoplastics material such as ABS and PLA as build material for the printing process. The operating condition for the material is stated by the company who produced the material. But, the mechanical properties of the finished part which had been machined need to be determine by the user. Currently, the geospatial model that produce by FDM 3D printing method is in early stage of development and not being commercialize due it require further research to ensure the printed geospatial model obtain high quality to be use as commercialize product. The mechanical properties of the finish part are important in order to determine the quality of the parts. The problem is the amount of force that can be resist by the material or geospatial product after the printing process is required to be determine in order to study the strength of material or the geospatial product to resist impact or load. It also needed to determine the limit and capabilities to withstand mechanical effect that can cause defect to the finished parts. The selection of material and printing parameter control is very important in 3D printing AM process in order to get a high quality product or part which are reliable, safe and effective for the user.

1.4 Objectives

The main objectives of this research are:

1. To evaluate the material properties (tensile, flexural, and impact) for ABS and PLA filament for geospatial topology product
2. To investigate the relationship between tensile, flexural and impact data on ABS and PLA filament.

1.5 Scope of Project

In this research the scope will be:

1. For mechanical testing it is focused on tensile, bending and impact test only.
2. Only PLA and ABS material will be used in this study.

1.6 General Methodology

This research is carried out to investigate the material properties on geospatial image product using 3D printer. The purpose of this project is to evaluate the material properties of ABS and PLA filament that use to print 3D geospatial image when the material applied under tensile, flexural and impact loading. Other than that, this project also required to investigate the relationship between tensile, flexural and impact data on both material filaments.

Literature review of this research will cover the related topic which focus on geospatial technology and 3D printing technology. It also involves the parameter that required or need to be control and also the material mechanical properties that important in order to produce high quality 3D printed product. In addition, there will be more information that will be discussed which involving the previous study which related to the research.

In this research, the suitable testing type will be chosen which related to study the mechanical properties on the geospatial product material. The testing need to be design according to standard guideline of ASTM standard that involves specimen size and machine capability. It involves the preparation of the specimen using 3D printing machine according to the standard size and chosen printing parameter.

The analysis of the testing involves the comparison of performance between ABS and PLA material. The relationship between all the testing material properties will be analyse by referring the data and comparison can be made between material filament use. The testing and measurement data will be analyse and tabulated for the purpose of the result presentation of the research.

When the testing process is finished, the analysis, conclusion and recommendation will be made and documented in a formal research report. This research will be consider complete and success when all the objectives of the project manage to be achieve. The flowchart in figure 1.1 represent the general methodology of the research.

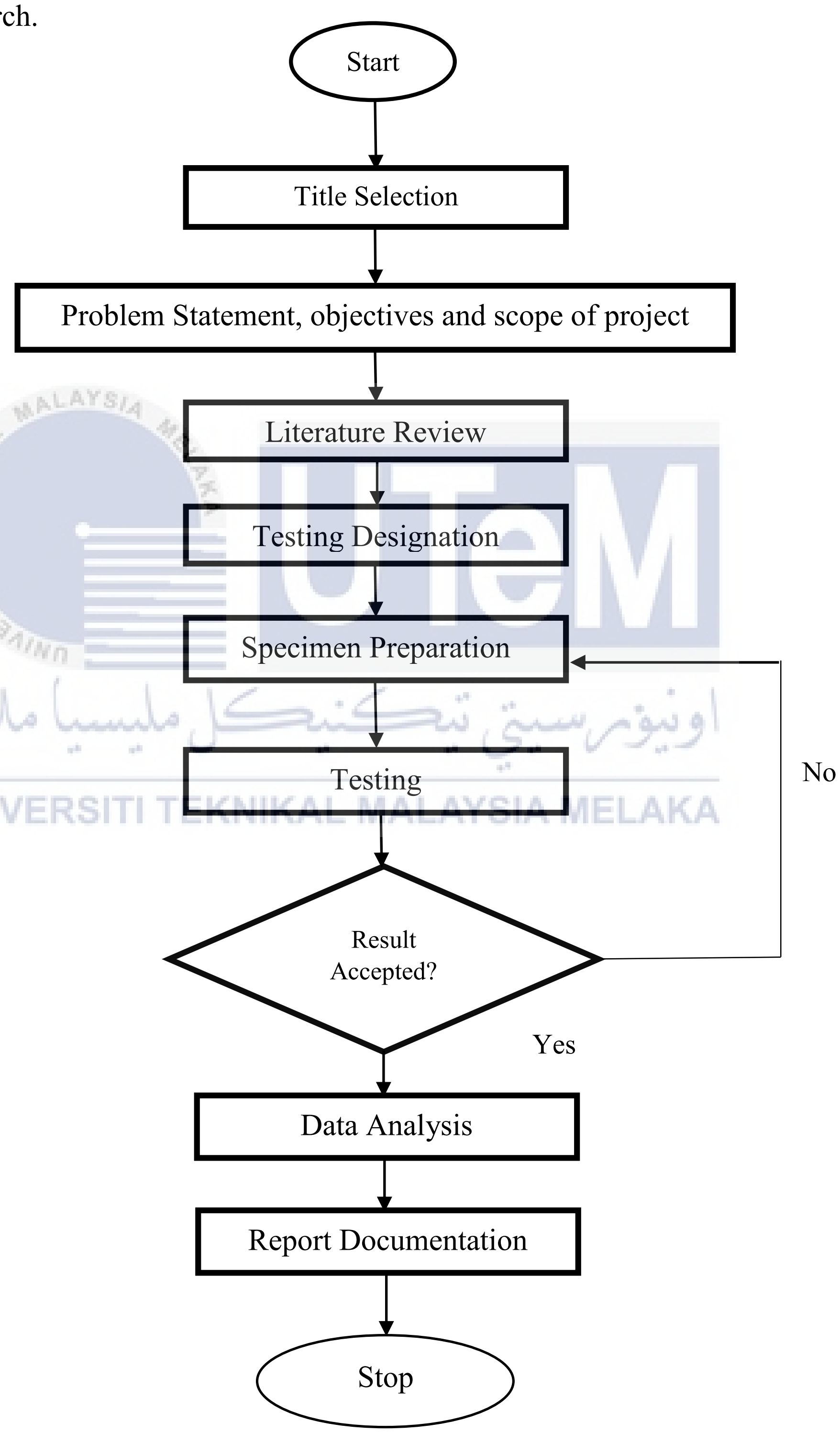


Figure 1.1: Flow chart of the general methodology

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter will cover the related literature review for the research. In this chapter will discuss on geospatial technology, Geographic Information System (GIS), GIS application and 3D printing technology. In addition, the related topic on 3D printing technology such as working principle on 3D printing, type of 3D printing and material for 3D printing will be discussed in detail in this chapter. Other than that, the discussion will be discussed on the geospatial technology in 3D printing aspects and also method for printing geospatial image using 3D printer. Last but not least, this chapter will discuss on factor affecting mechanical properties 3D printing product, testing method, American Standard for Testing Material (ASTM) and surface roughness of FDM additive manufacturing product.

2.2 Geospatial Technology

Geospatial technology is an advance technology that used by human which act as modern tools that provide the geographic mapping and analysis of the earth and human societies. Unconsciously, geospatial technology has been widely used in daily life and is evolving by time. The technology has been applied in variety of uses for the purpose to facilitate on human activities. The daily application of geospatial technology such as the Global Positioning System (GPS), Geographic Information

System (GIS) and remote sensing is significantly increasing especially for the purpose of monitoring aspect (Albert & Patrick, 2012).

Geospatial technologies consist of the two important thing which are computer hardware and software. These two things are used to collect, manipulate, store, analyse, and display geospatial data that has been gathered. This technology has evolved and adapt with other technologies for the usage of the human that involves visual positioning such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), remote sensing, and other visualization systems. These technologies have become available to nearly everyone through a variety of devices. Consumer demand has increase for these devices as a way to manipulate and display geospatial information which can be seen over the past decade. For example, the implementation of GPS data with digital maps has led devices and vehicles navigation devices that used every day for navigation and direction purpose by many of people in worldwide. The application of Google earth that has been launch in 2005 has enable everyone to manipulate digital maps and geospatial data (Folger, 2008).

2.3 Geographic Information System (GIS)

Geographic Information System (GIS) is computerised information storage, processing and retrieval system that have hardware and software specially designed to cooperate with geographical referenced data and corresponding attribute information (H.S.Sharma, Ram, Prasad, & Binda, 2006). It is an organized collection of computer hardware, software and geographic data designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographical referenced information. There are three steps in GIS spatial analysis which are preparation of an appropriate model, proper visualization and analysis of data from a simple map to statistical models (Baroš & Stojanović, 2015). The modern GIS use detailed digital maps, satellite images and computer models as its data source to locate position that necessary to react and all the data that collected can be interpret in a simple way.

According to Chakraborty & Sahoo, 2007, there are two basic concept of GIS. The first one is that the features have attributes associated with them. A GIS tells us “where” and “what” it is. Geographic location reply to “where” something is and “what” it is. Thus GIS clearly distinguishing itself from non-geographic spatial data management system like Computer Assisted Cartography (CAC) or Computer Aided Design (CAD), which do not use ‘georeferenced’ data. CAC system are excellent for visualization and can be used specifically for mapping purposes while CAD is excellent for producing architectural drawings and simplifying editing process but it also can perform maps analysis.

The second basic concept of GIS is that the information collected must be separated into layers. In GIS features like rivers, roads or forests are usually stored in different layers so that it can be added or taken off during GIS project as and when it needed. Layers is usually called as coverage or database and in most cases it consists of several computer files that have same name but different extensions. Layers represent the information of particular classes and can be combined to create new layer containing selected information specific to a particular query on the GIS. Basically, there are three fundamental features by which any layer can be presented.

a) Points: use for represent information in which necessary to show position of a feature but the feature physical shape is not important such as location of trees in an orchard.
b) Lines: Suitable to represent any real liner features such as road and river.
c) Polygons: It has solid multisided shape. Use to represent an area that have to draw a polygon and everything inside the boundary has the attributes associated with the record such as land use or land cover types.

2.4 GIS Application

Nowadays, the GIS has been widely use in various application and field such as scientific investigations, resource management, asset management, environmental impact assessment, urban planning, cartography, criminology, history, sales, marketing, and logistics. Topographic and mapping (cartography) visualization is one of the component that can be access using GIS. GIS can display the Earth in realistic, three-dimensional perspective views and animations that convey information more effectively and to audiences compare to conventional two-dimensional of static maps.

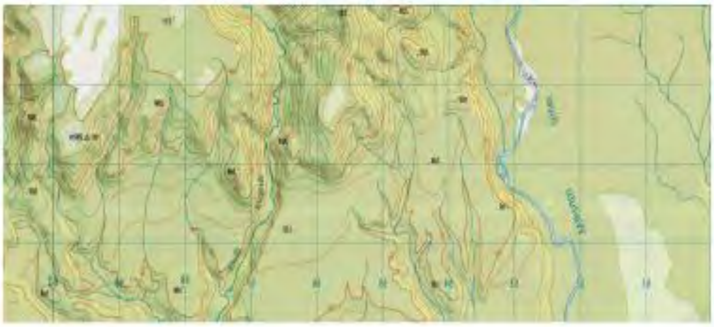


Figure 2.1: GIS topographic mapping.
(Source: More & Drekci, 2013)

According to Baroš & Stojanović, 2015, the application of GIS mapping in mine suspected area gives effective management of suspected mine, enhance mine security, offer interactive access and manage with database. It also enables the management to have statistical information analysis and visualisation of digital maps by multimedia data. Figure 2.2 shows mapping movements of suspected mine areas due to heavy floods in the Republic of Srpska and its region by using GIS mapping. The implementation of GIS mapping resulting two-thirds of 1230 km² area manage to be identified was covered by flood from 26 960 km² of mine contaminated areas. The implementation of GIS also manages to determine active landslide that occur which nearly above 2000 location or point manage to be identified. Mine Action Centre (BiH) have state that, there is more than 100,000 mines. In the situation, dangerous areas were labelled such as floods triggered mine and stolen signs. Some of the recorded cases of explosion of mines that are shifted by floods have occurred in the area of Brcko District in the north of the country.

Figure 2.2: Detection of suspected mine area in Republic Srpska using GIS.

(Source: Baroš & Stojanović, 2015)

In term of urban planning, there are three classification of urban planning function that use GIS as a function tool in urban planning which are general administration, development control and plan making. The use of GIS is according to functions, scales, sectors, and stages of urban planning that make different uses of GIS. According to figure 2.3, the statistical data shows that the use of the data management, visualisation, spatial analysis, and modelling components of GIS varies according to different functions of urban planning (Nyerges, Couclelis, & McMaster, 2011). Data management, mapping, and spatial analysis is generally important in urban planning process and spatial modelling is used as strategic planning tools. General administration employs mainly data management and mapping. Finally, development control uses the visualisation and spatial analysis functions of GIS most.

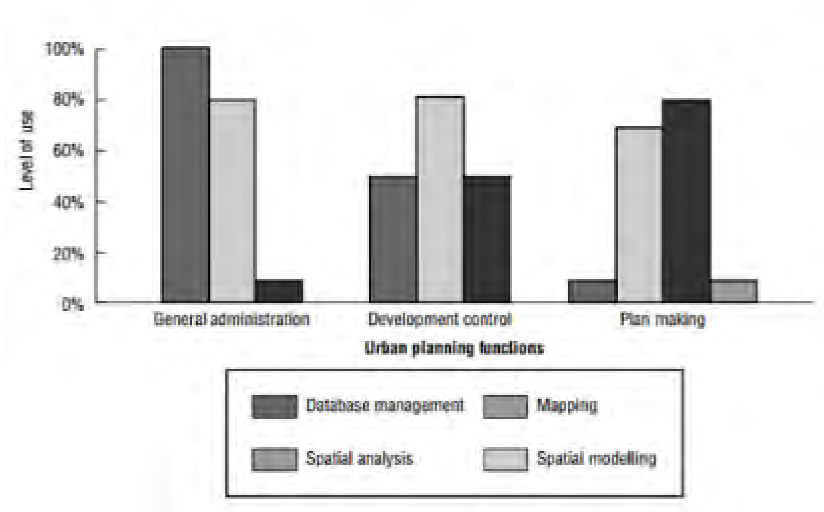


Figure 2.3: General usage of GIS Application in urban planning.
(Source: Nyerges, Couclelis, & McMaster, 2011)

2.5 3D Printing Technology

3D printing is fabrication of physical 3D arbitrary shape directly from numerical description (usually CAD model) by a rapid, completely automated and highly flexible process without any tooling element. It also can be refer as layer by layer fabrication process through deposition of build material through print head, nozzle or other printer technology (Noorani, 2017). 3D printing can be classified as one of Additive Manufacturing Technology. This fabrication method capable of generated 3D object in short time, affordable and easy to use compare than using other AM technologies. (Zhou, Herscovici, & Chen, 1999)

Even though 3D printing can save time generate 3D model, the limit size of the model and the resolution which usually has medium quality become the limit of this type of fabrication process. It enables to generate several model in a several hours compare to other type of fabrication which consume more time to finish a single part. The 3D printing machine work similarly like a normal inkjet printer which available in the market. The only different is it build layer by layer the 3D model compare with normal inkjet printer that only capable to generate 2D shape on paper. (Zhou, Herscovici, & Chen, 1999)

Additive manufacturing of 3D printing has three basic working principle to produce a 3D product or parts which are modelling, printing and finishing. Various type of 3D printing which use different type of material and method of fabrication. The 3D printing machine required 3D file format such as STL and VRML file which contain the 3D model data that usually generated from CAD or image scanning. This type of format file is capable to address polyhedron with any polygonal facet, but it only used for triangle in practice which means that much of the file syntax is superfluous.

3D printing technology development has rapidly increase in recent years which widely use across various industrial application. The suitability and reliability of this manufacturing technique for producing low volume products especially complex part geometries and parts that require customization become its advantage compared with subtractive manufacturing techniques (Guo & Leu, 2013). Figure 2.4 shows the percentage of industries that using 3D printing techniques as application in their sector. This statistic concludes that the demand of 3D printing technology increases and will become important in the future due to 4th industrial revolution.

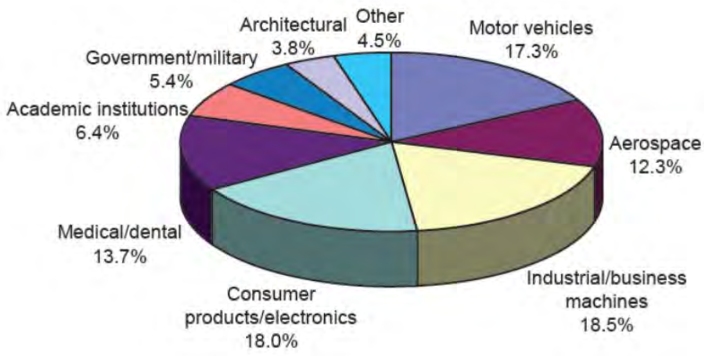


Figure 2.4: Usage of AM technology in industries.

(Source: www.moldmakingtechnology.com)

2.6 Working Principle of 3D Printing

For a machine to be operated, it required a set of working principle that need to be follow by the user in order for the machine to operate in optimum condition without having any error either on the machine, process or product. 3D printing also has its own working principle for the machine to be operated efficiently and produce 3D product that has high quality which fulfil the user requirement. There are three basic working principle of 3D printing in order to produce 3D printing product which are modelling, printing and finishing (Shahi & Singh, 2016).

Modelling of 3D product involving designing of the printable 3D product using suitable design tools. Usually 3D printed product is design by using Computer Aided Design (CAD) software for the designing purposes. By using the CAD software, it provides alternative way for the designing the 3D product which not only depend on the user to construct design only. Another way to get the 3D product design is by using 3D scanning. 3D scanning is a process of collecting digital data on the shape and appearance of a real object and creating a digital model based on the scan object. Plain digital camera and photogrammetry software also can be used in modelling 3D product which the data can be link with the CAD software that will be beneficial for the user to not conserve their time on modelling the product.

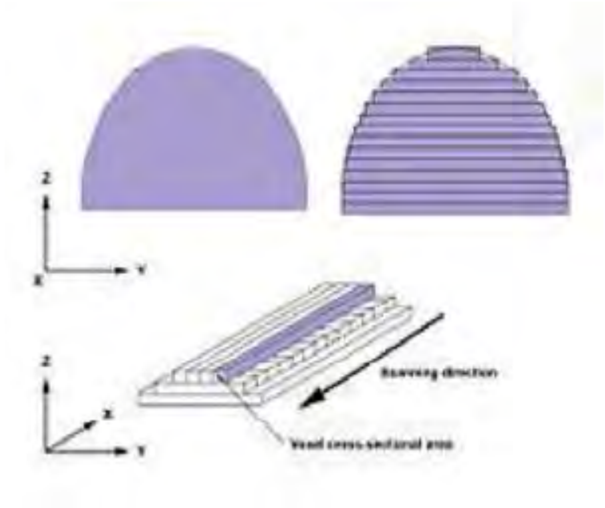


Figure 2.5: 3D Data digital model.
(Source: Shahi, 2016)

Printing is the process of producing 3D product according to the design data of the product by using 3D printing machine. 3D file format which contain 3D printing data of the product need to undergo “fixup” which the file will be examine for “manifold error”. Manifold error such as surface that does not connect, or gaps in the models which often found in 3D file format from 3D scanning need to be examine and rectified to fix the error. The fixup 3D file format need to be converts into a series of thin layers’ model and G-code file containing instructions tailored will be generated to a specific type of 3D printer by using software called “slicer”.

This G-code file can be print with 3D printing software of the machine which will be using the generated G-code as the instruction for the machine to print the product. Layer thickness and X-Y resolution in dots per inch (dpi) or micrometres (µm) is depends on the printer resolution. Typically, layer thickness is around 100 µm (250 DPI) but some machines can print layers as thin as 16 µm (1,600 DPI).

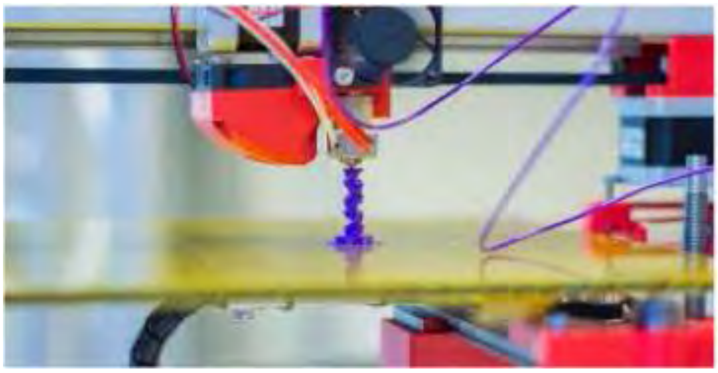


Figure 2.6: 3D Printing process.
(Source: Shahi, 2016)

Finishing is the necessary process in 3D printing which will be conducted after the product has completely finish printing. The finishing is needed due to the 3D product that produce slightly oversize from the desired object in standard resolution. Finishing that involving material removing or subtractive process can help to obtain the 3D product with greater precision. Chemical vapour processes usually is use for smoothing and improve surface finish of some printable polymer. Printing techniques such as FDM require supports to be built for overhanging features during construction and it can be mechanically removed or dissolved upon completion of the print. All of the commercialized metal 3-D printers involve cutting the metal component off of the metal substrate after deposition.

Figure 2.7: Part finishing process.
(Source: Shahi, 2016)

2.7 Type of 3D Printings

There are many types of 3D printing that use different kind of mechanism and concept of making 3D product or part. Each of the 3D printing type may use different type of material to build 3D product or part. Commonly, they are advantages and disadvantages of each type of 3D printing for producing varieties of 3D product or part.

2.7.1 Stereolithography

Stereolithography (SLA) is the 3D printing technique that use the method of light polymerization to produce 3D models from liquid photosensitive polymers that solidify when exposed to ultraviolet light. The process begins with construction of the product at the platform by exposing a low-power highly focused UV laser traces out the first layer of the product. The first layer of the model will solidify while leaving platform that has excess area of liquid. The piston platform will lower incrementally into liquid polymer. A sweeper will continue coating the solidified layer with the liquid and the laser will detect the second layer of build for the solidification of build material. The process continuously repeated until the finish product completely printed. (More P. , 2013)

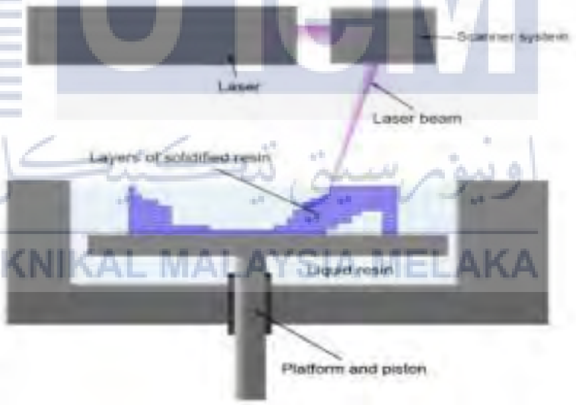


Figure 2.8: Stereolithography.

(Source: More, 2013)

2.7.2 Digital Light Processing

Digital Light Processing (DLP) 3D printing is the additive manufacturing process that use the method of light polymerization to create 3D product where the object is created by using 3D printer that use digital light projector (DLP) as the light source for curing the build material of photosensitive polymers. The process begins with curing thin layer of resin by projecting image on photo polymer resin. When the thin layer is solidified, the stepper motor will move to make new layer of thickness either upward or downward and the photo polymer will be cured. The process of producing new layer of thickness by projecting image on the resin will be continuous until the whole product completely printed. (Holtrup, 2015)

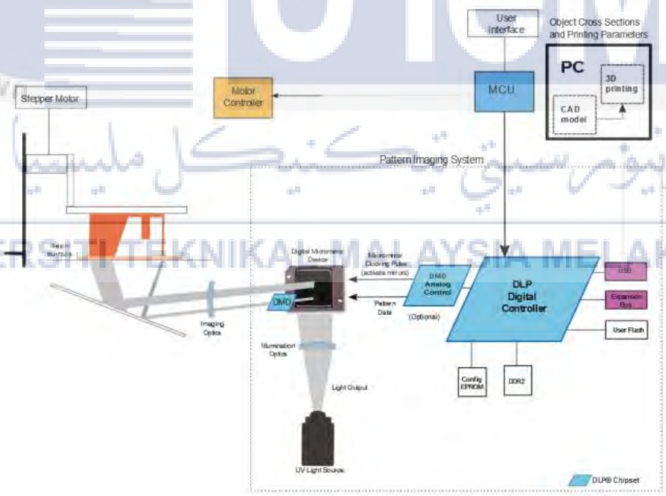


Figure 2.9: Digital light processing.

(Source: Holtrup, 2015)

2.7.3 Fused Deposition Modelling

Fused Deposition Modelling(FDM) which also known as Fused Filament Fabrication is 3D printing technology that use extrusion method to build 3D product by deposition of building material (filament) layer by layer from the bottom up by heating and extruding thermoplastic filament. The printing process start with the thermoplastics material is heat up into a semi-liquid state. Then ultra-fine bead will have deposited along the extrusion path at the printing bed. This method requires support structure or buffering for the printing of the model thus the machine will automatically create the support structure which act as scaffolding that is removable. After printing process completed, the user need to separate the support material from the product or dissolves it in the detergent and water before the product can be use. (Surange & Gharat, 2016)

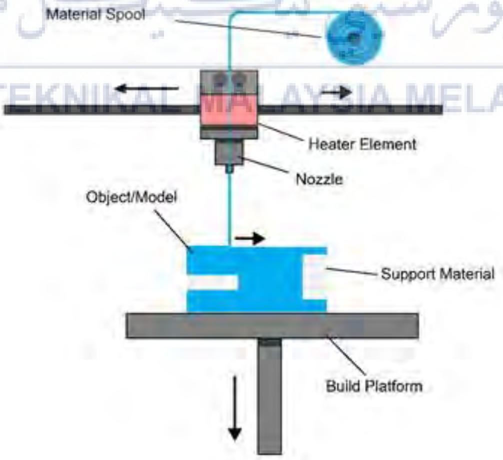


Figure 2.10: Fused deposition modelling.
(Source: www.tth.com)

2.7.4 Selective Laser Sintering

Selective Laser Sintering (SLS) is additive manufacturing methods that use powdered material for building components. The formation of 3D object is from powdered material which sintered layer by layer using the laser techniques as power source. High power laser such as carbon dioxide laser is commonly use to fuse powdered material into a mass that has 3D shape. Powdered material selectively fuses using laser by scanning the cross-sections of the 3D model according to 3D model data from CAD file or scan data on the surface of a powder bed. After cross-section has been scanned, the powder bed is lowered by one thickness of layer to form a new layer of material which applied on top. The process is repeated until the model completely printed (Pomell, et al., 2015).

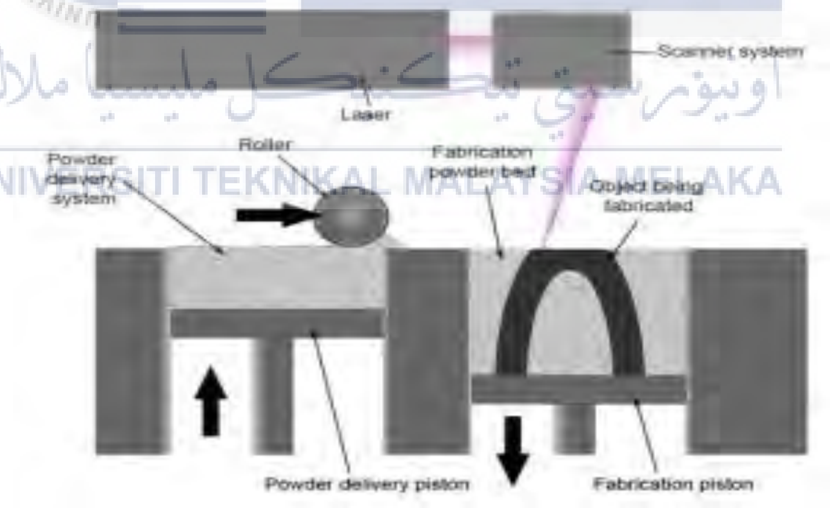


Figure 2.11: Selective laser sintering.

(Source: www.livescience.com)

2.7.5 Selective Laser Melting

Selective Laser Melting (SLM) is additive manufacturing of 3D printing process that use laser sintering to produce fully dense part by creating fluid phase which is called melt pool. (Gebhardt, Schmidt, & Jan-Steff, 2010). Figure 2.12, shows that the main components of an SLM machine are laser source, scanning system, building platform, feed container for storage purposes and a scraper for level up a new powder layer on solidified layer. The printing concept of the SLM is layer-by-layer building process, which it starts with build powder being bonded and melt by using high intensity laser beam. When the powder layer is placed on the base plate, the bed tracing geometry layer will be scans by projecting laser beam for the powder solidified. The build cylinder platform will be lowered to produce the new layer thickness (30-70 µm). The roller laid a new layer of powder and the laser will trace the printing path for the powder to be solidified. This process continues until the part is completely produced. The finishing process is required to remove the sticking powder on the outside of the part. Sand blasting and ultrasonic filling is the common method that used to remove the sticking powder from the printed part. (Yasa & Kurth, Application Of Laser Re-melting On Selective Laser Melting Parts, 2011)

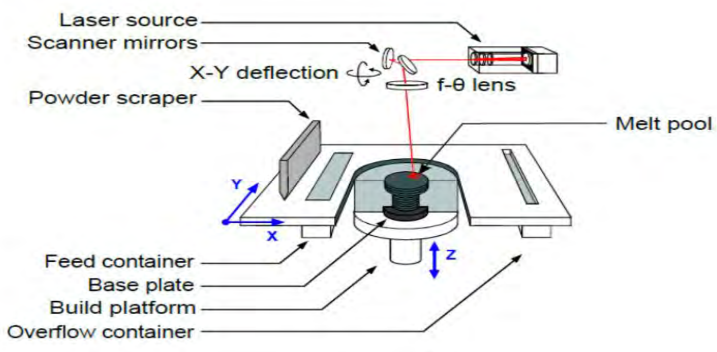


Figure 2.12: Selective laser melting.

(Source: Yasa, 2011

2.7.6 Electronic Beam Melting

Additive manufacturing of Electron Beam Melting (EBM) is rapid prototyping (3D Printing) process that use electron beam energy to melt build powder. The entire process takes place in a vacuum chamber to ensure high purity by supplying oxygen and lowering the hydrogen pick up risk. Elevated temperature about 700˚C is constantly maintained in the chamber to reduce residual stress. The building process start with spreading powder material on build platform by moving rakes to produce 100mm layer of thickness which is supply from hopper inside building chamber. The powder layer is pre-heated by electron beam with rapid scanning, then it melting the powder layer based on the geometry of the CAD file. EBM consist of two built steps which are building the outer boundary of the part that is referred as contouring and followed by melting the powder within the contour to complete (Sing, An, Yeong, & Wiria, 2015).

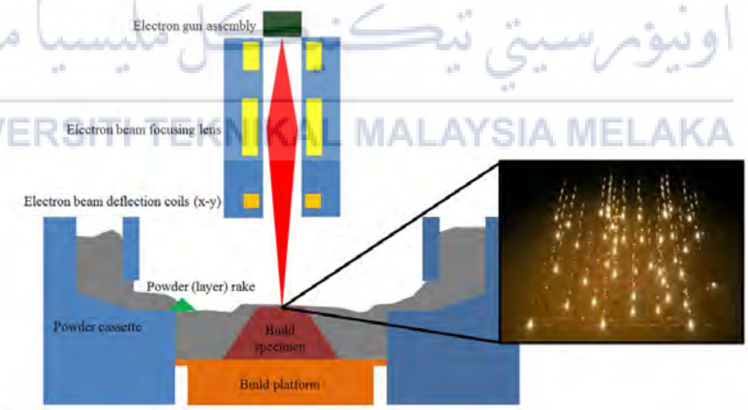


Figure 2.13: Electronic beam melting.
(Source: Sing, An, Yeong, & Wiria, 2015)

2.7.7 Laminated Object Manufacturing

This additive manufacturing of 3D printing method uses stacking, bonding and cutting layer of adhesive-coated materials techniques. Each layer is cut by using laser cutting method according to the outline of the part. When it finish, a new sheet layer of thickness (within 0.002-0.020 inch) is formed by lowering the build platform and another new material sheet is rolled on the top of previously deposited layer. The platform then rises slightly and the heated roller applies pressure to bond the new layer. After a layer is cut, the extra material remains in place to support the part during build. The laser cuts the outline and the process is repeated until the part is completed. (Ramya & Vanapalli, 2016)

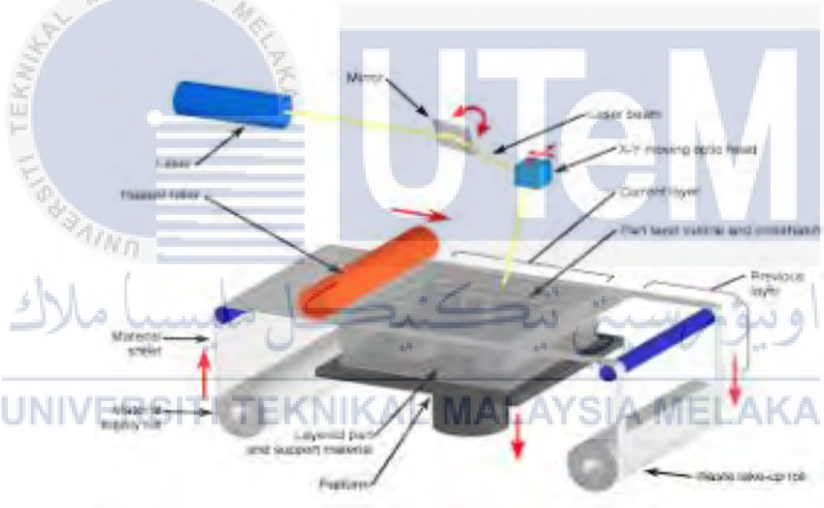


Figure 2.14: Laminated object manufacturing.

(Source: www.makepartsfast.com)

2.7.8 Binder Jetting

Binder jetting is an additive manufacturing method that used powder bed type printing method in which a liquid binding agent is selectively deposited to join powder particles. There are two type of material that is used in binder jetting which are powder base material and a liquid binder. Powder base material is spread in equal layers and binder is added through jet nozzles that bind the powder base material according to the 3D model data in the build chamber. The finished product is bind together by binder remains in the container with the powder base material. After the print is finished, the excess powder is cleaned and recycle for the usage of next printing process. (Al-Maliki & Qasim, 2015)

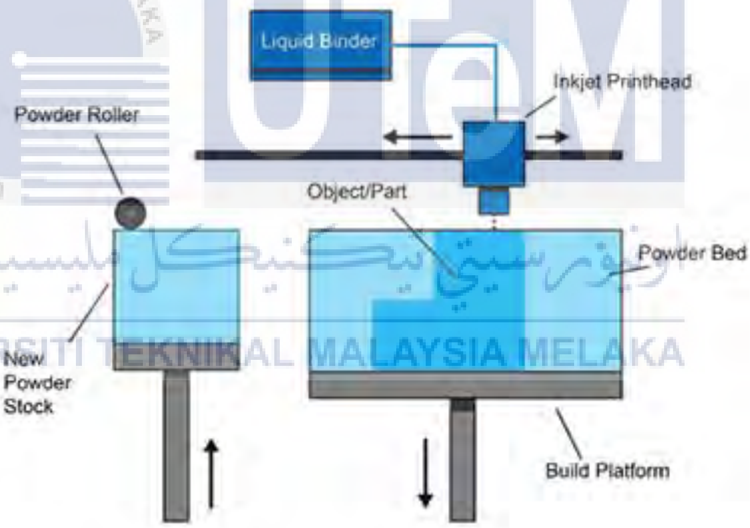


Figure 2.15: Binder jetting.

(Source: www.lboro.ac.uk)

2.7.9 Material Jetting

Material jetting which also known as inkjet 3D printing technique is an additive manufacturing method that can creates 3D models by depositing droplets of liquid photopolymers using piezo printing heads and curing the photopolymers using ultraviolet lamps. Material jetting printing required two type of material to produce 3D model which are build material (photopolymer) and bind material. The process begin with the liquid is heated until reach the specification temperature that the liquid archive optimal velocity for printing. The print head travels over the build platform according to the build path and hundreds of tiny droplets of photopolymer are deposited to the desire locations. The UV light which is attached at the print head will cured the deposited photopolymer material and it will solidify to create the first layer of the product. After the first layer through the process, the build platform will moves downwards to produce new layer of height and the process is repeated until the whole model is printed. (Yap, Wang, & Sing, 2017)

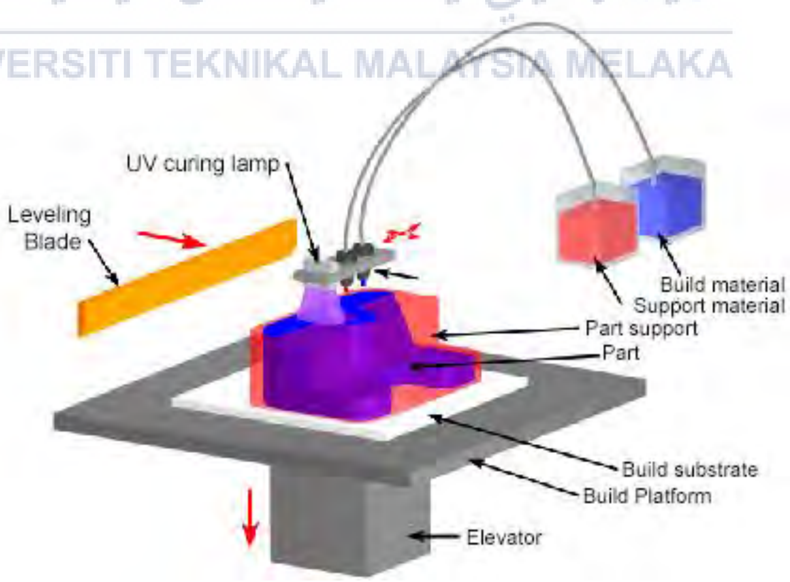


Figure 2.16: Material jetting.

(Source: www.lboro.ac.uk)

2.8 Material for 3D Printing

Material that used for 3D printing usually available in many state condition such as filament, powder and sheet. The usage of the material depends on the process or type of printing which require different type of material. For the fused deposition modelling (FDM), the material that commonly use is filament type material that suitable for extrusion process for part printing. Polymer such as Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) is common material that used for FDM printing and also some of other type of 3D printing.

2.8.1 Polylactic Acid

Polylactic Acid (PLA) is 3D printing polymer material which is biodegradable that produce from renewable raw material such as starch. SLA and DLP 3D printing use PLA material in form of resin while FDM 3D printing use in form of filament. PLA material has lower performance of material properties compared to ABS, but it available in several of colours and it is user friendly due to easy to handle in 3D printing. The extrusion temperature which also known as melting point of PLA is around 180 to 230 degree Celsius and the printing bed temperature required to be controlled around 50 to 60 degree Celsius which beneficial for the quality of the printed object or part. (Chua, Matham, & Young-Ji, 2017)

PLA material prefer to be use for printing large part due to it has thermally less contractive properties. At high temperature process, PLA material does not emit toxic fumes and the installation of fume hood is optional. Such as ABS material, PLA material also has the characteristic to absorb moisture from ambient air and it will affect the material properties and cause difficulties in printing process.

2.8.2 Acrylonitrile Butadiene Styrene

Acrylonitrile Butadiene Styrene (ABS) is 3D printing polymer material that commonly use in varieties of application especially for FDM 3D printing. This is due to it is an inexpensive material and can be easily 3D printed by heating nozzle to a temperature until 250 degrees Celsius. The melting point of ABS materials is 230 degrees Celsius and the standard printing temperature is 230 degrees Celsius and above. ABS has excellent material properties which are strong, durable, partially flexible and heat resistant which make it suitable for varieties of application. ABS material that used for FDM 3D printing usually in filament form which is available in various colour commonly used. Temperature of printing bed need to be controlled around 110 degrees Celsius for ABS material 3D printing. (Chua, Matham, & Young-Ji, 2017)

However, this type of polymer is not biodegradable polymer but can be recycled. The safety precaution is needed due to the ABS will produce harmful fumes when it undergoes high temperature process. ABS required proper handling and storage due to its performance can be degrade when exposed to sunlight for a long time. The printer performance also can be effect when it use moisture ABS due to its properties to attract moisture from the air.

2.9 Geospatial Technology in 3D Printing Aspects

Commonly, 3D model is very important that use by various planning sector such as city or urban planning, natural resource management and transportation planning. With higher demand on application of GIS in industry and the need of proper visualisation of 3D model, 3D modelling has been evolved in producing more realistic model such as city landscapes with building, street furniture, and topographic variation as shown in figure 2.17. The 3D modelling for GIS data require more analytical process in creating 3D model or 3D topology. (Ellul, Zlatanova, Rumor, & Rober, 2013)

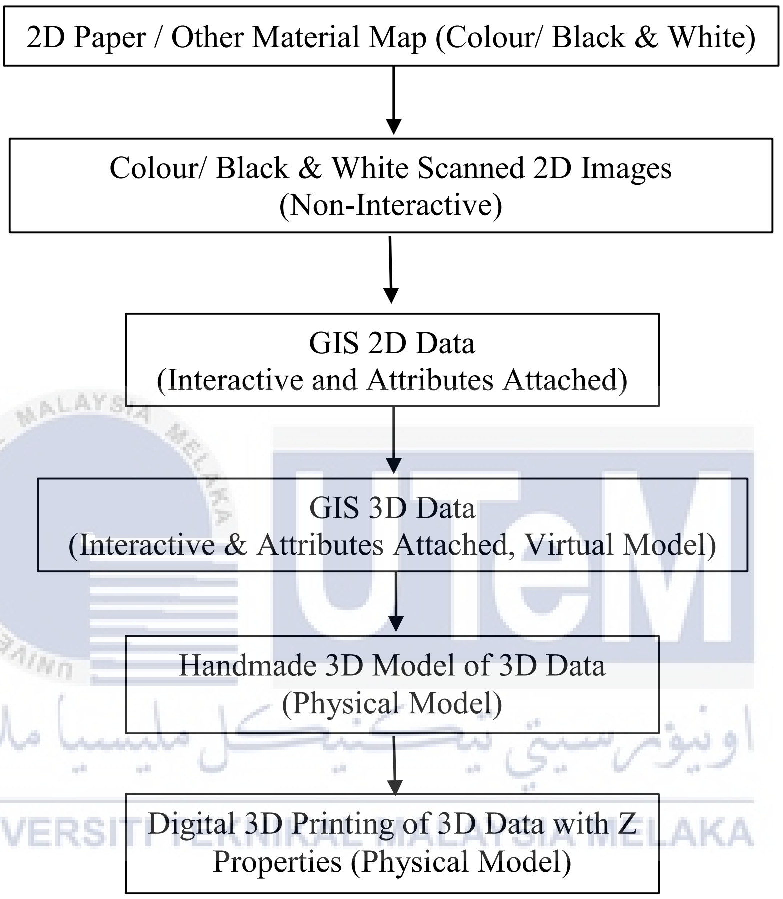


Figure 2.17: Development process of spatial data visualization enhancement.

Traditionally, 3D physical models of landscape or mapping are generated or produce by manually or semi-manual methods. The implication of this method is it consume more time and manual effort to make a model which has high quality of visualization and precise according to the GIS data. It involving the use of cardboard sheet as material to build the 3D model. The cardboard sheet required to be cut and paste on top of each other to produce a three-dimensional representation of topography. The geographic element significantly can be mark by using suitable common tool such as pushpins (point), coloured string (lines) and paint (area). The advance technology of 3D printing and with the help from GIS Data enable the 3D model rapidly build and could avoid the business or operation delay due to 3D model production, thus it can speed up the process of negotiations for conflict resolution.

GIS 3D model development is not for replacement of paper maps or VR technique. The development of GIS 3D model has solved the problem from visualisation of current mapping method (2D) such as depth prediction which can be resolved by a minor movement of the head or body. Other than that, the distance and height estimation become more effective and precise with 3D printing model due to lifelong experience with 3D views. (Buchroitner, 2012)

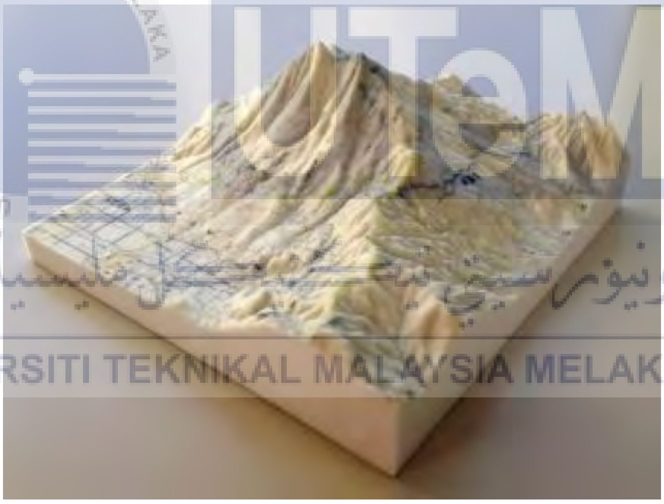


Figure 2.18: 3D print geospatial model.

(Source: www.vrzone.com)

2.10 Printing Geospatial Using 3D Printing Method

In order to produce geospatial model by using 3D printer, there are several methods that can be used for that purposes. One of the method is to print 3D geospatial model from GIS data. GIS consist of spatial data that can be access for the geographic (mapp-able) information by inserting the location or geographic information system (latitude-longitude) or address system. According to Ellul, Zlatanova, Rumor, & Rober, 2013 there are several procedures for printing 3D geospatial model from GIS data. Figure 2.19 shows the procedure for printing 3D geospatial model from GIS data.

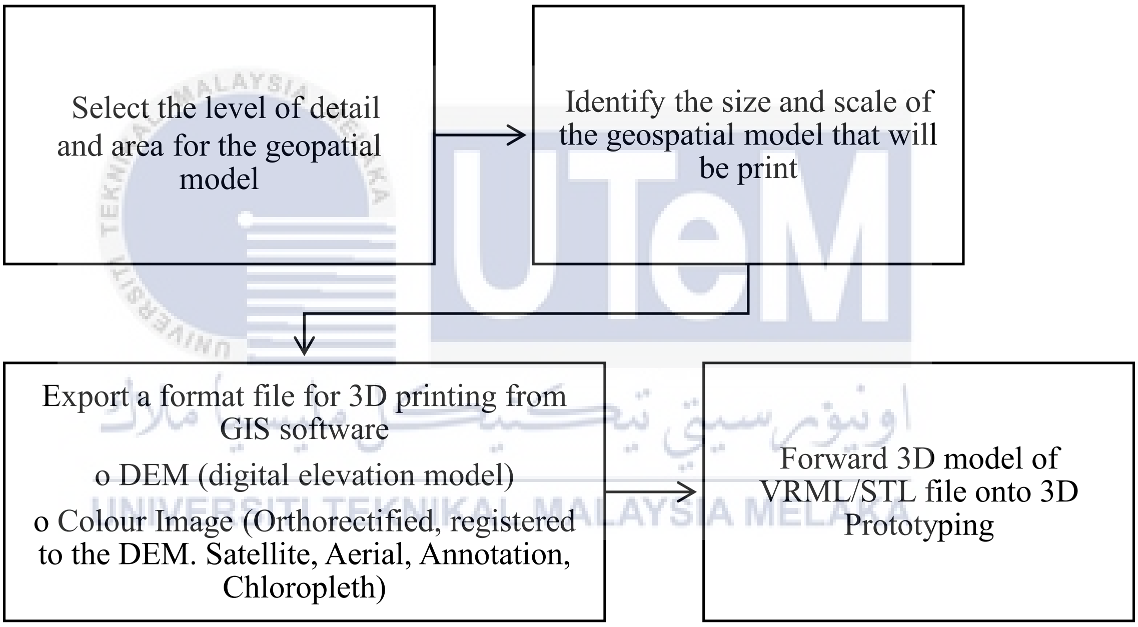


Figure 2.19: Procedure for printing 3D geospatial model from GIS data.

The first procedure acquires Geospatial Information from valid mapping source. The landscapes of the geospatial data need to be obtain from valid mapping source. The common mapping source that use to get the geospatial data is from The National Mapping Website, USGS. The Digital Elevation Model (DEM) data can be obtain and access by selecting the geospatial region or coordinates.

Figure 2.20: Obtaining geospatial information from USGS.
(Source: www.instructables.com)

Figure 2.20 shows the method for selecting region for extracting GIS data from USGS. The selected GIS data need to be adjust according to the range of the standard size and scale by referring the limit of the printing size of the 3D printer. The sizing and scaling is very important for the purpose of the representation of the model to be display when it has been printed.

The GIS data that has been sizing and scaling need to be convert to format file that can be access by 3D printer. There are several type of format file that used for printing 3D product such as VRML or STL file. The current generation of 3D printers typically uses a STL file, which defines a shape by a list of triangle vertices (Berman, 2007).

Suitable GIS software is required for the conversion GIS data to STL format file for the 3D printer. DEM data is needed for the representation of the terrain surface of the model. Usually the DEM can also be access from USGS according to the GIS data. The main purpose of using the GIS software is for converting and editing the GIS data to printable geospatial model. The geospatial model in STL format can be export to 3D printing software which need to be link with the 3D printer for printing the 3D geospatial model

2.11 Factor Affecting Mechanical Properties 3D Printing Product

The variation of printing parameter that involves printer setting parameter may influence the material properties which will affected on reliability of 3D part. The variation may alter the material properties either make the material durable or not. There are several printing parameters which has been identified that may influence the material properties of printing material which are layer thickness, printing speed, printing and build orientation and build infill of material

2.11.1 Layer Thickness

According to Jaya Christiyan & Chandrasekhar, 2016 the build layer of thickness can affect the material properties of tensile and flexural strength. It summarizes that, the 3D printing part which made with thicker layer than each individual layer is capable to have high resistance against failure compared with the 3D printing part which is made with thinner layer. The "stepped effect" is suspected affecting the flexural and tensile strength which it decreasing respected to the increasing layer thickness. Smaller layer height interlayer has strong bond strength. By decreasing layer height, more layers are needed to print any given object. It will give benefits due to layer can be reheating on the underlying bond lines promoting polymer diffusion and entanglement which cause by increase on the number of layer printing. (A.C. Abbott, 2017)

The strength of the segment of 3D printing is vary with the process parameter which is layer thickness. The smallest layer of thickness will have higher impact strength of the segment compared with high layer thickness. This is due to the small layer thickness provide the material to have higher absorption of impact energy compared with the part that made with high layer thickness (Abbas, Othman, & Hind, 2018)

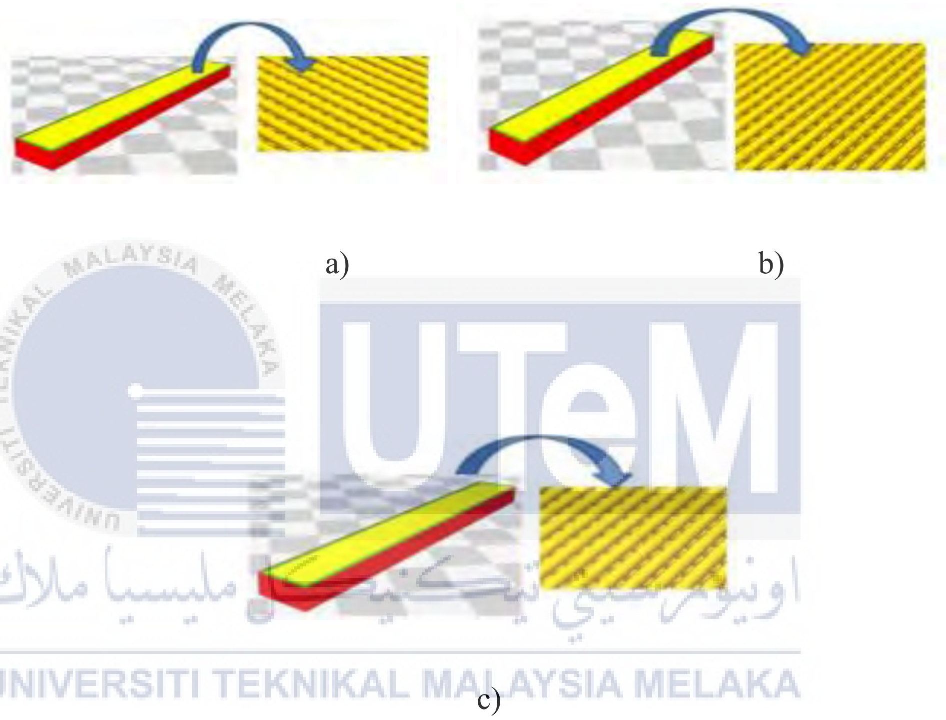


Figure 2.21: Sample of Impact Test at Layer a) Thickness 0.20mm b) Thickness 0.25mm c) Thickness 0.3mm.

(Source: Abbas, Othman, & Hind, 2018)

2.11.2 Printing Speed

The optimization of printing speed for 3D printing is a very important factor to be optimize for durability. Printing at high speed results in very bad layer bonding performance. The high speed printing will result in lower quality of layer bonding. This may have been caused by high rate cooling factor of plastics when the printing speed is at high rate. The extruded layer does not have sufficient temperature for the cooling which cause the bad adhesion to the layer below. (Johansson, 2016)

Print speed is predicted to influence the bond strength of material. As bond strength is derived from polymer diffusion which is a function of among other things, time at temperature and print speeds that maximize time at temperature are favourable. Adjacent and underlying bond lines was expected to be reheated by radiation and conduction through depositing molten polymer. The effect of the reheating is it would accelerate the diffusion and entanglement of polymer. By this, bond formation would intermittently progress in response to reheating from continued road deposition during a print. Slower print speed promoted this type of bonding formation. The heated printing nozzle expected to supply enough local heat for a longer time through radiation at slow print speed. Once the print progresses far enough that a specific bond line is no longer heated above transition temperature by deposition of subsequent roads, bond development is considered to have ceased. (A.C. Abbott, 2017)

2.11.3 Printing and Build Orientation

Different build orientation of 3D printing can influence the quality of the printed product. Build material can react dissimilarly due to the relative position and the internal channel to the axial load which depends on building orientation. The bond between layers which is discover to have only 74% to 79% of strength which is due to weaker bond between the layers. Build part which is build according to X-directions (flat) has high strength and elongation before it achieves failure followed by the part built in Y-direction and Z-direction (vertical). (Kyle Raney, 2016)

Figure 2.22: Test specimen different build orientation.
(Source: Kyle Raney, 2016)

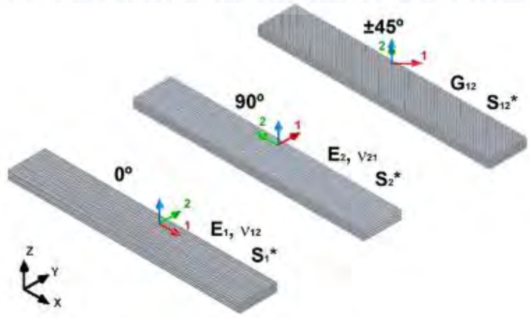


Figure 2.23: Test specimen different printing orientation.
(Source: Kyle Raney, 2016)

2.11.4 Infill

3D printing infill can be refer as the internal structure of the print model. Infill density is the amount of build material deposited inside the printing object which is the most important printing parameter that need to be set up when printing a 3D model. The higher the infill density which usually can be maximum up to 100% of infill, the 3D model will contain more build material in the inside that lead to a stronger object structure. In general, a fill density between 10% and 20% will be strong enough for most objects, but it can be increase it if necessary. A hallow printing object which are used for a certain case can be done by simply setting the 3D model to have infill density of 0%. In a certain printing machine, the infill thickness can be set up which allow it to have different thickness from the build thickness layer.

2.12 Testing Method

There will be various kind of testing method in this research. Generally, this method depends on the specimens that have to be tested.

Tensile Test

Tensile test or also known as tension test is the most basic type of mechanical test on material. Tensile test is simple, relatively inexpensive and fully standardize. The concept of this testing is by pulling on testing material in order to determine the behaviour of the material react to forces being applied in tension. When the material being pull, it will reveal the strength along with how much it will elongate. The standard which available for tensile test are ASTM D638 and ISO 527.

Impact Test

Impact testing is testing on object's performance withstand high-rate loading. The reason why impact test conducted is to determine the energy absorbed in fracturing test piece at high velocity. The method can be explained by simple concept of one object striking another object at a relatively high speed. ASTM 256 and ISO 180 is the common standard use for impact testing

Flexural Test

Flexural testing is material testing by applying certain load at the midpoint of the specimen object causing the deformation of material from its original testing shape without occurrence of fracture for determine the ductility or resistance of fracture of a material. ASTM D790 and ISO 178 are common standards for flexural test for polymer.

2.13 American Society for Testing and Material (ASTM)

ASTM International is international standard developing organization that cultivate and issue voluntary technical standards fir wide range of products, service, system or material. Consensus process is used for develop standard which conducted by ASTM international.

This standards organization was establish since 1898 founded by a group of engineers and scientist, led Charles Benjamin Dudley to solves the problem of rail road due to rapid growing of rail-road industry. The first standards that develop by the group is a standard steel for fabricate rail. This standard is the pioneer of the standards for testing and material such as BSI (1901), DIN (1917) and AFNOR (1926) which there are not national standards organization that role being taken in the USA by ANSI. ASTM has it dominant role among the standard developers in USA and claim to be world largest standard for material and testing.

Currently, ASTM International assists thousands of technical committees, which attract their members around the world and as a whole maintain more than 12,000 standards.

2.14 Surface Roughness of FDM Additive Manufacturing Product

Surface roughness of additive manufactured parts quality are often not comparable with cut parts. Most of the part produce require post process for the surface treatment of the printed part which involving mechanical and chemical finishing process. The factor influences the surface roughness of the AM parts involving the printing parameter which it resulting the poor surface roughness if it is not controlled.

According to Lamikiz, Sanchez, Lopez de Lacalle , & Aran, 2007 notwithstanding the critical advance made in material flexibility and mechanical performance of AM, a generally poor surface finish when contrasted with the surface finish of conventional manufacture techniques still displays a noteworthy confinement in a wide range of AM process. Based on research made by Nsengimana, 2015 there are two factor that influence surface roughness of FDM part that involves the printing parameter which are “stair-step” and “chordal” effect. The "stair-step" effect influence the surface integrity or surface finish of additive manufacturing product. The surface quality is significantly impacted by the "stair-step" effect, which is the ventured estimate by layers of curves and inclined surfaces. This “stair-step” effect causes the geometric gap between CAD model and produce part surface integrity. The geometric gap problem consumed to poor surface finish of fabricated part and can reduce by decreasing the thickness layer that can effect build time to produce the 3D part (Yasa & Kruth, Application of Laser Re-Melting on Selective Laser Melting Parts, 2011).

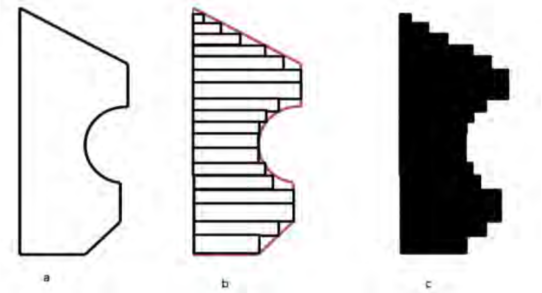


Figure 2.24: Stair step effect: a) CAD surface profile, b) Layer slices, c) Additive Manufactured profile.

(Source: Nsengimana, 2015)

Pandey, Reddy, & Dhande, 2003 states that burring which present on the part surface after the model detached from support structure known as chordal error may influence surface quality of FDM produce part. This chordal error occurs due to curve surfaces that form from series of triangles on CAD model which generated to STL files, hence cause burring that leads to non-smooth surface. The solution that proposed by Vasudevarao, Natarajan, & Henderson to solve the chordal error is to provide a positive offset to the surface in the process of prototype building and performing post process of finishing to alter the dimension accuracy of the prototype.

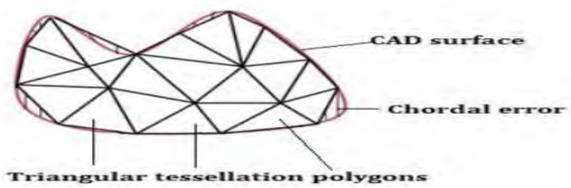


Figure 2.25: Chordal effect.

(Source: Nsengimana, 2015)

2.15 Previous Researcher

Table 2.1: List of previous research.

Researcher	Configuration	Remarks	Year
Heechang Kim et.al	Mechanical properties of single and dual material 3d printed products	Study on process parameter, comparison the material strength of different type of material deposition	2017
Kyle Raney	Characterization of the tensile strength of ABS parts manufactured by fused deposition modelling process	Study on build parameter and its effect on strength of material mechanical properties	2017
Zixiang Weng et.al	Mechanical and thermal properties of abs/montmorillonite nanocomposites for fused deposition modelling 3d printing	Study on process parameter, comparison strength of abs material with abs improve material.	2016
K.G. Jaya Christiyan et al	Influence of process parameters on the mechanical properties of 3d printed abs composite	Study on process parameter, effect of parameter on mechanical properties of 3D part.	2016
Rafael Thiago Luiz Ferreira et.al	Characterization and micrography of 3d printed PLA and PLA reinforced with short carbon fibers	Study on material orientation and its effect on mechanical	2016

		properties of 3D part	
Frans Johansson	Optimizing fused filament fabrication 3d printing for durability	Study the process parameter and its effect on build material for post-processing	2016
Terry.T Wohlers	Rapid prototyping, tooling and manufacturing state in the industry annual worldwide report progress	Study on process of rapid prototyping and rapid prototyping machine.	2004

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, the methodology of the research is covered based on the information gathered from the literature review. This research focus on FDM 3D printing material which are ABS and PLA for the testing. This chapter will discuss on manufacturing process that will be use in the research followed by the sample preparation according to the suitable standard of testing for tensile, impact and flexural test for both materials. In addition, testing procedure of each testing will be discussed in detail on every aspect in conducting material testing. Lastly, the sample of data that will be collected when conducting the experiment will be stated for data recording purposes. The plan of the research flow is shown by the flow chart in figure 3.1.

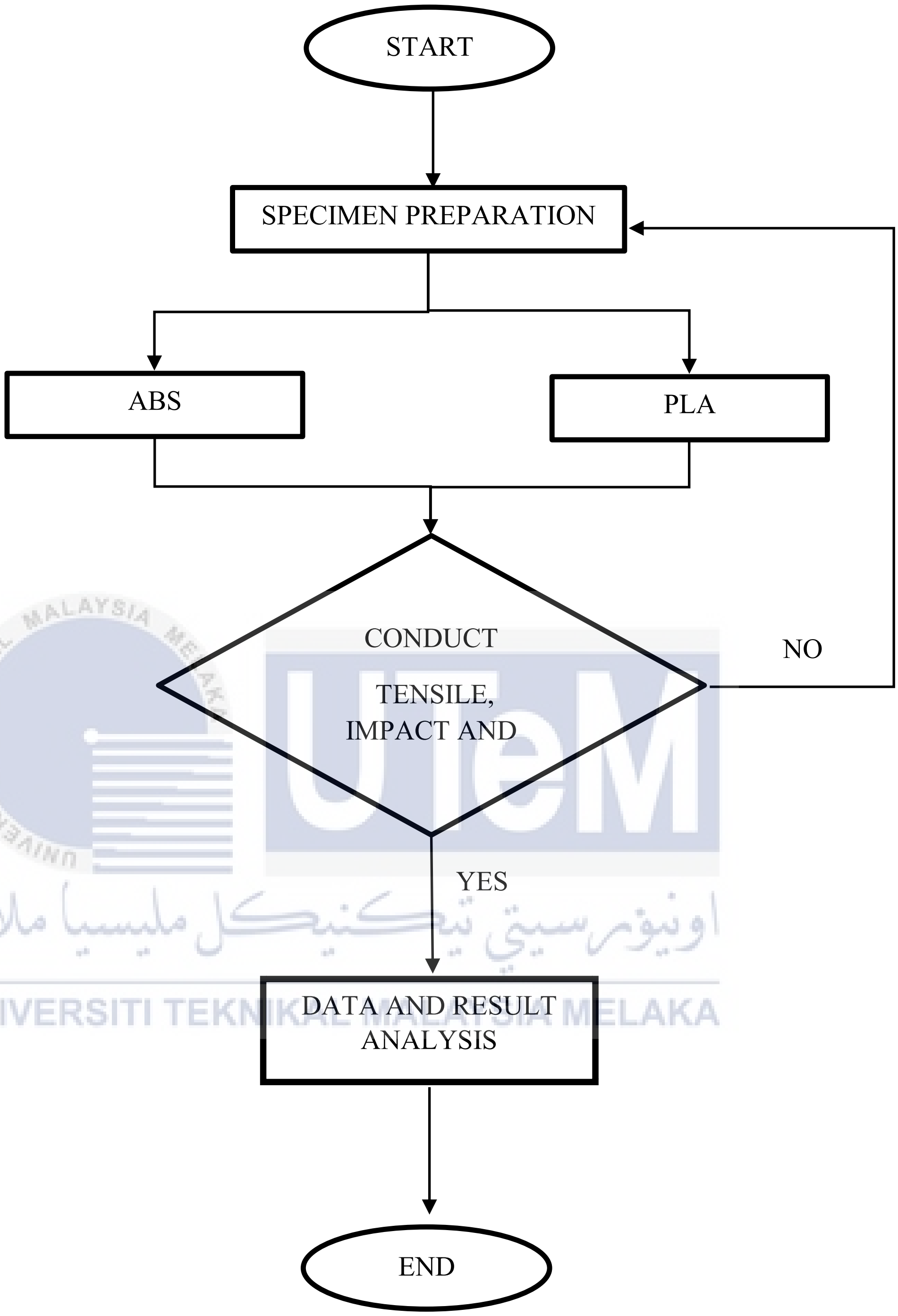


Figure 3.1: Flow chart of the research's methodology.

3.2 Manufacturing Process

Manufacturing process is a process of converting raw material into a product. It involving several aspects which are raw material, machinery, tooling, power, and manpower to produce a profitable product. Additive Manufacturing (AM) of 3D printing refers to a process by which digital 3D design data is used to build up a component by depositing material layer by layer. In this research, FDM 3D printing machine that used to produce geospatial product will be used for specimen preparation for the testing. It uses deposition of building material method layer by layer from the bottom up by heating and extruding thermoplastic filament. There are two type of 3D printing machine that use in this research which are UP MINI and PRUSA I4 3D printing machine.

3.2.1 UP Mini

UP MINI 3D printer is one of FDM 3D printing machine which manufactured by Tier Time Technology. This home purpose 3D printer is the smallest in size among the other model of 3D printing machine which manufactured by the company. This printer suitable for material ABS and PLA filament for the extrusion process to build 3D product. Moreover, it has innovative magnet coupling print head design which allows for an easy installation and replacement of print head. It capable to produce 3D product rapidly within build size below 245mm by 345mm by 360mm. Other than that, the printer has three types of quality modes which are normal, fine and fast which the printing parameter has already been set up by the manufacturer for ease the user to print 3D product. Only single nozzles available for deposition of thermoplastic material.

Figure 3.2: UP Mini 3D printer.

Table 3.1: Specification for UP Mini 3D printer.

Printing Material	ABS or PLA
Build Size	245mm x 345mm x 360mm
Layer Thickness	Selectable layer thickness;(0.2,0.25,0.3 and 0.35mm)
Nozzle Diameter	0.2mm
Print Speed	(fine) 10– (fast) 100 cm3/h
Extrusion Temperature	ABS: 260-270c PLA:200
Platform Temperature	ABS: 50c PLA:50c
Print Bed Size	120mm × 120mm × 120mm
Input Format	STL
Connectivity	USB
System Software	UP Studio use STL file for 3D print (Selecting parameter and scaling function). The software runs on Microsoft XP, Vista, 7 and Mac.
Printer Size	245mm × 350mm × 360mm
Weight	5 Kg

3.2.2 PRUSA I4

PRUSA I4 is a 3D printing machine that manufacture by Sunhokey Electronics Co. It capable to produce 3D product from various type of material through FDM method. The parameter of PRUSA I4 can be set up manually which consist of various type of parameter that can be customize according to user needs to produce 3D model. Proper calibration is needed to be set up properly for this printer which it can leads printing defects if the printer calibration not being properly done. In addition, LCD panel of the machine display the information on the printing parameter which can be tuned directly and enable to print 3D model directly using SD card input.

Figure 3.3: PRUSA i4 3D printer.

Table 3.2: Specification for PRUSA i4 3D printer.

Printing Material	PLA, ABS, HIPS, WOOD, PVC, Nylon, PC and Flexible PLA.
Build Size	210mm x 210mm x 190mm.
Layer Thickness	0.1 mm- 0.5 mm
Nozzle Diameter	0.4 mm (customized 0.2/0.3mm/0.5mm)
Print Speed	40 to 100 mm/sec
Extrusion Temperature	280 degree C
Platform Temperature	130 degree C
Print Plate Size	213mm x 200 mm
Input Format	STL, G-code
Connectivity	USB, LCD display and SD card reader
System Software	Repetier-Host Windows/MAC/Linux
Printer Size	430 x 505 x 380 mm
Weight	11 kg

3.3 Specimen Preparation

The testing specimen produced by using 3D printing machine. The specimen needs to be design by using CAD software which require to be converted to STL file for the printing purpose. SOLIDWORKS CAD software is used to design the specimen according to the standard size of the testing. There are three types of specimen that need to be produce for the testing which are tensile, flexural and izod impact specimen. All the specimen will be printed according to the specification as shown in table 3.3. The specification is estimated to be the maximum specification of the machine to produce fine 3D printing product.

Table 3.3: Specification for specimen printing.

Parameter \ Printer	UP Mini	PRUSA i4
Material	ABS	PLA
Nozzle diameter	0.2mm	0.2mm
Nozzle temperature (degree Celsius)	260-270	200
Temperature of Bed	50	70
Infill	Solid-100%	Solid-100%
Infill type(Print Orientation)	Rectilinear	Rectilinear
Print speed	40-60 mm/s(normal)	80mm/s
Layer thickness	0.2mm	0.2mm
Build Orientation	Horizontal	Horizontal

3.3.1 Tensile Test Specimen

Usually, they are two type of specimen that used in tensile testing which are "dog bone" and "dumbbell" shape specimen. The ASTM standard stated to use type I specimen as shown in figure 3.4 for moulding specimen. In the previous studies, type IV specimen is used to study on tensile properties of FDM extruding material due to consideration of non-rigid plastic properties which is stated in the ASTM standard as shown in figure 3.5. For the ISO standard, the "dog bone" specimen as shown in figure 3.6 is preferred for extrusion and moulding thermoplastic material. However, if it is not possible this type of specimen, then other specimen such as specimen shown at figure 3.7 "dumbbell" type may be used.

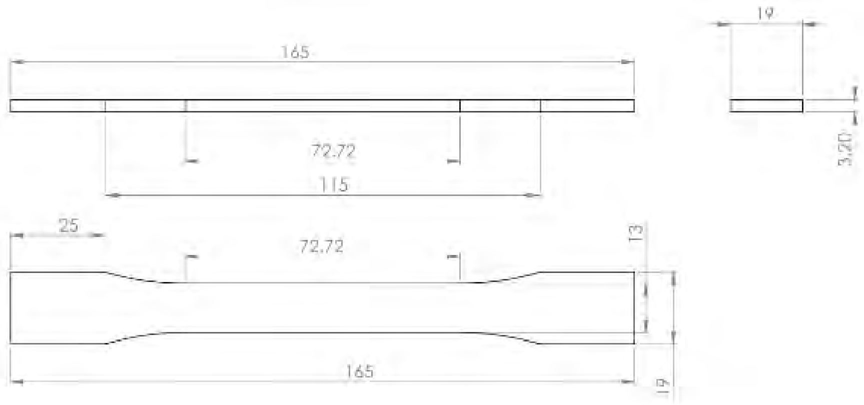


Figure 3.4: Schematic diagram of the specimen for tensile test ASTM D638

(Type I).

Table 3.4: ASTM D638 type I dimension for tensile test.

Standard	Dimension (mm)				
	Length	Width	Thickness	Throat Width	Gauge length
ASTM D638(Type I)	165	19	3.2	13	50

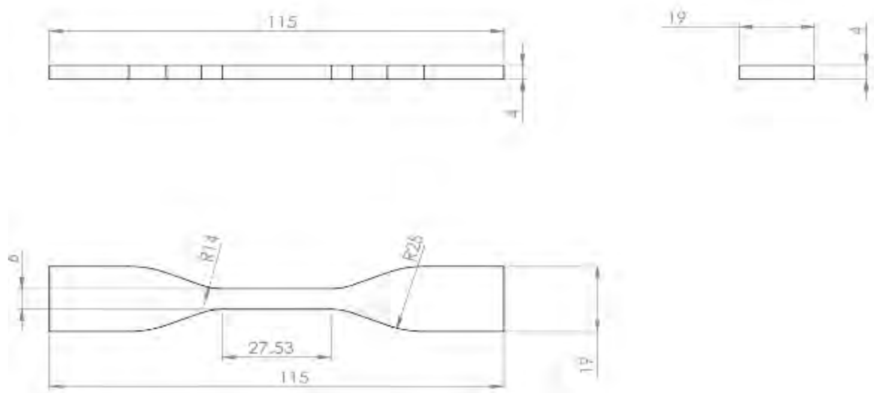


Figure 3.5: Schematic diagram of the specimen for tensile test ASTM D638

(Type IV).

Table 3.5 ASTM D638 type IV dimension for tensile test.

Standard	Dimension (mm)				
	Length	Width	Thickness	Throat Width	Gauge length
ASTM D638(Type IV)	115	19	4	6	25

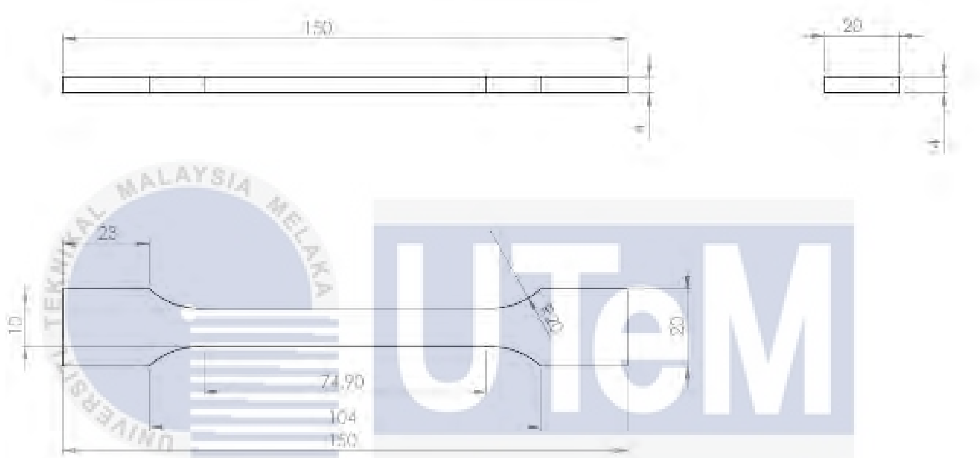


Figure 3.6: Schematic diagram of the specimen for tensile test ISO 527 (Type 1A).

Table 3.6: ISO 527 type 1A dimension for tensile test.

Standard	Dimension (mm)				
	Length	Width	Thickness	Throat Width	Gauge length
ISO 527(Type 1A)	150	20	4	10	50

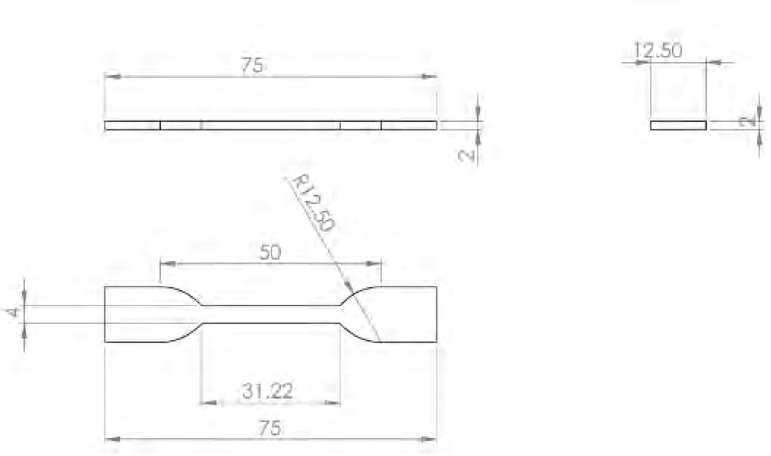


Figure 3.7: Schematic diagram of the specimen for tensile test ISO 527

(Type 5A).

Table 3.7: ISO 527 type 5A dimension for tensile test.

Standard	Dimension (mm)				
	Length	Width	Thickness	Throat Width	Gauge length
ISO 527(Type 5A)	75	12.5	2	4	20

3.3.2 Impact Test Specimen

There are two standards which available to be use to conduct Izod Impact Test which are ASTM 256 and ISO 180. These standard are focusing on impact testing on notch specimen. The Izod impact test specimen size for ASTM 256 and ISO 180 are shown at figure 3.8 and figure 3.9 respectively.

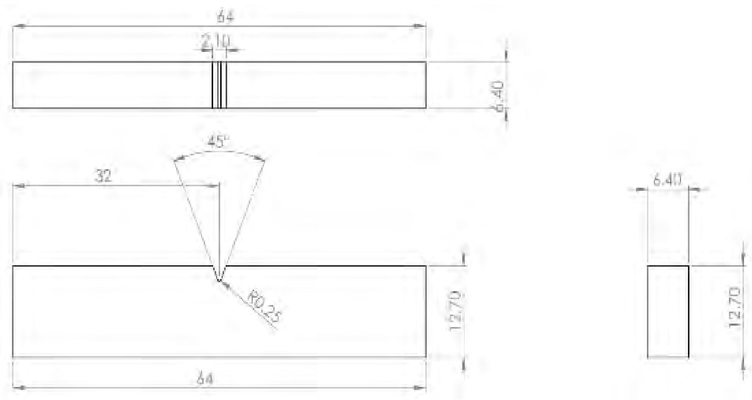


Figure 3.8: Schematic diagram of the specimen for izod impact test ASTM 256.

Table 3.8: ASTM 256 dimension for izod impact test.

Standard	Dimension (mm)		
	Length	Width	Thickness
ASTM D256	64	12.7	6.4

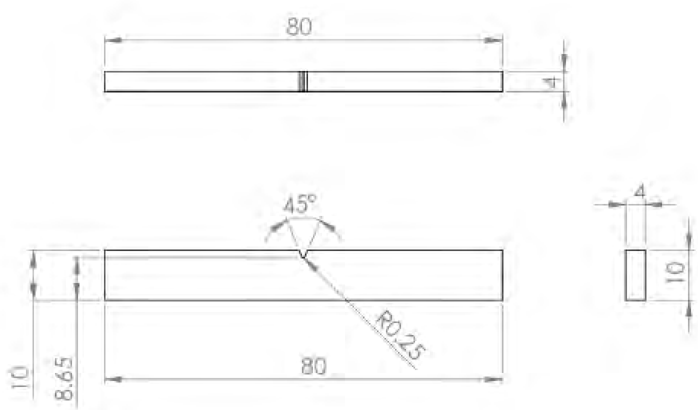


Figure 3.9: Schematic diagram of the specimen for izod impact test ISO 180.

Table 3.9: ISO 180 dimension for izod impact test.

Standard	Dimension (mm)		
	Length	Width	Thickness
ISO 180	80	10	4

3.3.3 Flexural Testing Specimen

They are two standard of specimen size for flexural testing of plastic material which are ASTM D790 and ISO 178 standard. For the ASTM D790 standard the specimen size is 127mm by 12.7mm by 130mm which this size is suitable for thermoplastic and moulding material as shown in figure 3.10. For the ISO standard, which identical to British (BS) and ISO standard, the specimen size that stated in the standard is 80mm by 10mm by 4mm as shown in figure 3.11.

Figure 3.10: Schematic diagram of the specimen for flexural test ASTM D790.

Table 3.10: ASTM D790 dimension for flexural test.

Standard	Dimension (mm)		
	Length	Width	Thickness
ASTM D790	127	12.7	3.2

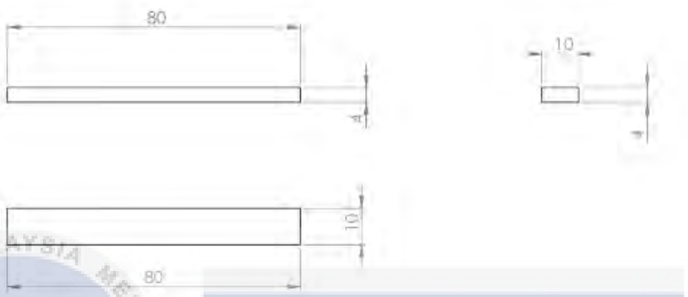


Figure 3.11: Schematic diagram of the specimen for flexural test ISO 178.

Table 3.11: ISO 178 dimension for flexural test.

STANDARD	Dimension (mm)		
	Length	Width	Thickness
ISO 178	80	10	4

3.4 Standard for Testing

Standards are the documents which define requirement for products and how they are to be tested. In material testing standard is used as guideline on procedure to conduct material testing and its requirement to be follow to get the testing result. In plastic material testing, there are several standard that considered to be use which are

ASTM, British, European and ISO standard of testing. Generally, ISO standard are identical to other standard such as British (BS) and European (CEN). This identical standard system may involve the type of specimen and size, condition of the specimen and testing, method of material testing and also testing machine specification which gives the benefits the user to refer a standard document that recognized. Usually, this identical standard is identified by dual or triple numbered system such as BS EN ISO XXX., BS EN XXX, and BS ISO XXX.

ASTM standard is widely use as standard for material testing especially in industries and also for the research purposes. This standard recognized globally as a leader in development and delivery of voluntary consensus standards and develop according to the World Trade Organization Principle. In other words, this is the world standard for material testing that used to find the vital information on such as material properties that need to be prove as reliable material. In industries, this standard give benefits to the manufacturer to make testing to ensure their product at top notch and they can offer high quality product to their customer. The advantages of ASTM standards are concerned in this research and has been choose as testing standard for the testing on the material that is used to produce 3D model with the aim to give the best quality product to the customer which is reliable.

3.5 Testing

There are three type of testing which involves in this research which are tensile, flexural and impact testing. All this testing is conducted to investigate the material properties ABS and PLA material used in development geospatial product. ASTM standard is used as testing guideline to conduct the testing. The most important is the availability and capability of the machine that will used for the research testing need to fulfil the requirement of the standard.

All the testing will be running fifteen specimen of each material for each testing which three times higher than standard minimum number of testing that stated in the standard. This is due to the repeatability factor that important to determine the closeness of the measurement agree with each other. In addition, the measurement of uncertainty especially standard deviation calculation for the measurement is important to observe the distribution of the measurement around the mean value. The lower the standard deviation gives the lower uncertainty, thus more the confidence the testing which tends to have higher the reliability of the result.

3.5.1 Tensile Test

Tensile test is conducted in order to determine the force require to break specimen and extent to which the specimen elongates to breaking point. This type of testing usually used for quality purpose of material that to determine the material capability to withstand load or forces in tensional condition. There are varieties of tensile test that are used for mechanical testing. Most common tensile tests are tension, tensile adhesion, tensile shear, tensile grab, tensile pulling, tensile fatigue and tensile creep. These type of testing use the same principle which testing the material until it reach failure. The only the different are specimen size or shape and gripping position used.

By doing tensile test, material properties such as tensile strength, tensile strain, yield point and modulus of elasticity can be determined. Tensile stress is the tensile force per unit area of the original cross section within the gauge length carried by the specimen at any given moment. Tensile strain can be define as the increase in length per unit of original length of the gauge. Besides that, tensile test can also determine the relationship of tensile stress and strain of the material. Usually the tensile test will produce Stress-Strain curve diagram for the specimen tested for the purpose to measure modulus elasticity of material.

For this research, Universal Testing Machine is used for the testing the tensile properties of the material. This machine is manufactured by SHIMADZU modelled AG-10KNX as shown in figure 3.12. It applicable to delivering up to 10 kN for the material testing and reliable for ASTM D638.

Figure 3.12: SHIMADZU Universal Testing Machine.

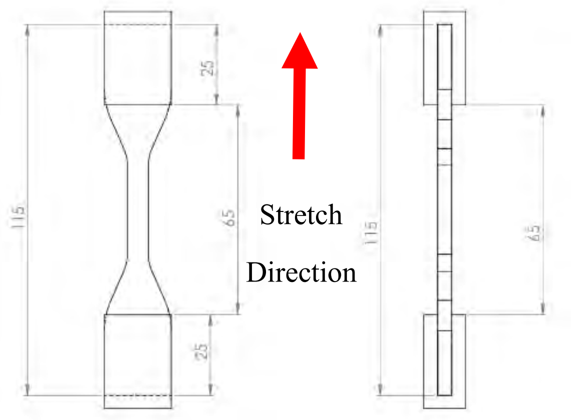


Figure 3.13: Schematic of the tensile test.

This testing will be conducted according to ASTM D638 standard as testing guideline. ASTM D638 is one of the most common plastic strength specifications and covers the tensile properties of unreinforced and reinforced plastics. The concept of this testing is by pulling on testing material in order to determine the behaviour of the material react to forces being applied in tension. In other words, this standard is used to determine the plastic material behaviour under tensional loading condition. The specimen size for the testing which is called "dumbbell" is prepared according to the standard as shown in figure 3.5. Then it followed by the set up the specimen on the machine for the testing. To set up the specimen on the machine, the specimen need to be carefully grip to avoid damages at each end to be pulled apart for the testing as shown in figure 3.13. In many cases, the grips (jaws) that hold specimen which exerting clamping force will cause damage to the specimen especially break at or near the jaws. According to the standard, the required gauge length for the testing specimen in this research is 65mm at the centre of the specimen which gives the distance from the end of the specimen to be clamped is 25mm. The testing need to be conducted within the standard temperature of the which the conditioning required temperature 23 degrees Celsius with 50 relative humidity.

Before testing begins, the universal testing machine need to be set up according to the standard parameter which are length and width of the middle section of the specimen and speed of testing. The length and width of the middle section of the specimen are 6mm and 4 mm respectively and the speed of the testing need to be set up for the machine to be running at 5mm/min of testing speed. After all the parameter has been configured and the specimen is clamped at jaw the testing can be running until the specimen break or fracture. The experiment of tensile test using UTM testing machine will automatically generate Stress-Strain diagram of the testing. The raw data such as applied force, time and elongation of the testing specimen is recorded by the testing machine. By using this raw data, the tensile stress and modulus elasticity can be calculated. The calculation of tensile stress will involves dividing the maximum tensile force with throat area geometry of the specimen according to the calculation below:

$$\sigma_T = \frac{F_t}{bh} \tag{1}$$

Where;

σ_T=Tensile Stress (MPa)

F_t= Tensile Force (N)

b=Throat width of specimen (mm)

h=Thickness of specimen (mm)

Meanwhile, the calculation of modulus elasticity can be done by dividing the changes of maximum force with the changes of strain for the straight curve.

$$E = \frac{\Delta\sigma_T}{\Delta\varepsilon} \tag{2}$$

Where;

E=Modulus Elasticity (MPa)

σ_T=Tensile Stress (MPa)

ε=Strain (mm/mm)

3.5.2 Impact Test

Impact testing is a mechanical testing that used to study the ability of material to resist impact loading by striking the tested material at high-relative speed. There are two type of impact testing method which are pendulum and drop method. The pendulum method of impact testing involves striking specimen using accelerated swinging pendulum. There are two type of pendulum method of impact testing that commonly used for plastic testing which are Charpy and izod pendulum impact test. In charpy impact test, the specimen is supported as horizontal beam and is broken at the line of impact between the supports by a single swing of a pendulum. The izod impact testing is similarly with charpy impact testing and the only different is the position of the specimen which is vertically against the striking pendulum. Another method impact testing is drop method that consist of two type which are falling dart and falling testing specimen method. The falling dart method involving striking the specimen with falling impact dart by gravity to determine its failure against falling impact, while the falling specimen method involves dropping the specimen at certain height to determine the material behaviour when the impact is applied to the material.

By doing impact testing, the impact strength of a material can be determine. Impact strength is the material ability to sustain mechanical energy due to deformation and fracture under loading impact. It is also related to evaluate toughness of material which is the ability of material to absorb energy. This research will focus on testing the specimen by striking pendulum. Theoretically, the material which has high toughness has the ability to absorb higher amount impact energy. Meanwhile, the low toughness material tends to absorb lower energy prior to fracture.

In this research, impact testing of pendulum method is used to determine the impact energy and evaluate toughness of material. Izod impact test is choose as impact testing method in this research. This is due to it is the common method that is used study the plastic polymer properties against the failure due to impact loading.

The machine used in this testing is electronic impact testing machine manufactured by VICTOR as shown in figure 3.14. This machine capable of conducting charpy impact testing (ISO 179) and also izod impact testing (ISO 180). It can run ASTM 256 standard due to the standard mostly similar to ISO 180 and follow the standard requirement such as pendulum shape and pendulum energy. Even this machine can perform charpy impact, but the pendulum for the testing is not available and only pendulum for izod is available. The pendulum that available can delivered energy within range 1.0 joule to 22 joules. The absorb energy of the testing material can be show on the display panel for the purpose of data recording.

Figure 3.14: Electronic impact testing machine.

In this research, the experiment will be conducted according to ASTM 256 standards. This standard involves testing on plastic material to determine resistance of plastic to standardize pendulum type hammers, mounted in standardize machine which breaking standard specimen with one pendulum swing. This standard require specimen to be prepared according standard as shown in figure 3.8. There are several type of test method which are stated in the standard. The test method A is selected for this testing which this method require the specimen is held as vertical cantilever beam and broken by single swing of pendulum. For the placement of the specimen on testing jig, the specimen line of initial contact is at fixed distance from the specimen clamp and from centre line of the notch. The notch of the specimen will be facing striker pendulum as shown in figure 3.15.

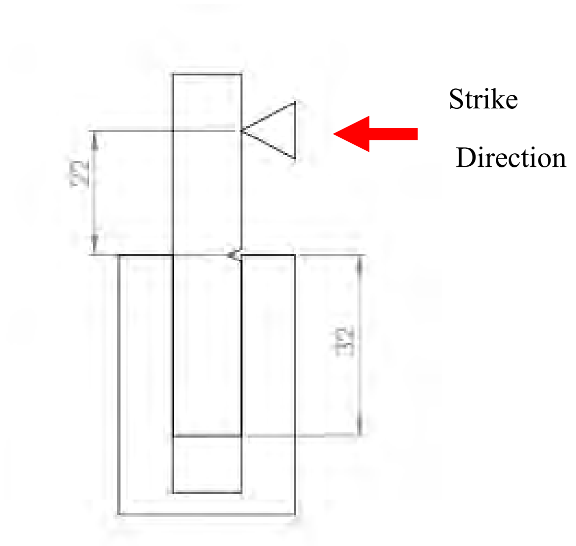


Figure 3.15: Schematic of the izod impact test.

The striker of the pendulum should be hardened steel type with cylindrical surface and capable to deliver 2.7 joule. If the material requires more energy to break, the additional load for the pendulum can be added. The test began by placing the specimen at testing jig and the pendulum is pulled until reach 120 degree which was measured by taking the location of specimen at zero location. The testing need to be conducted within the standard temperature and conditioning which at 23 degree Celsius and 50 relative humidity respectively. The pendulum will be released from its position when all parameter of the testing has been set up and the energy of impact is recorded. The impact strength of the material is calculated by dividing the material energy of impact with cross sectional area of specimen as shown as formula below.

$$Gc = \frac{Uc}{Ac} \tag{3}$$

Where;

Gc= Impact Strength of Material (J/m^2).

Uc=Energy of Impact (J).

Ac=Cross-Sectional Area of the Specimen (m^2).

3.5.3 Flexural Test

Flexural test is a mechanical test which conducted to determine the flexural properties of testing material. There are three type of flexural testing for material which are three point, four point and simple cantilever loading, but for plastic flexural testing the common type of flexural testing used is three-point flexural testing method. This type of flexural testing is conducted to determine the flexural effect on material properties under three-point loading condition. This type of method is applicable for plastic testing due to the highest or maximum bend stress occurs under the loading anvil and also suitable for homogenous material such as plastic material in three point flexural tests.

By doing flexural test, material properties such as flexural strength, flexural strain and modulus elasticity in bending can be determine. Flexural strength is the amount of stress or force of material can withstand such resist any bending failure. In other words, is the amount of stress for the material before it yields in in flexural loading condition. Flexural strain is strain produce due to flexural stress which result in increment of material from its original length. Commonly this testing can determine the relationship between flexural stress and strain of material which can be compute by generating Stress-Strain diagram. This diagram is used to determine modulus elasticity of bending or flexural modulus. Flexural modulus is the ratio of stress to strain flexural deformation which require to determine the slope of a stress-strain curve.

In this research, the experiment will be conducted according to ASTM D790 standards. It involves testing on plastic material on three-point loading condition in order to determine the flexural properties of the material. For this research, UTM manufactured by INSTRON as shown in figure 3.16 is used for the testing the flexural properties of the material. It applicable to delivering up to 250 kN for the testing with maximum speed 500mm/min. The most important is the machine must be following the requirement for the testing such as properly calibrated.

Figure 3.16: INSTRON 5585.

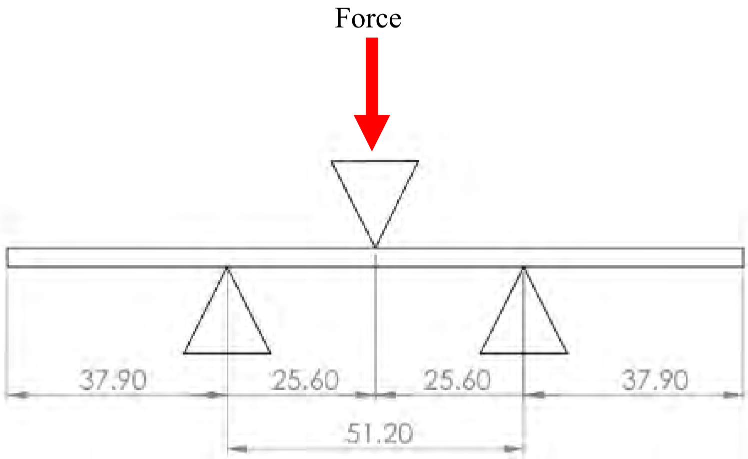


Figure 3.17: Schematic of the flexural test.

The procedure of this testing require specimen preparation according ASTM D790 standard. For the thermoplastic extrusion material, the specimen size is 127mm by 12.7mm by 3.2mm as shown in figure 3.10. Then, it followed by set up the support span for the material placement on the machine. According to the standard, the support span-to-depth of the beam ratio is 16:1. By referring the depth of the specimen the standard support span that need to be set up for the placement of the material is 51.2mm as shown in figure 3.17. The testing procedure preferred strain rate of 0.01mm/min based on ASTM D790. Eventually, the rate of crosshead motion need to be determine according to the formula as shown below:

$$R = \frac{ZL^2}{6d} \tag{4}$$

Where:

R= Rate of Crosshead Motion, mm/min

L=Length of Support Span, mm

D=Depth of Beam, mm

Z=Rate of Straining Outer Fibre, mm/mm/min (*Z* shall be 0.01)

According to the formula, the rate of the crosshead motion is 1.367mm/min which it need to be set up on the UTM for the testing. The standard required the testing to be conducted at least five times. The testing will be running fifteen times of trial for both materials to fulfil the research requirement. When the testing of the specimen running, the test will terminate when the maximum strain in the outer surface of test specimen has reach 5 % (0.05mm) strain limit. The deflection at which this strain will occur will be calculated using the mid-span deflection, D using the formula as shown below:

$$D = \frac{rL^2}{6d} \tag{5}$$

Where;

D=Mid-Span Deflection, mm

r=strain, mm/mm (*D* shall be 0.05mm/mm)

L = support span, mm

d = depth of beam, mm

The experiment of flexural test using INSTRON 5585 testing machine will automatically generate Stress-Strain diagram of the testing. The raw data such as applied force, time and elongation of the testing specimen is recorded by the testing machine. By using this raw data, the flexural stress and modulus elasticity in bending can be calculated. The calculation of flexural stress involves the calculation of stress according to the formula as shown below:

$$\sigma_f = \frac{3PL}{2bd^2}$$

(6)

Where

σ_f= Flexural Stress, MPa

P= Force, N

L=Length of Support Span, mm

b=Width of Beam, mm

d=Depth of Beam, mm

For the calculation of modulus elasticity which also known as flexural modulus in bending, it requires to determine the slope of the tangent curve, m in the initial straight-line portion of the load deflection curve. The calculation of modulus elasticity in bending will involves the calculation of stress according to the formula as shown below:

$$E_f = \frac{L^3 m}{4bd^3}$$

(7)

Where

E_f= Modulus Elasticity in Bending, MPa

m= Slope of The Tangent Curve

L=Length of Support Span, mm

b= Width of Beam, mm

d=Depth of Beam, mm

3.6 Sample of Data

Data of the testing is collected and record for the analysis and discussion of the testing. An excellent research or project should have proper presentation of data for the analysis. Commonly, every experiment or testing data will be tabulated for easier the experimenter to make analysis and finding of the experiment or testing that has been conducted. Most of the testing data in this research that generated by the machine will be tabulated for the analysis that will involve generation of statistical graph to find the relationship between the variable and also to conclude the finding of the testing,

Every testing or experiment have the variable that has been choose to be tested which is basically align with the aim of the testing or experiment. It needs to be determine before conducting the testing or experiment to avoid mistakes in data collection that will affect the testing or experiment result, thus the objectives of the testing and experiment cannot be achieve. There are two type of variable which are independent and dependent variable for every experiment and testing. Independent variable is the variable to be tested and control in scientific experiment or testing and dependent variable is the variable that tested and measured. Theoretically, changes in independent variable of experiment or testing directly will changes the value or behaviour of the dependent variable. This means that the dependent variable is the output of the testing or experiment which depend on the input which is independent variable.

3.6.1 Tensile Test Result Data

In tensile testing, the independent and dependent variable of the testing are strain and stress respectively. The tensile stress of the material depends on the amount of strain that used at the material. The raw data of the testing that generated by the UTM machine are applied force and elongation is record and tabulated. From the raw data, the tensile stress and the strain of the testing can be calculated, thus the stress-strain graph can be generated to analyse the relationship between the tensile stress and strain of the tested material. The sample of testing data that will be recorded in a table as shown in appendix A.

3.6.2 Flexural Test Result Data

For the flexural test, the independent variable that control in the testing is the strain and the dependent variable that will varied depends on the independent variable is the flexural stress. The changes of strain will cause the changes of the flexural stress of the material. The data that generated from the UTM machine such as applied force and elongation will be recorded and tabulated as shown in table in appendix A. Flexural strength and modulus elasticity due to flexural effect will be calculated by using the raw data that will be collected. The analysis of the result will be made to find the relationship and correlation between the testing variable.

3.6.3 Impact Test Result Data

The study of impact strength of material usually related to the factor of affecting the impact strength of material. Commonly, the study is about the effect of rate of loading, temperature, notch sensitivity, fillers, orientation, processing condition and molecular weight and degree of crystallinity on impact strength of a material. In this research, the izod impact test is used to study the effect of different type of material used that effect their ability to resist impact loading. In other words, to determine and compare the toughness of material that used in this research to produce 3D product. The raw data that can be collected from izod impact test is the absorb energy of impact of the material at rupture. By using the raw data, the impact strength of the material can be calculated and compared to determine which material that has high impact strength against the failure. The data for the testing will be tabulated in a table as shown on table in appendix A.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

This chapter consist of the result and discussion regarding the finding of the research. In this chapter, the printed specimen condition before and after testing showed for the observation purposes to compare between testing material. All the data collected from the material testing were tabulated and illustrated in the figure. The obtain result of the testing is analysed and discussed in this chapter. For the result and discussion are based on tensile, flexural and impact test of the ABS and PLA material which had been conducted in this research.

4.2 Tensile Testing

The tensile test had been conducted fifteen times on two type of material which are ABS and PLA material. The tensile specimen was prepared using 3D print method according to type IV ASTM D638 standard as shown in figure 4.1 for ABS and figure 4.2 for PLA. From the observation, the specimen can be identified by the surface roughness of the specimen where PLA has fine surface compare to ABS specimen. The tensile test is conducted to observe the material behaviour on tensional loading. By doing tensile test, material properties such as tensile strength, yield strength and stress failure of the ABS and PLA material can be determine. Having this measurement, stiffness of material can also determine which is known as modulus of elasticity of the material. Table 4.1 shows the tensile test results for the ABS and PLA material. The specimen condition after testing after testing is shown in figure 4.3 and figure 4.4. (Refer appendix B)

Figure 4.1: Tensile test specimen for ABS material.

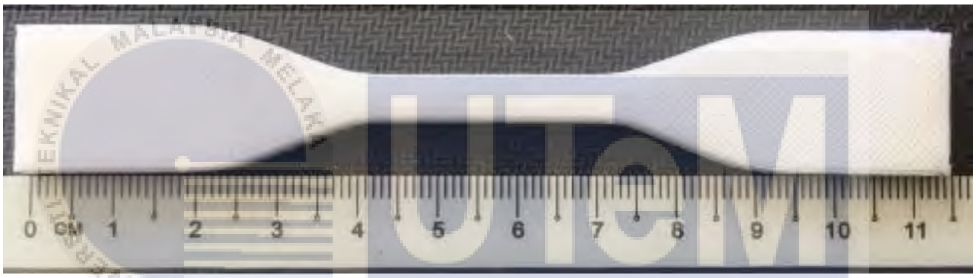


Figure 4.2: Tensile test specimen for PLA material.

Figure 4.3: ABS specimen after tensile test.

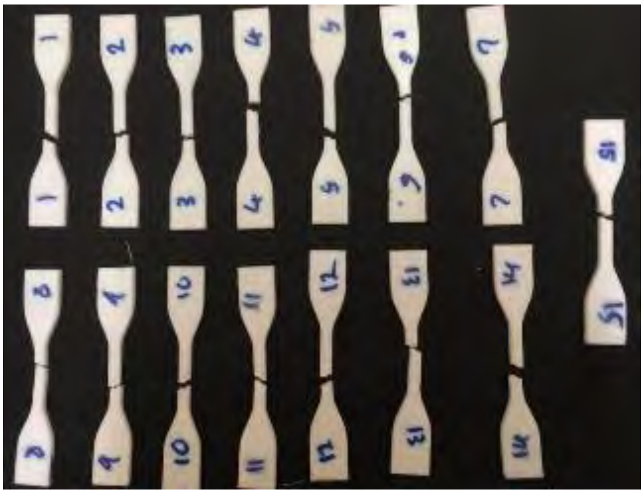


Figure 4.4: PLA specimen after tensile test.

Table 4.1: Data and result for tensile test.

Material	No. Speci-men	Max. Force (N)	Tensile Strength (MPA)	Tensile Strain (mm/mm)	Modulus Elasticity (MPa)	Yield Stress (MPa)	Yield Strain (mm/mm)	Failure Stress (MPa)	Failure Strain (mm/mm)
ABS	1	868.67	36.19	0.08	782.37	30.28	0.06	35.49	0.08
	2	820.52	34.19	0.08	738.37	30.00	0.05	31.92	0.08
	3	870.34	36.26	0.09	816.56	31.00	0.06	34.03	0.09
	4	856.91	35.70	0.08	737.29	33.50	0.06	33.11	0.08
	5	831.11	34.63	0.07	802.99	31.02	0.06	33.13	0.07
	6	847.98	35.33	0.08	785.60	30.76	0.06	33.23	0.08
	7	848.77	35.37	0.07	720.70	34.24	0.06	33.32	0.07
	8	848.77	35.37	0.07	720.70	33.60	0.06	33.32	0.07
	9	815.42	33.98	0.07	758.90	31.87	0.06	32.21	0.07
	10	857.79	35.74	0.08	808.85	32.00	0.06	34.01	0.08
	11	817.97	34.08	0.08	770.68	31.24	0.06	32.09	0.08
	12	806.79	33.62	0.07	777.00	31.50	0.06	31.14	0.07
	13	804.83	33.53	0.07	712.39	31.32	0.05	31.61	0.07
	14	825.82	34.41	0.08	766.48	32.17	0.06	30.94	0.08
	15	817.19	34.05	0.07	790.85	31.02	0.06	33.06	0.07
	Average	835.93	34.83	0.08	765.98	31.70	0.06	32.84	0.08
	Std. Dev	22.24	0.93	0.006	33.58	1.23	0.004	1.21	0.006
	R-squared	0.3294	0.3192		-	0.1166		0.09420	

PLA	1	922.22	38.43	0.07	862.88	35.00	0.05	36.79	0.08
	2	904.57	37.69	0.08	869.60	33.00	0.05	35.91	0.10
	3	858.77	35.78	0.08	841.61	32.47	0.05	35.08	0.10
	4	902.7	37.61	0.07	881.68	34.13	0.05	37.19	0.08
	5	905.06	37.71	0.08	866.7	34.12	0.05	36.46	0.08
	6	876.03	36.50	0.07	880.96	33.00	0.06	35.39	0.09
	7	873.77	36.41	0.07	877.8	32.88	0.05	35.09	0.09
	8	914.77	38.12	0.09	868.2	34.00	0.05	37.11	0.11
	9	896.03	37.33	0.08	709.24	32.51	0.06	35.59	0.10
	10	853.87	35.58	0.07	804.75	33.17	0.05	35.15	0.08
	11	876.81	36.53	0.07	825.27	33.61	0.05	35.10	0.08
	12	880.64	36.69	0.09	869.81	33.10	0.05	34.67	0.10
	13	937.42	39.06	0.08	898.23	35.96	0.05	37.97	0.08
	14	939.58	39.15	0.08	899.9	35.12	0.06	37.07	0.09
	15	939.58	39.15	0.08	899.9	35.12	0.06	37.07	0.09
	Average	898.79	37.45	0.08	857.10	33.81	0.05	36.11	0.09
	Std. Dev	28.41	1.18	0.007	48.83	1.08	0.005	1.04	0.01
	R-squared	0.0926	0.0924		-	0.0052		0.0482	

4.2.1 Tensile Test Fundamental

Tensile test basically the measurement of strain and stress of material due to tensile loading. From the data finding, the properties of material which focusing on tensile loading effect on the material can be determine. Figure 4.5 shows the theory of stress-strain curve for tensile test. This curve shows the properties of the material that can be determine from the tensile test data. One of the important properties is the tensile strength of the material which refer to the maximum stress of a material will sustain with uniform elongation (uniform strain). This stress is address as amount of force that material can exert before failure occur. Uniform strain can be state as the extensibility of the material which is the maximum strain or elongation of the material can withstand before it fails or rupture.

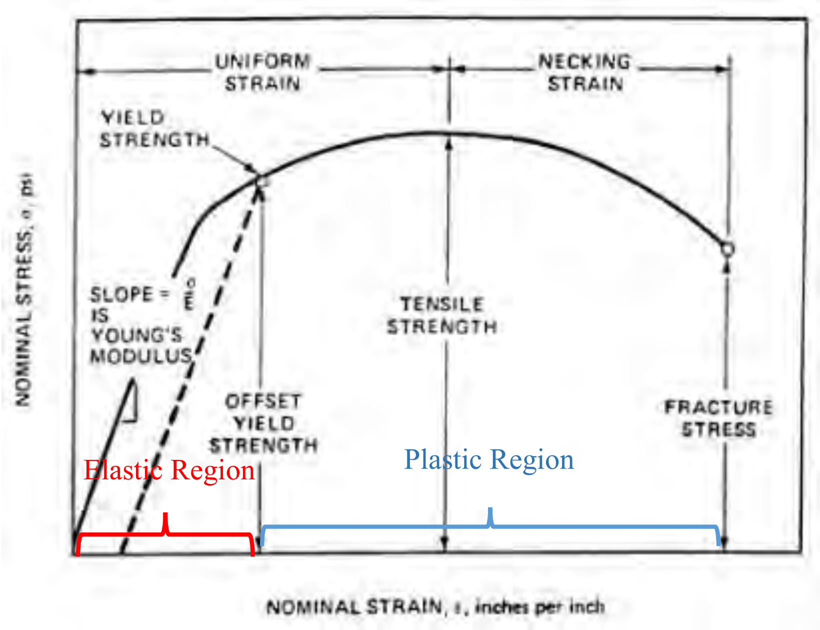


Figure 4.5: Theoretical stress strain diagram for tensile test.

Other than that, properties of material due to deformation from elastic to plastic deformation which is known as yield. Yield points is the transition point of material deformation from elastic to plastic. Elastic deformation is the deformation of material when force is applied to material and the material return to its original size and shape. This means that the deformation occurs only in elastic region without exceeding the yield strength limit. Differs to plastic deformation, it is condition when deformation of material is permanently when apply force that exert on the material is too great. This type of deformation occur due to the material deformation has passed the yield point which entering the plastic region deformation permanently until if fail or break. The yield point can be determine by 0.2% offsetting of strain which the material result in plastic usually when exceed 0.2% strain offset. The stress located at the yield point is called yield strength which refer as stress of material when the material archive or begin plastic deformation.

Stiffness of material is referred as young's modulus or modulus of elasticity. Modulus elasticity or young's modulus is the material resistance to elastic deformation or the stress that needed to produce a given amount of elastic strain. In other words, is the measurement of stress take to produce a given amount of strain. This modulus elasticity can be determine by calculating the slope of the curve in the elastic deformation region using equation(2). The high stiffness material should have high value of modulus elasticity. Which means that the steeper the slope, the stiffer the material thus the higher the modulus elasticity. Last but not least, Fracture point is the point at where the failure or break occur. At this point, the fracture stress which is the stress of material at break and necking strain which is the maximum strain at material break can be determine.

4.2.2 ABS Material Tensile Test Result

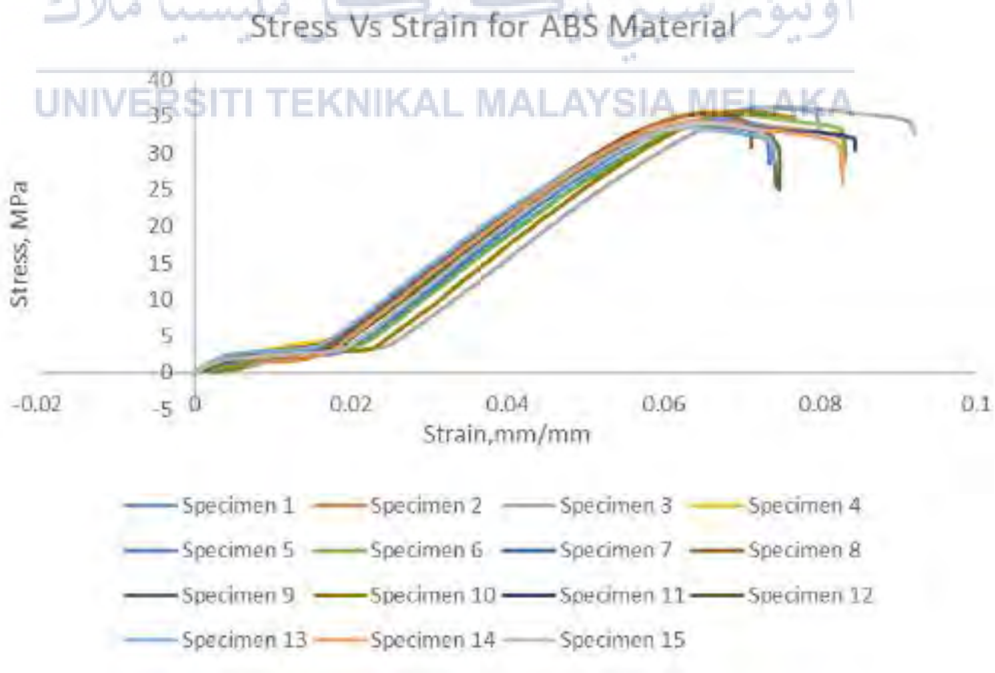


Figure 4.6: Tensile stress versus strain graph for fifteen specimen of ABS material.

Figure 4.6 shows tensile test stress-strain graph for ABS material. The graph consists of stress-strain curve for fifteen specimen of ABS material. The graph behaviour shows that, at the proportional limit of the strain stress curve it shows the sigmoidal strain curve graph pattern where the tensile stress begins to fall at a certain elongation ratio and beginning to rise again until it reaches fracture or failure. It begins by the stress on the material is increasing to yield at a single position which then produce necking due to non-uniform distribution of strain along the gage length. At the neck position, the material required greater stress to stretch and it neck propagates outward from the initial yield location. Then, at the end neck location material is stretched to a strain position which the stress will rise until it failure.

From the graph, it shows that the stress-strain curve for all specimen is concentrated nearly at the same region. From the data that have been collected, the tensile strength which is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking can be determine. The average tensile strength and maximum strain for ABS material is 34.83MPa and 0.08 mm/mm. For modulus elasticity or, the average value for ABS material is 7765.98MPa and the average stress at material fracture is 32.84MPa.

4.2.3 PLA Material Tensile Test Result

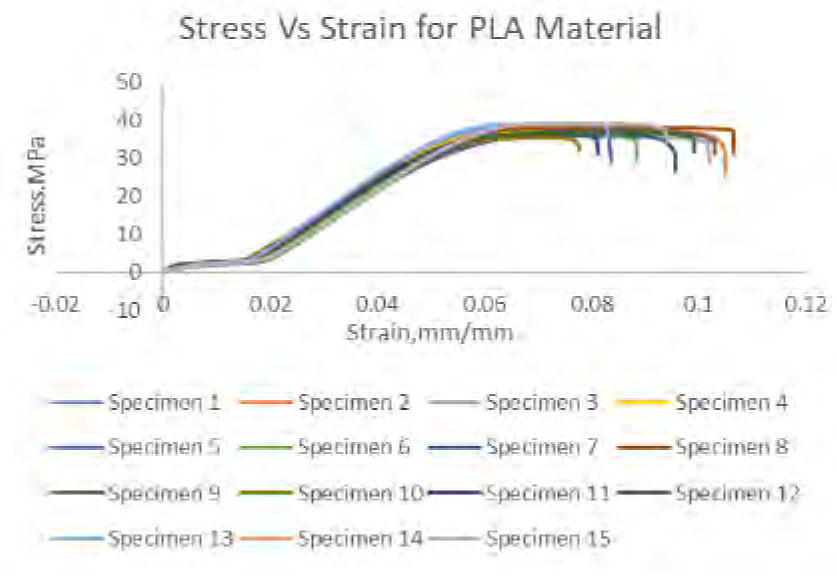


Figure 4.7: Tensile stress versus strain graph for fifteen specimen of PLA material.

Figure 4.7 shows tensile test stress-strain graph for PLA material. The graph consists of stress-strain curve for fifteen specimen of PLA material. The graph behaviour shows that, at the proportional limit of the stress strain curve it shows the sigmoidal strain curve graph pattern where the tensile stress begins to fall at a certain elongation ratio and beginning to rise again until it reaches fracture or failure. It begins by the stress on the material is increasing to yield at a single position which cause non-uniform distribution of strain along the gage length resulting necking. The material required greater stress at the neck position, for stretch and it neck propagates outward from the initial yield location. Then, at the end neck location material is stretched to a strain position which the stress will rise until it failure.

The graph shows all specimen stress-strain curve concentrated nearly at the same region. Maximum stress that a material can withstand while being stretched or pulled before failing or breaking which is known as tensile strength is determined from the data that have been collected. The average tensile strength and maximum strain for

PLA material is 37.45 MPa and 0.08mm/mm. For modulus elasticity or Young modulus, the average value for PLA material is 857.10MPa and the material is failure at average stress 36.11MPa.

4.2.4 Comparison ABS and PLA Material

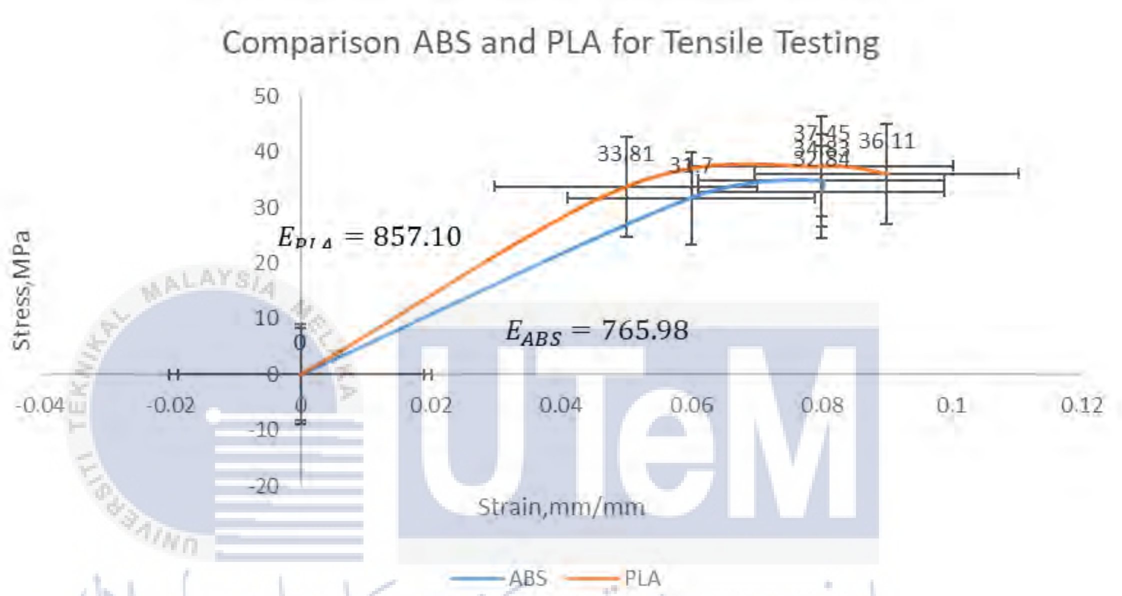


Figure 4.8: Stress versus strain diagram specimen of ABS and PLA material for tensile test.

Table 4.2: Data and result for tensile test of material properties

Material	Yield stress (MPa)	Yield Strain (mm /mm)	Max. Stress (MPA)	Max. Strain (mm/ mm)	Stress failure (MPa)	Strain failure (mm/ mm)	Modulus Elasticity (MPa)
ABS	31.02	0.06	34.83	0.08	32.84	0.08	765.98
PLA	33.81	0.05	37.45	0.08	36.11	0.09	857.10

By making comparison between the ABS and PLA material tensile test result, correlation and relationship between types of material with their properties can be identified. According to figure 4.8, the diagram shows the comparison on ABS and PLA material for the tensile test. From the diagram, it shows the average yield strength of PLA material is higher than ABS material yield strength with 33.81MPa and 31.02MPa respectively. According to figure 4.9, shows the pattern of yield strain and yield stress of each specimen for ABS and PLA material. The figures indicate the observation of degree of the yield strain and stress to the average value. The yield stress difference percentage of PLA and ABS material is 8.25% higher. This show that the PLA material require high stress compare to ABS material to begin or achieve plastic deformation.

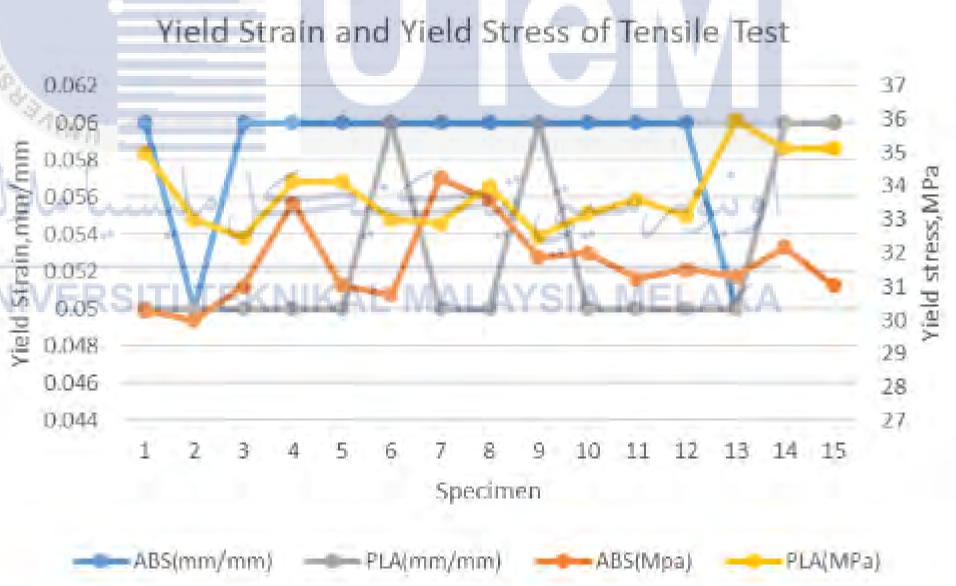


Figure 4.9: Specimen versus yield strain and yield stress of tensile test.

Other than that, the average of tensile strength of PLA material is higher than ABS material with 37.45MPa and 34.83MPa. The difference between average tensile strength of PLA material and ABS material is 7% higher. This can be observe by referring figure 4.10, where almost all the specimen of ABS and PLA tensile strength value is has high degree of closeness. The PLA material ability to sustain load without undue deformation or failure is higher compare to ABS material.

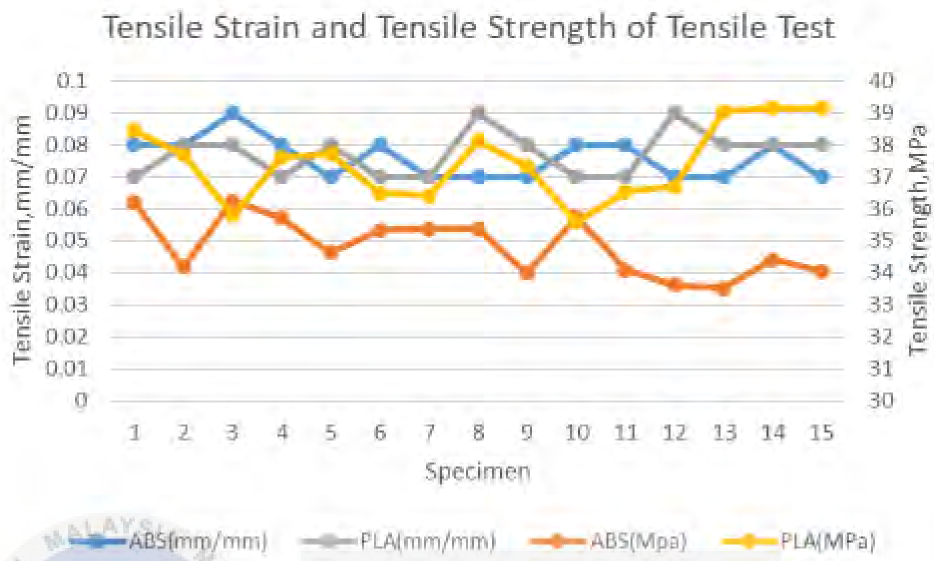


Figure 4.10: Specimen versus tensile strain and tensile strength of tensile test.

For modulus elasticity or young modulus, the average modulus elasticity of ABS and PLA material is 857.10 MPa and 765.98 MPa respectively. From the figure 4.8 and figure 4.11, the modulus of elasticity of PLA material is higher than ABS material by 13.45%. This show that the slope of curve in elastic deformation region of PLA material is steeper than ABS material slope. From this, the resistance of PLA material to elastic deformation under load higher than ABS material. The modulus elasticity is related to stiffness of material. This is due to the modulus of elasticity is directly proportional to stiffness of material. A stiff material has a high modulus of elasticity and deform slightly under elastic loads. In this testing, the result show that the stiffness of PLA material is greater than ABS material due to higher modulus of elasticity.

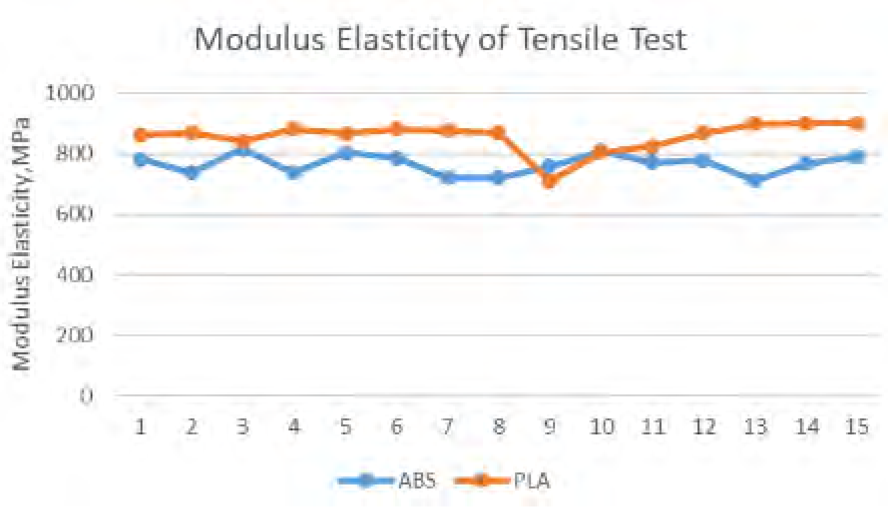


Figure 4.11: Modulus elasticity versus specimen of tensile test.

For the failure point, the PLA experience failure at high amount of stress and strain compare to ABS material. In average, the failure stress of PLA and ABS is 36.11MPa and 32.64MPa respectively. The value of fracture strength of PLA and ABS material is 9.05% difference. In the meantime, PLA fail at higher elongation point compares to ABS by referring to the strain failure of both materials. The stress of material fracture at necking strain of PLA material is higher than ABS material. Figure 4.12 shows the value of failure stress and failure strain each specimen for both materials. Most of the PLA specimen shows the higher value of failure stress and strain compares to ABS.

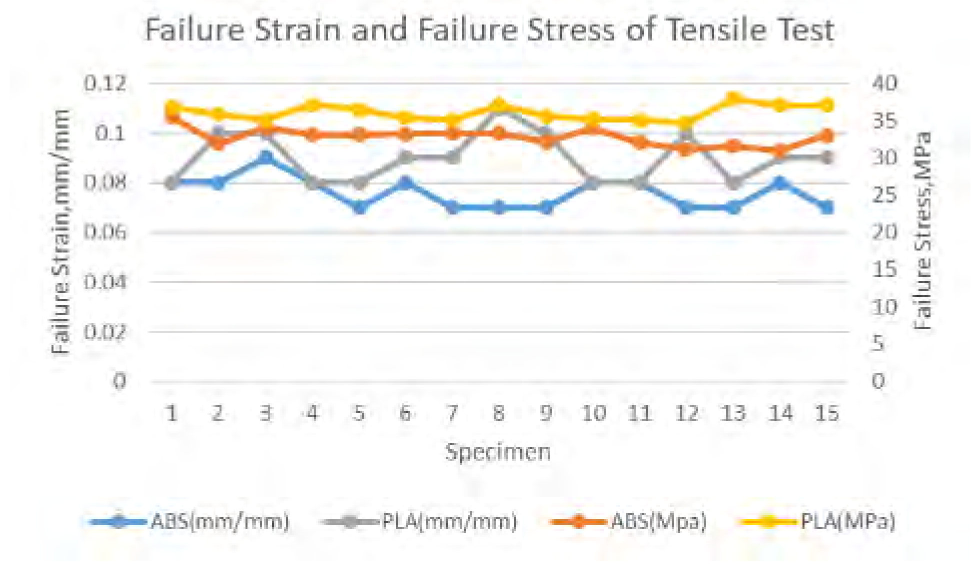


Figure 4.12: Specimen versus failure strain and failure stress of tensile test.

4.3 Impact Testing

Impact testing involving the study on material behaviour against the Impact loading which in this research focusing on dynamic loading effect on ABS and PLA material. Izod impact test had been conducted to study the impact toughness which also known as impact strength of material which familiar has been use on plastic material. Fifteen specimen of each material which involving v-notch specimen had been prepared and tested to compare the impact strength between ABS and PLA material. The impact specimen were fabricated according ASTM 256 specimen size by using 3D printing method as shown in figure 4.13 for ABS and figure 4.14 for PLA. Even though the specimen notch is printed, the additional milling process to make notch is applied to the specimen in order to have desired notching according to standard. Table 4.3 shows the impact test results for the ABS and PLA material and figure 4.15 and 4.16 shows the specimen condition after testing for ABS and PLA respectively.(Refer appendix C)

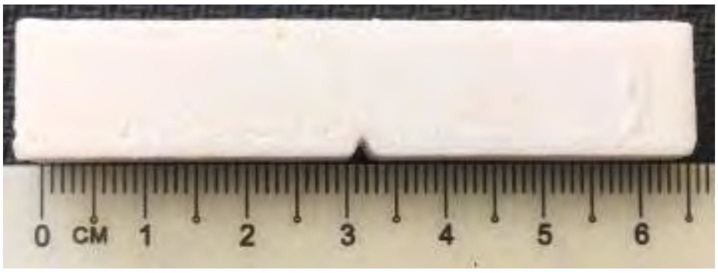


Figure 4.13: Impact test specimen for ABS material.

Figure 4.14: Impact test specimen for PLA material.

Figure 4.15: ABS specimen after impact test

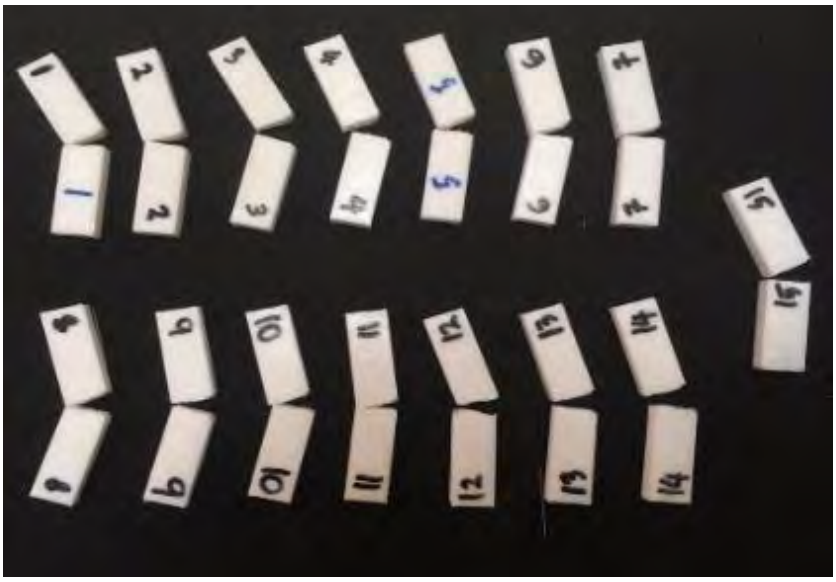


Figure 4.16: PLA specimen after impact test.

Table 4.3: Data and result for impact test.

Material	Specimen	Cross sectional area(m^2)	Type of Failure	Energy of Impact(J)	Impact Strength (kJ/m^2)
ABS	1	0.00006848	Hinge Break	0.78	11.39
	2	0.00006848	Hinge Break	0.84	12.27
	3	0.00006848	Complete Break	0.81	11.83
	4	0.00006848	Hinge Break	0.78	11.39
	5	0.00006848	Complete Break	0.81	11.83
	6	0.00006848	Hinge Break	0.76	11.10
	7	0.00006848	Hinge Break	0.83	12.12
	8	0.00006848	Hinge Break	0.87	12.70
	9	0.00006848	Complete Break	0.69	10.06
	10	0.00006848	Hinge Break	0.71	10.37
	11	0.00006848	Hinge Break	0.76	11.10
	12	0.00006848	Hinge Break	0.74	10.81
	13	0.00006848	Hinge Break	0.86	12.56
	14	0.00006848	Hinge Break	0.95	13.87
	15	0.00006848	Hinge Break	0.76	11.10
	Average	-	-	0.80	11.63
	Std.Dev	-	-	0.80	0.98
	R-Squared			0.997	
PLA	1	0.00006848	Complete Break	0.20	2.92
	2	0.00006848	Complete Break	0.28	4.09

	3	0.00006848	Complete Break	0.30	4.38
	4	0.00006848	Complete Break	0.20	2.92
	5	0.00006848	Complete Break	0.17	2.48
	6	0.00006848	Complete Break	0.23	3.36
	7	0.00006848	Complete Break	0.29	4.23
	8	0.00006848	Complete Break	0.19	2.77
	9	0.00006848	Complete Break	0.16	2.34
	10	0.00006848	Complete Break	0.20	2.92
	11	0.00006848	Complete Break	0.30	4.38
	12	0.00006848	Complete Break	0.21	3.07
	13	0.00006848	Complete Break	0.20	2.92
	14	0.00006848	Complete Break	0.27	3.94
	15	0.00006848	Complete Break	0.22	3.21
	Average	-	-	0.23	3.33
	Std.Dev	-	-	0.05	0.69
	R-Squared			0.991	

4.3.1 Impact Test Fundamental

In material behaviour studies, the method that use to evaluate material toughness that familiar had been use is impact test. The theory of material toughness is related to the ductility and brittleness of a material. Figure 4.17 shows the theory of ductility and brittleness which related to the material toughness.

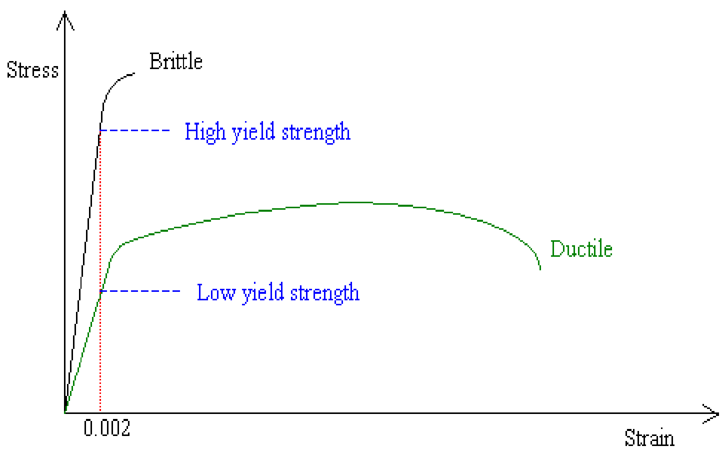


Figure 4.17: Theoretical diagram of ductile and brittle material.

From the theory, it can be explained by stress strain diagram to compare the differences between the ductile and brittle material. The measure of ductility and brittleness of material depends on the degree of plastic deformation which has occurred that leads to material fracture which also known as the work done material to fracture. Brittle material will have small region of plastic deformation compared to ductile material. The impact energy of material is the area under the stress-strain curve. Theoretically, the material that has greater impact energy which is ductile material will have greater area under the stress-strain curve compare to brittle material.

In impact test, there are four type of categories material fracture which ae complete break, hinge break, partial break and non-break fracture. This type of fracture should be recorded for the purpose of microstructure study of the material behaviour. The notch specimen is used due to enhance the sensitivity and reproducibility of the measurement which serves as a stress concentration zone.

By doing impact test on material, the absorb energy for the material break or fracture can be determine in order to find the impact strength of the material. The absorb energy cause material break can be determine by hitting the material with high velocity impact pendulum. Absorb energy is the amount of energy that absorb by the specimen during the entire impact test from start to end which the value is represent as the energy to maximum load when the specimen experience failure at the maximum load point. In other words, it is the total impact energy that involve energy from initial and after impact as describe in the formula as shown. At the end of the impact test, the toughness of the material can be determine or compare by referring the impact strength of the material.

Impact energy= Initial energy of impact- Energy after rupture

4.3.2 ABS Material Impact Test Result

Table 4.4: Impact test result for ABS material.

Material	Specimen	Cross sectional area(m2)	Type of Failure	Energy of Impact (Joule)	Impact Strength (kJ/m^2)
ABS	1	0.00006848	Hinge Break	0.78	11.39
	2	0.00006848	Hinge Break	0.84	12.27
	3	0.00006848	Complete Break	0.81	11.83
	4	0.00006848	Hinge Break	0.78	11.39
	5	0.00006848	Complete Break	0.81	11.83
	6	0.00006848	Hinge Break	0.76	11.10
	7	0.00006848	Hinge Break	0.83	12.12
	8	0.00006848	Hinge Break	0.87	12.70
	9	0.00006848	Complete Break	0.69	10.08
	10	0.00006848	Hinge Break	0.71	10.37
	11	0.00006848	Hinge Break	0.76	11.10
	12	0.00006848	Hinge Break	0.74	10.81
	13	0.00006848	Hinge Break	0.86	12.56
	14	0.00006848	Hinge Break	0.95	13.87
	15	0.00006848	Hinge Break	0.76	11.10
	Average	-	-	0.80	11.63
	Std.Dev	-	-	0.80	0.98
	R-Squared			0.997	

Table 4.4 shows the impact test result for the ABS material. The result shows there are two type of fracture that occur in the testing which are hinge break and complete break. Almost all the material experience hinge break type of failure when the impact pendulum striking the specimen. According to figure 4.18, 80% of the specimen which represent 12 pieces of specimen experience hinge break fracture while 20% of the specimen which is 3 pieces' experience complete break facture when the impact pendulum impacts the specimen. When the impact pendulum hitting the specimen to fracture, the absorb energy that cause the material fracture is recorded. The average absorb energy that recorded for ABS material is 0.80 joule with 0.8

standard deviation which the highest absorb energy was recorded is 0.95J and the lowest absorb energy that recorded was 0.65J. The calculated Impact strength of ABS material shows that the average impact strength for the material is 11.63 kj/m^2.

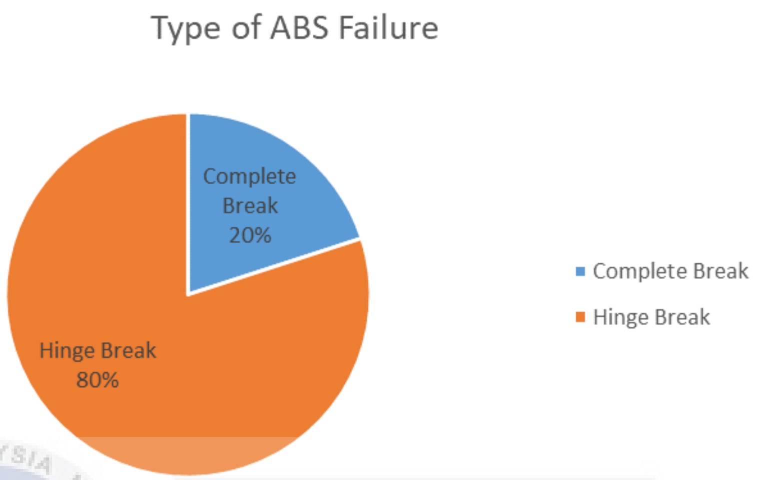


Figure 4.18: Type of fracture ABS material.

4.3.3 PLA Material Impact Test Result

Table 4.5: Impact test result for PLA material.

Material	Specimen	Cross sectional area(m2)	Type of Failure	Energy of Impact(J)	Impact Strength (kJ/m^2)
PLA	1	0.00006848	Complete Break	0.20	2.92
	2	0.00006848	Complete Break	0.28	4.09
	3	0.00006848	Complete Break	0.30	4.38
	4	0.00006848	Complete Break	0.20	2.92
	5	0.00006848	Complete Break	0.17	2.48
	6	0.00006848	Complete Break	0.23	3.36
	7	0.00006848	Complete Break	0.29	4.23
	8	0.00006848	Complete Break	0.19	2.77
	9	0.00006848	Complete Break	0.16	2.34
	10	0.00006848	Complete Break	0.20	2.92
	11	0.00006848	Complete Break	0.30	4.38
	12	0.00006848	Complete Break	0.21	3.07
	13	0.00006848	Complete Break	0.20	2.92

	14	0.00006848	Complete Break	0.27	3.94
	15	0.00006848	Complete Break	0.22	3.21
	Average	-	-	0.23	3.33
	Std.Dev	-	-	0.05	0.69
	R-Squared			0.991	

Table 4.5 shows the impact test result for PLA material. The result shows that the all the PLA specimen experience complete break fracture. As shown in figure 4.19, all the fifteen specimen fracture until the specimen break or separated into two parts. The average absorb energy that has been recorded for PLA material is 0.23J with 0.05 standard deviation. The range of absorb energy recorded is within 0.17J to 0.30J that cause the specimen to fracture. The average calculated impact strength for the PLA material is 3.33kJ/m^2

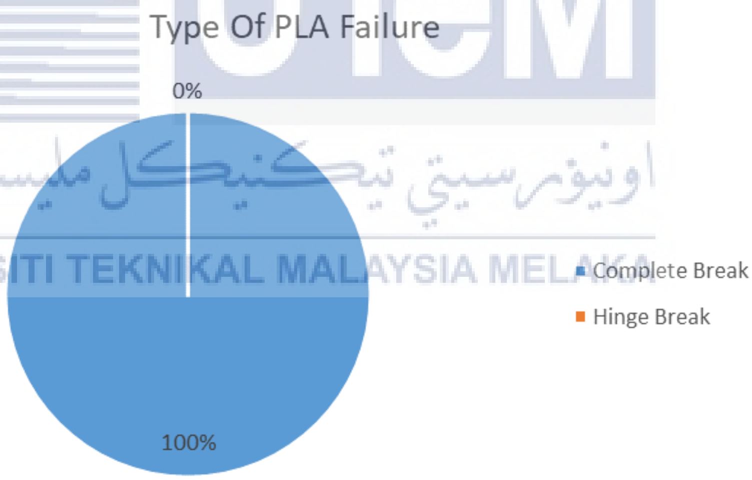


Figure 4.19: Type of fracture PLA material.

4.3.4 Comparison ABS and PLA Material Impact Test Result

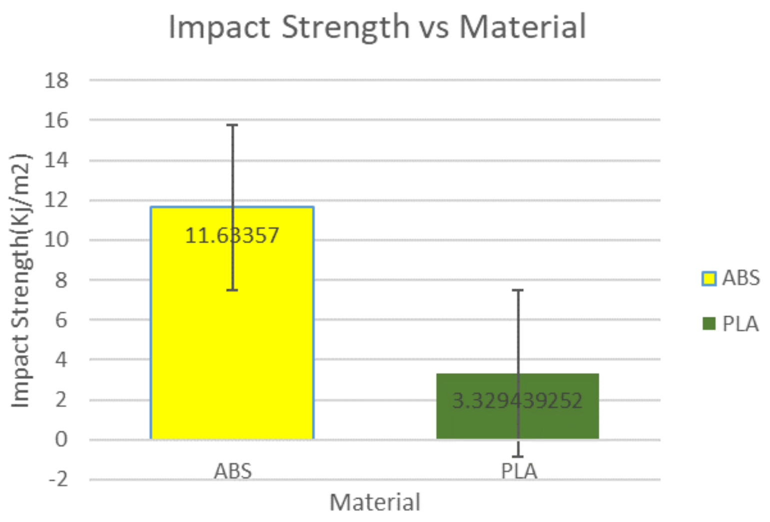


Figure 4.20: Comparison of impact test result between ABS and PLA material.

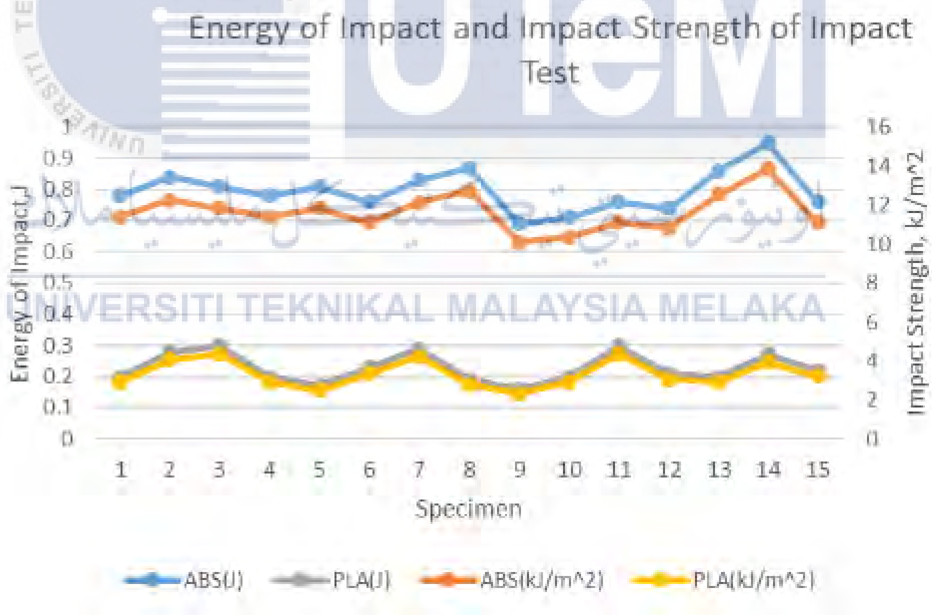


Figure 4.21: Specimen versus energy of impact and impact strength of impact test

By making comparison between the impact test result between ABS and PLA material, the correlation between both material impact test result can be found. According to figure 4.20, shows that the value of impact strength between ABS and PLA material. From the testing, the ABS material has higher value of impact strength with 11.63 kJ/m^2 compare to PLA material with value of 3.329 kJ/m^2. This show that the ABS can resist higher impact loading compared PLA material with 71.36% differences. By referring figure 4.21, all the ABS specimen shows the higher value of energy of impact and impact strength compare to PLA material. The ABS and PLA material categorize as polymer which classified as brittle material. From the theory of toughness as compared to the result, PLA material is brittle than the ABS material. This is because, the PLA material has lower degree of plastic deformation compare to ABS. The smaller region of plastic deformation after the PLA material yield affect the work done of the material to fracture. The PLA material has lower work done to fracture which also known as modulus of toughness compare to ABS material due to the PLA material has lower area under the stress-strain curve than ABS material. With this, the PLA material only require low absorb energy for the material to be fractured.

The other reason on why the PLA has lower impact strength compare to ABS material is due to inconsistency or poor formation of first build layer of printing. As shown in figure 4.22, the PLA material shows that the poor formation of first layer of build compare to ABS material. From the observation the PLA build filament which deposited as the first layer of build does not consistently deposited that cause the poor first layer of build. This will affect the next layer of build which it did not deposited perfectly with other build layer. The poor deposited build material will cause the formation of high intensity of air gaps and voids. The presents of air gaps and voids will affect the strength of material against impact. Other than that, the higher intensity of voids and air gap has poor filling degree of build material and cause air inclusion between the printed strand. The PLA material is suspected to have this kind of problem that leads it's to have very lower impact strength. This because the present of high intensity of the air gaps represent the printed parts responsible for weaker bonding between the build layer and printed filament which cause the specimen absorb low amount of energy that required for complete fracture. (Santhakumar, Maggirwar, & Golla, 2016). As shown in the figure 4.23, there are strand of filament that dissociated when the specimen fracture after testing. This show that the weak bonding between the build filament that cause by voids and air gaps present that effect the toughness of the material.

Figure 4.22: Comparison first layer of build between ABS and PLA material.

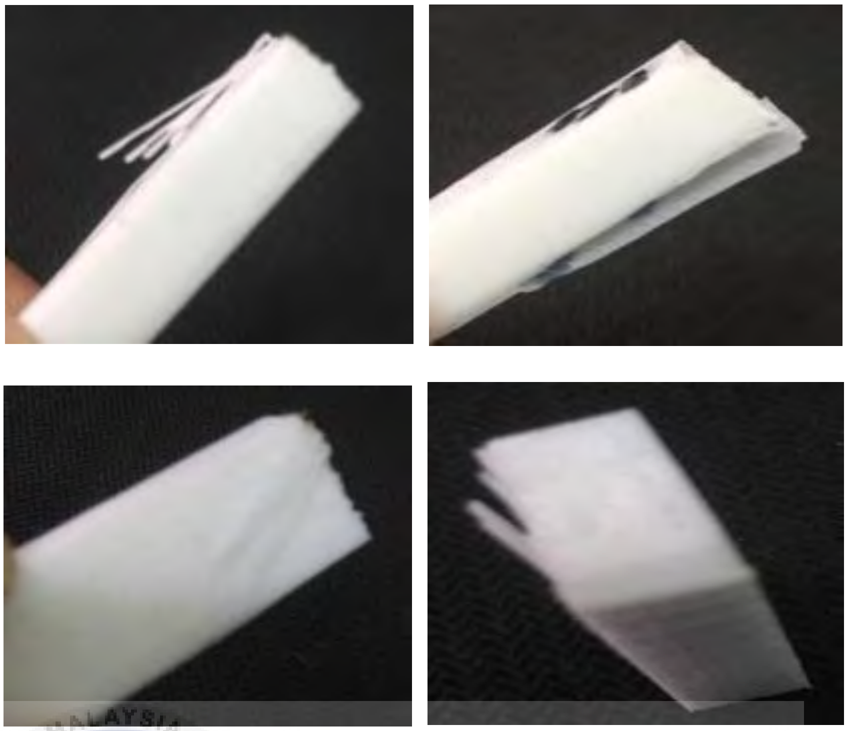


Figure 4.23: PLA material after impact test.

4.4 Flexural Testing

The flexural test had been conducted fifteen times on two type of material which are ABS and PLA material. For both material ABS and PLA, specimen is fabricated according specimen size of ASTM D790 standard as shown in figure 4.24 for ABS and figure 4.25 for PLA. The flexural test is conducted to observe the material behaviour on flexural loading. By doing flexural test, the flexural strength, flexural yield strength and the flexural stress at failure of the ABS and PLA material can be determine. Other than that, stiffness of material can also determine which is known as flexural modulus of the material by finding stress to strain ratio at elastic region, m and calculated using equation (7). Table 4.6 shows the flexural test results for the ABS and PLA material and figure 4.26 and 4.27 shows the specimen condition after testing for ABS and PLA respectively. (Refer appendix D)

Figure 4.24: Flexural test specimen for ABS material.

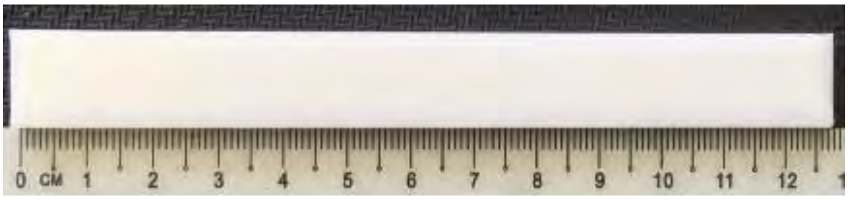


Figure 4.25: Flexural test specimen for PLA material.

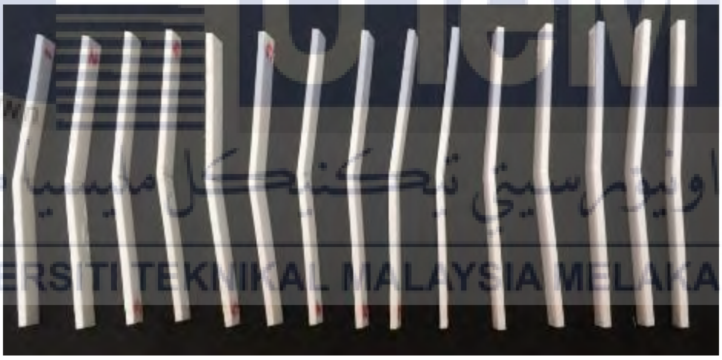


Figure 4.26: ABS specimen after flexural test.

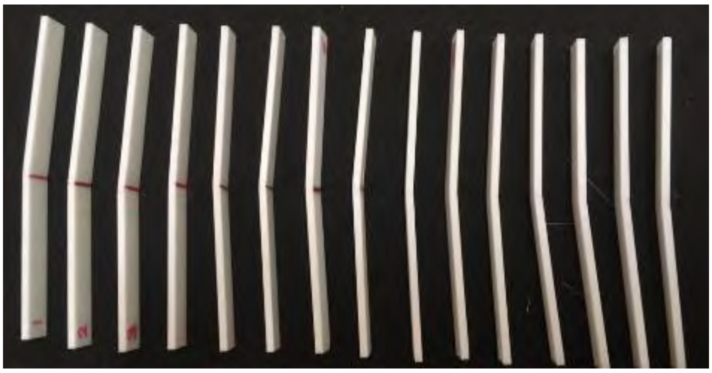


Figure 4.27: PLA specimen after flexural test.

Table 4.6: Data and result for flexural test.

Material	Specimen	Max Load (N)	Extension At Maximum (mm)	Flex-ural Modulus (MPa)	Yield Strength (MPa)	Yield Strain (mm/mm)	Flexural Strength (MPa)	Flexural Strain (mm/mm)	Stress Failure (MPa)	Strain Failure (mm/mm)
ABS	1.	90.23	5.44	1919.36	46.3	0.029	53.29	0.040	42.22	0.047
	2.	90.63	6.22	1897.27	45.81	0.031	53.52	0.046	20.67	0.051
	3.	91.81	6.40	1950.90	44.62	0.028	54.22	0.049	28.59	0.054
	4.	91.51	5.79	1945.73	44.78	0.028	54.04	0.042	26.72	0.058
	5.	86.68	5.88	1836.15	43.78	0.029	51.19	0.043	40.61	0.049
	6.	90.57	6.11	1846.05	45.37	0.029	53.49	0.045	40.95	0.058
	7.	90.63	5.59	1953.24	44.41	0.028	53.52	0.041	38.37	0.054
	8.	90.09	6.05	1924.73	44.04	0.028	53.20	0.044	34.65	0.049
	9.	90.50	5.97	1947.22	45.12	0.028	53.44	0.044	40.15	0.051
	10.	92.26	6.32	1940.99	46.34	0.030	54.48	0.046	38.56	0.055
	11.	89.59	5.82	1892.97	45.89	0.030	52.91	0.043	38.03	0.051
	12.	90.07	5.76	1980.10	45.57	0.028	53.19	0.042	42.56	0.050
	13.	86.87	5.49	1884.47	43.14	0.027	51.30	0.040	39.89	0.048
	14.	88.79	5.65	1894.01	45.31	0.029	52.44	0.041	32.43	0.046
	15.	89.70	5.83	1914.52	44.21	0.028	52.97	0.043	41.99	0.049
	Average	90.00	5.89	1915.18	44.98	0.029	53.15	0.043	36.43	0.051
	Std.Dev	1.57	0.29	40.45	0.95	0.001	0.93	0.0021	6.55	0.0037
	R-Squared	0.2916		-	0. 4912		0.2899		0.0567	
PLA	1.	112.02	4.569	2846.39	58.7	0.026	66.16	0.033	44.57	0.042
	2.	122.63	4.64	2972.34	64.5	0.027	72.42	0.034	47.89	0.039
	3.	117.03	4.57	2872.37	61.8	0.027	69.11	0.033	37.83	0.037
	4.	120.32	4.39	3165.12	64.2	0.026	71.05	0.032	59.13	0.035
	5.	119.67	4.53	2946.52	64.1	0.028	70.67	0.033	49.57	0.037
	6.	119.37	4.62	3023.32	62.3	0.026	70.49	0.034	39.70	0.040
	7.	110.90	5.40	2542.77	57.9	0.028	65.49	0.040	43.52	0.042
	8.	111.91	5.10	2659.62	57.5	0.027	66.09	0.037	24.05	0.041
	9.	117.17	4.44	2872.39	63.3	0.027	69.19	0.033	49.50	0.036
	10.	108.84	4.88	2547.12	47.5	0.031	64.27	0.036	44.53	0.042
	11.	115.41	4.40	2982.15	62.5	0.026	68.15	0.032	42.26	0.036
	12.	122.79	4.66	3097.61	65.4	0.027	72.51	0.034	45.95	0.040
	13.	112.77	5.03	2664.12	58.3	0.028	66.60	0.03685	42.75	0.042
	14.	114.30	4.19	2966.04	61.7	0.026	67.50	0.031	47.25	0.035
	15.	115.33	4.51	2768.28	61.7	0.027	68.11	0.033	36.84	0.036
	Average	116.03	4.66	2861.74	60.76	0.027	68.52	0.034	43.69	0.039
	Std.Dev	4.31	0.32	190.56	4.46	0.0013	2.54	0.0024	7.70	0.0028

	R-Squared	0.2331	-	0.5567	0.2392	0.1306

4.4.1 Flexural Test Fundamental

Flexural test is similarly to tensile test which involving the measurement of stress-strain. But, for flexural test it is focusing on the study of material behaviour under flexural loading. Flexure or bending occur when an axial loading is applied at the longitudinal plane of beam with constant cross section which is homogenous until it reaches the elastic limit of the material that resulting the compression and tension at the neutral axis of the beam as shown in figure 4.28. When an axial force is applied at any point on an object, then the surface of the object that contains the point of contact of force is under compressive stress. On the other hand, the opposite surface of the object experiences tensile stress. By doing flexural test, the flexural modulus, flexural yield, flexural strength and flexural stress at failure of the material can be determine.

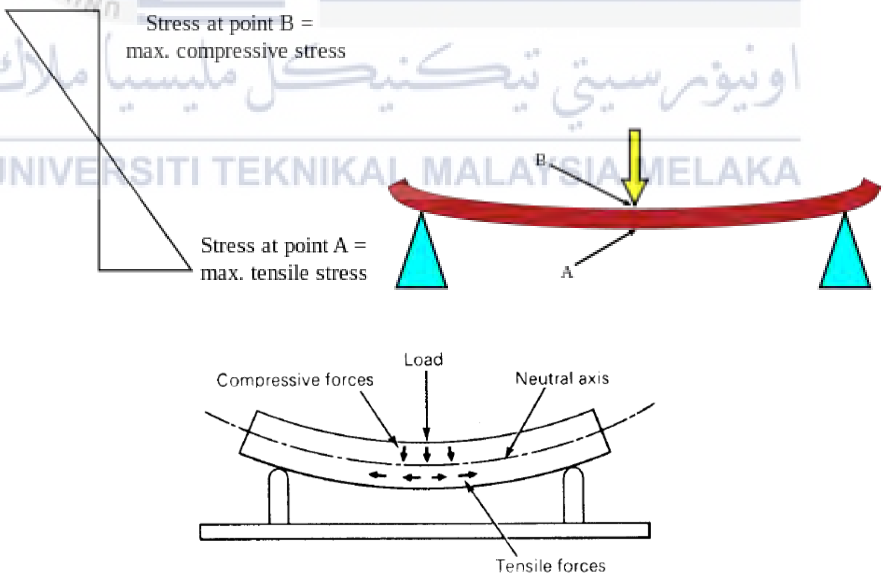


Figure 4.28: Theory of flexure or bending.

Flexural modulus which also known as bend modulus is representing the degree of material stiffness. It involves measurement of the material stiffness during the initial of the bending process that involves elastic region of the material. In flexural test, the flexural modulus is determine in order to study the ability of material resistance to bend when a force is applied perpendicular to the long edge of an object. The flexural modulus can be determined by finding the change in stress by the corresponding change in strain in the material elastic region which also can be describe as the ratio of stress to strain during a flexural elastic deformation. In other words, the slope at the initial straight line portion of the stress-strain curve represent change in stress by the corresponding change in strain which also known as modulus. The flexural modulus that use to determine the material stiffness in flexural loading condition is calculated using equation (7) by using the value of calculated slope.

For the material to plastic deformation, the applied load or stress need to be applied until the material reach its yield point. Flexural yield is the transition point of the material from elastic to plastic deformation region when the require amount of flexural stress is achieved. The yield point can be determine by 0.2% offsetting of strain due to the material result in plastic at 0.2% strain offset. The stress located at the yield point is called flexural yield strength which refer as stress of material when the material archive or begin plastic deformation due to flexural loading.

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its neutral axis. It can be defined as the maximum stress at the outermost fibre on either the compression or tension side of the specimen. The stresses induced due to the flexural load are a combination of compressive and tensile stresses. At the edge of the object on the inside of the bend (concave face) the stress will be at its maximum compressive stress value. At the outside of the bend (convex face) the stress will be at its maximum tensile value. Most materials fail under tensile stress before they fail under compressive stress, so the maximum tensile stress value that can be sustained before the beam or rod fails is its flexural strength. In flexural test, the flexural strength determines by the highest stress applied to specimen before its failure. The flexural stress can be calculated using equation (6).

Lastly, fracture point is the point at where the failure or break occur. At this point, the fracture stress which is the stress of material at break and necking strain which is the maximum strain which represent the maximum elongation of material can be determine.

4.4.2 ABS Material Flexural Test Result

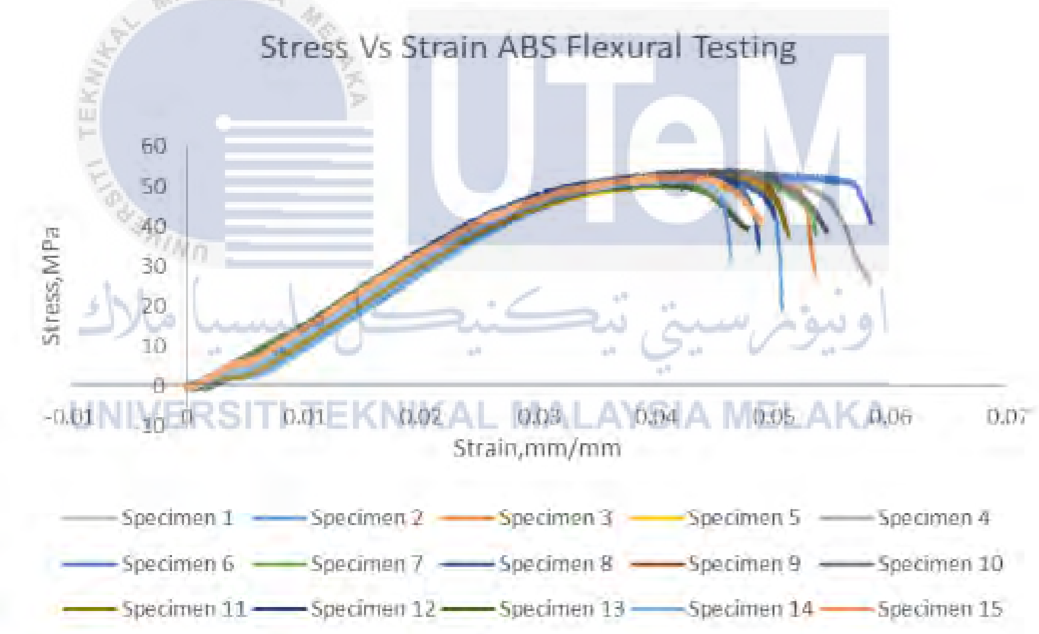


Figure 4.29: Stress versus strain graph for fifteen specimen of ABS material in flexural testing.

Figure 4.29 shows the stress-strain curves for ABS material that undergo flexural testing. It consists of fifteen ABS specimen result which represent in stress-strain curve that recorded to test the specimen under flexural loading. Based on the observation, all the ABS specimen shows similar pattern for all specimen. In average, the pattern of the curve starts with sinusoidal pattern at the beginning flexural load is applied which is known as material proportional limit. This because the material requires a certain amount of load which in flexural condition for its to start the deformation. After that the flexural loading is applied until it reach failure. The average flexural strength and maximum strain for ABS material is 53.15 MPa and 0.043 mm/mm. For flexural modulus, the average value for ABS material is 1915.18 MPa and the material is failure at average stress 36.43 MPa

4.4.3 PLA Material Flexural Test Result

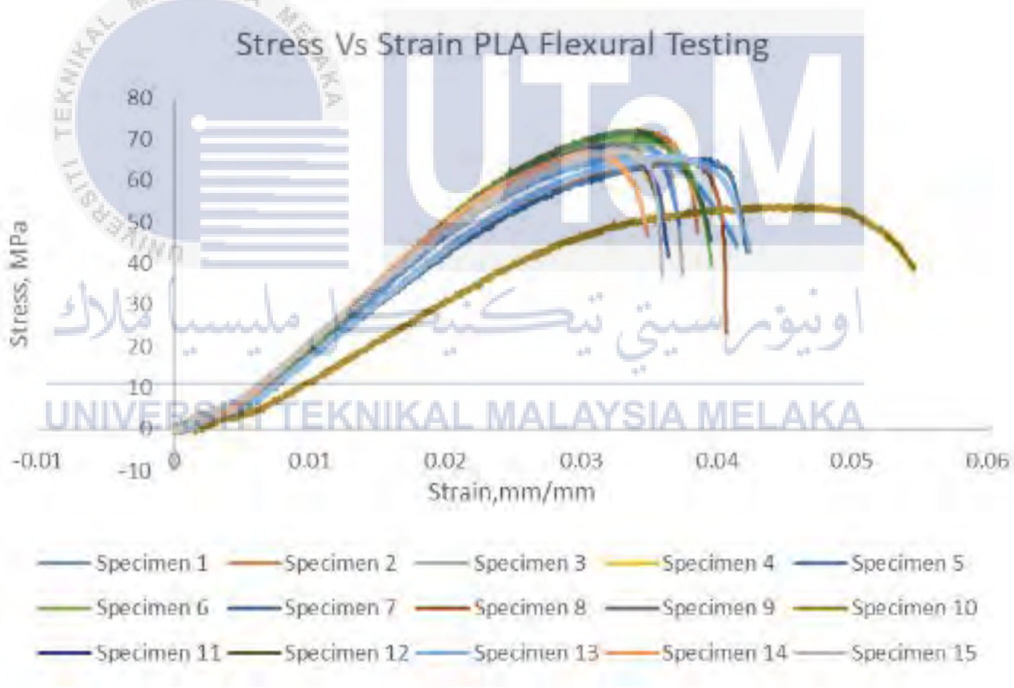


Figure 4.30: Stress versus strain graph for fifteen specimen of PLA material in flexural testing.

Figure 4.30 shows the stress-strain curves for PLA material that undergo flexural testing. The figure consists of fifteen ABS specimen result which represent in stress-strain curve which is recorded to test the specimen under flexural loading. Based on the observation, all the PLA specimen shows similar pattern for all specimen. In average, the pattern of the curve is also starts with sinusoidal pattern at the beginning flexural load is applied which is known as material proportional limit. This is due to material requires a certain amount of load which in flexural condition for its to start the deformation. After that the flexural loading is applied until it reach failure. From the observation, all the specimen curves less concentrated at the same region compared which cause the significant different value of material properties. The average flexural strength and maximum strain for PLA material is 68.52 MPa and 0.034 mm/mm. For flexural modulus, the average value for PLA material is 2861.74 MPa and the material is failure at average stress 43.69 MPa.

4.4.4 Comparison ABS and PLA Material Flexural Test Result

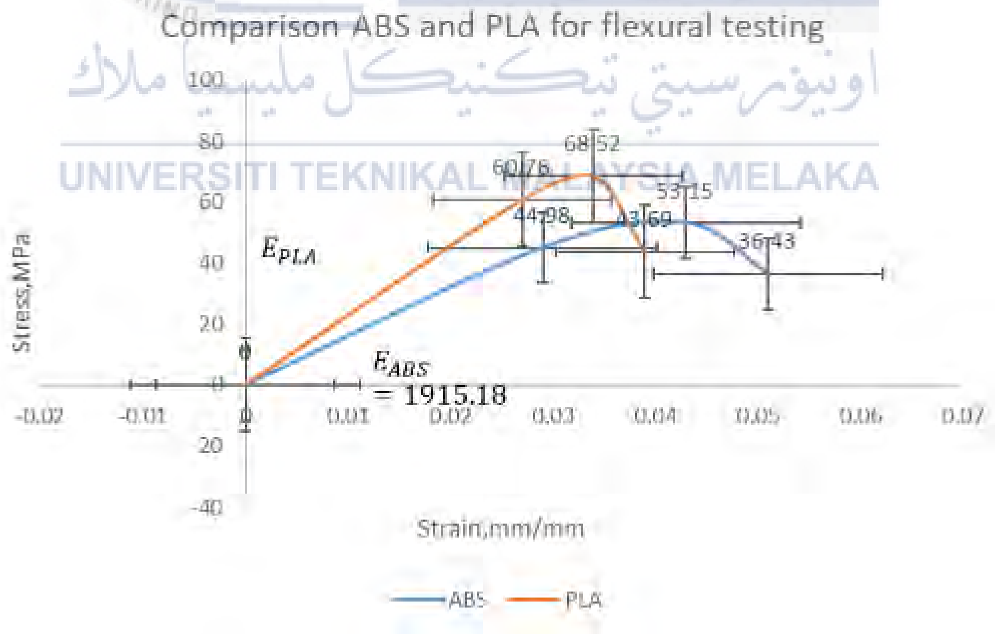


Figure 4.31: Stress versus strain diagram specimen of ABS and PLA material for flexural test.

Table 4.7: Data and result for flexural test of material properties.

Material	Yield stress (MPa)	Yield Strain (mm /mm)	Flexural strength (MPA)	Max. Strain (mm/ mm)	Stress failure (MPa)	Strain failure (mm/ mm)	Flexural Modulus (MPa)
ABS	44.98	0.029	53.15	0.043	36.43	0.051	1915.18
PLA	60.76	0.027	68.52	0.034	43.69	0.039	2861.74

Figure 4.31 shows the stress-strain curve for ABS and PLA material that constructed by using average data of flexural test from both materials. From the figure, the comparison between the behaviour of both materials under flexural loading can be analyse. According to figure, the value of flexural modulus of PLA material is higher compared to PLA material with value of 2861.74MPa and 1915.18 MPa. From the observation there are significant different of flexural modulus value which the modulus elasticity value of PLA material is higher by 33% compared to ABS material. From the figure 4.32, shows that the value of flexural modulus of PLA specimen is constantly higher than ABS specimen. This indicates that the PLA material slope of the curve at the elastic region is steeper than ABS material. In terms of stiffness comparison which also related to comparison of modulus elasticity, the PLA material has higher stiffness compares to ABS material when under flexural loading condition. In other words, the ability of PLA material to resist bending is higher due to it has higher stress to strain ratio for the material during flexural deformation compare to ABS material

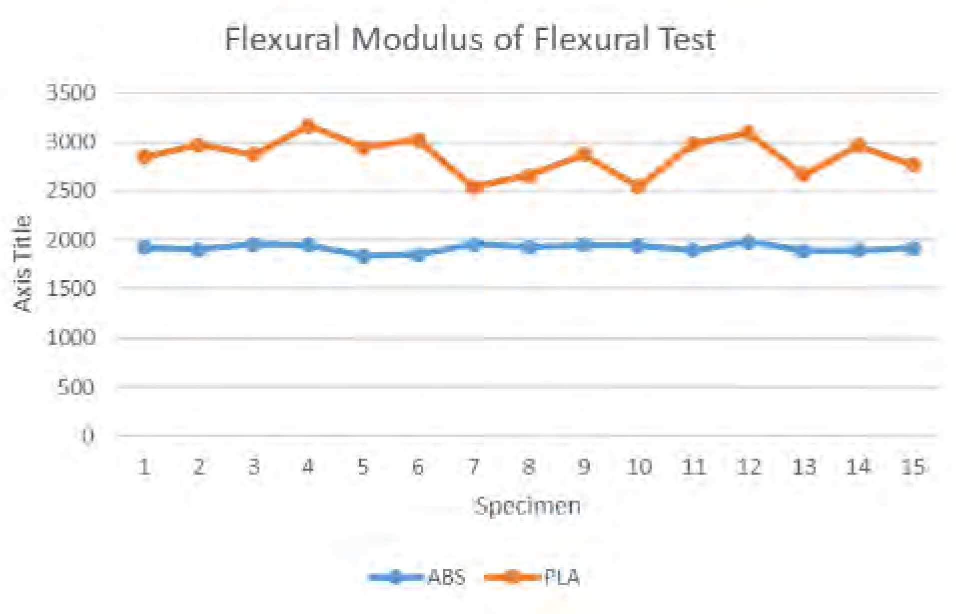


Figure 4.32: Modulus elasticity versus specimen of flexural test.

Next, from the comparison the yield strength due to flexural for PLA material is higher than the ABS material with value 60.76 MPa compares to ABS material with 44.98MPa. The difference between yield strength due to flexural is the PLA material is 23.63% higher than ABS material. This different indicates that the PLA material require higher stress or load for the material to plastic deformation compare to ABS material. This show that the tendency of PLA material to resist plastic deformation is higher due to it require higher stress for the material to yield. Even though the PLA material has higher yield strength due to flexural compare to ABS material, but the yield strain due to flexural for PLA material is lower than the ABS material as shown in figure 4.31. This indicates that the elongation of the PLA material before it yields is smaller even though the material requires higher stress to yield. As compare to ABS material, the elongation of the material to achieve plastic deformation is larger even the it requires smaller stress to yield than ABS material. The pattern of yield strain and yield stress is shown in figure 4.33.

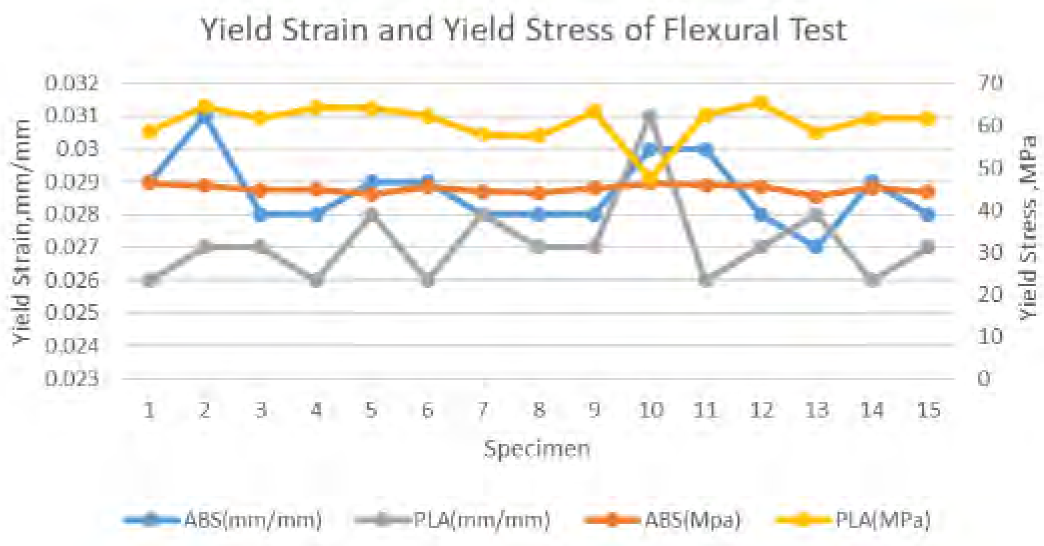


Figure 4.33: Specimen versus yield strain and yield stress of flexural test.

For the flexural strength properties, the PLA material seems to have higher flexural strength compare to ABS material with the value of 68.52 MPa for PLA material and 53.15 MPa for ABS material. The difference of value of flexural strength of PLA and ABS material is 22.43%. this shows that, the PLA material require higher amount of force compared to ABS material for the material experience flexural failure. According to figure 4.34, both material shows the consistent pattern of flexural strain and stress which the value between specimen is nearest to average. This is due to the PLA material require higher maximum bending moment of resistance which cause the material reach higher flexural point for the failure occur. Other than that, the comparison shows that the elongation of the specimen at maximum stress of PLA is lower than ABS material by making comparison for strain at maximum stress. This show that, at the plastic deformation region the PLA material deform plastically with lower elongation than ABS material at maximum flexural stress.

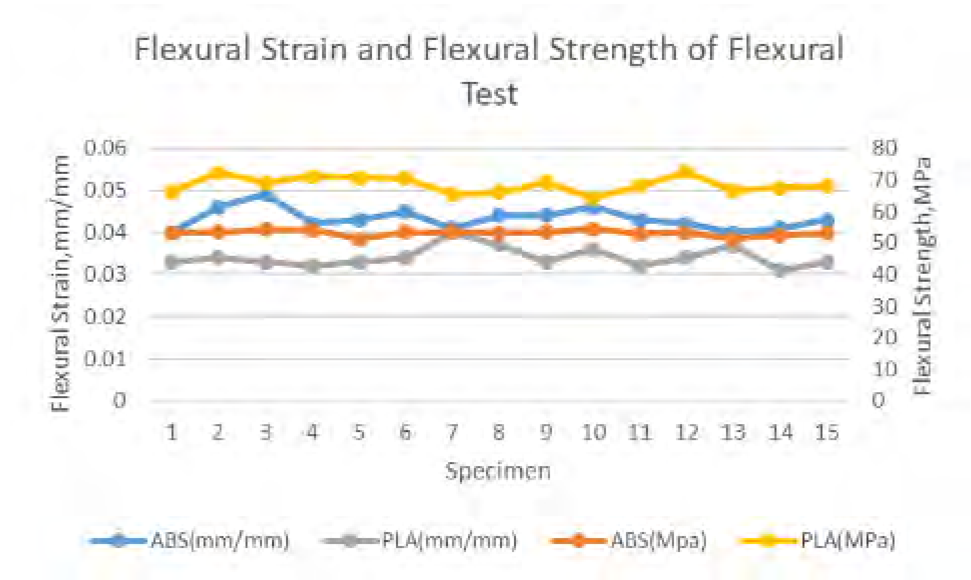


Figure 4.34: Specimen versus flexural strain and flexural strength of flexural test.

According to ASTM D790, the ABS an PLA material curves can be represented as curve b where specimens yield and then break before the 5% strain limit. From the observation the PLA material break at strain of 0.039 mm/mm which quiet far from the strain limit of the testing. Unlike ABS material curve, the material yield before the 5% strain limit region but it failure slightly over from the strain limit at value of strain 0.051 mm/mm. The specimen value of failure strain and failure stress does not consistent as shown in figure 4.35 resulting high value of standard deviation. This occur due to varies of the ability of material to elongate until it failure under flexural loading. For the stress at failure, the PLA material fail at 43.69 MPa which higher than the ABS material with value of 36.43MPa. This can be conclude that, for the failure the PLA material has higher stress at failure compare to ABS material but it fails at lower strain compare to ABS material.

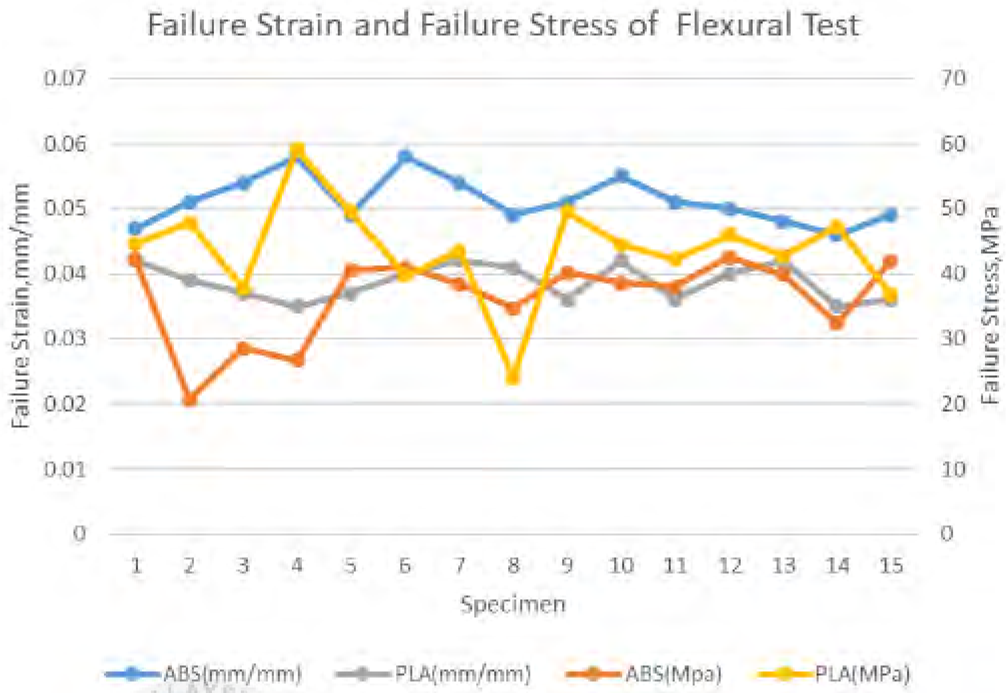


Figure 4.35: Specimen versus failure strain and failure stress of flexural test.

4.5 Mechanical Properties of Geospatial Product Material

The material properties which had been identified is tabulated as shown in table 4.8. Table 4.8 shows that the comparison between material properties for ABS and PLA material. The comparison shows that the PLA material has higher tensile strength and flexural strength as well as it has higher tensile yield and flexural yield compare to ABS material. In addition, PLA material has higher value of modulus elasticity and flexural modulus than ABS. Other than that, even though ABS has lower performance of material properties which PLA material performed but the ABS material has higher impact strength compare to PLA material

Table 4.8: Material properties of geospatial product material.

Material Properties \ Material	ABS	PLA
Tensile Strength, MPa	34.83	37.45
Flexural Strength, MPa	53.15	68.52
Impact Strength, MPa	11.63	3.33
Tensile Yield, MPa	31.70	33.81
Flexural Yield, MPa	44.98	60.76
Modulus Elasticity, MPa	765.98	857.10
Flexural Modulus, MPa	1915.18	2861.74

The comparison has been made between material properties of experimented ABS and reference ABS from the material data sheet as shown in table 4.9. Based on the comparison shows that, reference ABS shows greater performance compare to reference ABS with percentage of different between range 11 to 53 percent.

Table 4.9: Material properties comparison of data between experiment ABS and reference ABS.

Material Properties \ Material	ABS (Experiment)	ABS (Reference)	Percentage Of Difference,%
Tensile Strength, MPa	34.83	42.50	-22.00
Flexural Strength, MPa	53.15	70.50	-32.65
Impact Strength, MPa	11.63	13.00	-11.80
Tensile Yield, MPa	31.70	39.00	-23.00
Flexural Yield, MPa	44.98	68.90	-53.20

Note: reference data taken from material data sheet according to standard ASTM D638, ASTM D790 and ASTM 256.

For the comparison between material properties of experimented PLA and reference PLA from the material data sheet is shown in table 4.10. The result also shows the performance of reference PLA is higher compare to experimented PLA in all expected tested in this research with percentage different between range 7 to 53 percent.

Table 4.10: Material properties comparison of data between experiment PLA and reference PLA.

Material Properties \ Material	PLA (Experiment)	ABS (Reference)	Percentage Of Difference,%
Tensile Strength, MPa	37.45	46.80	-25.0
Flexural Strength, MPa	68.52	103.00	-50.30
Impact Strength, MPa	3.33	5.10	-53.20
Tensile Yield, MPa	33.81	36.30	-7.40
Flexural Yield, MPa	60.76	77.50	-27.60

Note: reference data taken from material data sheet according to standard ASTM D638, ASTM D790 and ASTM 256.

The difference between experimented and reference material properties for both materials due to the variation of printing parameter which may affect the performance of material against various type of loading. The variation of parameter of printing may affect the bonding between layer which may leads to formation of voids which lower its capability against loading that cause the higher difference compared to reference ABS.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Overview

This chapter will state the summarize of the research that has been conducted in order the research objectives. The conclusion of the research involves summarization on the research that had been conducted. Other than that, the recommendation section will discuss on the propose future works regarding the research which beneficial for the future researcher to continue the study.

5.2 Conclusion

As conclusion, the research that had been conducted is about mechanical properties investigation on PLA and ABS materials for geospatial topology product printed by rapid prototyping method. Overall for this project studies, it has achieved the objective which are to evaluate the material properties (tensile, flexural, and impact) for ABS and PLA filament for geospatial topology product and investigate the relationship between tensile, flexural and impact data on ABS and PLA filament. The focus of the study is on mechanical testing that had been conducted which are tensile, flexural and impact test that involving only two type of FDM filament material which are ABS and PLA. The needs of this research is to solve the problem on the current development of geospatial product which to identify the material properties of the geospatial product for the purpose to test the product ability or performance against various type of loading.

Other than that, the implementation of the research had been implemented as planned according to the research methodology flow. The method of testing to study the material properties begins with the identifying the suitable standards, following by the specimen preparation and testing and ends by making analysis of the finding from the testing that had been conducted. In this research, ASTM standard had been chosen as standard of testing for tensile, flexural and impact testing which act as guidelines in conducting the testing according to the correct procedure. The fabrication of specimen using 3D printing method has been done according to the parameter of printing geospatial product. The method of material deposition had been used involves the filament type material to produce the specimen according standards specimen size. The experimental data generated by conducting material testing against three different type of loading and analysis is made to summarize the finding from the testing.

According to the result and finding of the research, the material properties of ABS and PLA material that use to produce geospatial product can be determine by using proper standard of testing and procedure. The performance of the ABS and PLA material is measured on the capability of the material to withstand the highest amount of force or load before it reaches failure which in this research focusing on the tensile, flexural and impact loading. For the studies on the material behaviour against the tensile loading, tensile test result has shown that the PLA material has recorded the highest tensile strength compare to ABS material by 2.62 MPa higher. The elasticity measurement which is the tensile modulus shows significant difference which PLA material value is higher by 91.12 MPa than ABS material. The flexural strength for PLA material also give very large difference from ABS material where about 28.92

percent which 15.37 MPa higher. Then, the flexural modulus also shows very large difference between PLA and ABS which the difference is 946.56 MPa. The study of the material resistant against dynamic impact loading which focusing on izod impact testing had shown the difference performance result of the material compare to tensile and flexural testing. The testing had identified that the ABS material can resist higher impact loading compares to PLA material. The impact strength of ABS material is higher than PLA material with greater difference value which gives 71.37 percent difference. The difference is 8.3 MPa higher.

By making comparison of the result for both material, it can be summarize the finding of comparison between material. Tensile testing had clarified that the PLA material can withstand higher tensile force or loading before it experiences failure. In addition, the tendency of the PLA material compares to ABS material to deform plastically is lower due to it has higher modulus elasticity and yield point. This testing proves that geospatial product which made by using PLA material can withstand higher force or loading and it has high ability to resist against tensile deformation due to it has high modulus elasticity and yield point when the product experience in tensile loading condition. Next, flexural testing had proved that the geospatial product which made by using PLA material can withstand greater bending force or loading which can lead to experience failure compare to geospatial product which made by ABS material. Furthermore, PLA material has lower degree of the material to deform plastically compare to ABS material due to require greater flexural loads to achieve the yield point and it has higher flexural modulus. For the impact testing, it had been identified that ABS material can withstand higher dynamic impact loading for the material to fracture compare to PLA material. This may be due to the poor formation of first layer of build which would affect the next deposited layer which suspected leads to formation of voids which cause the porosity for PLA material.

Overall, this research had managed to determine of the material that used for the geospatial product. From this research, it can be conclude that the PLA material has higher tendency to resist tensile and flexural loading but poor to resist impact loading which had been justified in this research by determine the material tensile strength, flexural strength and impact strength. With the material properties of the material that had been identified give benefits to the development of the geospatial product to make improvement for increase the quality of the product to make it more reliable to be use by the potential customer.

5.3 Recommendation

This research only focusing on tensile, flexural and impact testing only to study material properties of material used for geospatial product made by 3D printing method. The disadvantages of using 3D printing method compare to other type of manufacturing process is the produce parts may contain high degree of porosity due to formation of voids and pores especially between deposited layer as stated in the previous study. For the further research, the compression testing which involving to test the material against the compressive loading is suggested to be done. By making this testing, the specimen will be compressed until it reaches failure and the result of the compressive strength will indicate the degree of porosity that present in both materials after 3D printing process. Next, the study on the microstructure on the specimen in order to study the pattern of failure of the specimen which is important to find the scientific reason on why the failure occur.

REFERENCES

Ramya, A., & Vanapalli, S. l. (2016, June). 3D Printing Technologies in Various Applications. International Journal of Mechanical Engineering and Technology, 7(3), 396–409.

A.C. Abbott, G. T. (2017, November 4). Process-structure-property Effects on ABS Bond Strength in Fused Filament Fabrication. Additive Manufacturing, pp. 29-37.

Abbas, T. F., Othman, F. M., & Hind. (2018, Febuary). Influence of Layer Thickness on Impact Property of 3D-Printed PLA. International Research Journal of Engineering and Technology, 5(2), 1-4.

Albert, & Patrick, D. (2012). Geospatial Technology and Advancing Geographic Decision Making: Issues and Trends. United States of America: IGI Global.

Al-Maliki, & Qasim, J. (2015, October). The Processes and Technologies of 3D Printing. International Journal of Advances in Computer Science and Technology, 4(10), 161-165.

Baroš, T., & Stojanović, T. (2015). Geographic Information System (GIS) in Mapping of Mine Suspected Area in the Republic of Serpska. Global Journal of Science Frontier Research: Environment & Earth Science, 15(3), 2.

Berman. (2007). 3D Printing: Making the Virtual Real. EDUCAUSE Evolving Technologies Committee, Art Center College of Design.

Buchroitner, M. (2012). True-3D in Cartography: Autostereoscopic and Solid Visualisation of Geodata. New York: Springer Heidelberg.

Chakraborty, D., & Sahoo, R. N. (2007). Fundamental of Geographic Information System. New Delhi: Viva Books Private Limited.

Chua, C. K., Matham, M. V., & Young-Ji. (2017). Lasers in 3D Printing and Manufacturing. Singapore: World Scientific Publishing Co.Pte.Ltd.

Ellul, C., Zlatanova, S., Rumor, M., & Rober. (2013). Urban and Regional Data: UDMS Annual 2013. Broken Sound Parkway: CRC Publication Press.

Folger, P. (2008). Geospatial Information and Geographic Information System (GIS): Current Issues and Future Challenges. Washington DC: Congressional Report Service for Congress.

Gebhardt, A., Schmidt, F. M., & Jan-Steff. (2010). Additive Manufacturing By Selective Laser Melting The Realizer Desktop Machine And Its Application For The Dental Industry. Physics Procedia, pp. 543-549.

Guo, N., & Leu, M. (2013, September). Additive Manufacturing: Technology, Applications and Research Needs. 8(3), pp. 215-243.

H.S.Sharma, Ram, D. R., Prasad, R., & Binda, P. R. (2006). Mathematical Modelling in Geographical Information System, Global Positioning System And Digital Catography. New Delhi,India: Conce[t Publishing Company.

Holtrup, R. (2015). A Multi-material 3D Printer Using DLP Technology. Univerity Of Twente.

Jaya Christiyan, K. G., & Chandrasekhar, K. V. (2016). A Study On The Influence Of Process Parameters On The Mechanical Properties Of 3D Printed ABS Composite. IOP Conference Series: Materials Science and Engineering,. IOP Publishing Ltd.

Johansson, F. (2016). Optimizing Fused Filament Fabrication 3D Printing For Durability: Tensile Properties & Layer Bonding. Karlskrona, Sweden: Blekinge Institute of Technology.

Kyle Raney, E. L. (2016). Experimental Characterization Of The Tensile Strength Of ABS Parts Manufactured By Fused Deposition Modeling Process. International Conference on Advancements in Aeromechanical. Denver, USA: Elsevier Ltd.

Lamikiz, A., Sanchez, J., Lopez de Lacalle , & Aran. (2007). Laser Polishing Of Parts Built Up By Selective Laser Sintering. International Journal of Machine Tools & Manufacture, 2040-2050.

More, A., & Drekci, I. (2013). Geospatial Visualization. New York: Springer.

More, P. (2013, July). 3D Printing Making Digital Real. International Journal Of Engineering Sciences & Research, 1822-1825.

Noorani, R. (2017). 3D Printing: Technology, Applications, and Selection. Broken Sound Parkway NW: CRC PRESS.

Nsengimana, J. (2015). An Investigation Into Surface Finish Improvement Of Small Plastic Parts Manufactured Through Additive Manufacturing. Free State: Central University of Technology.

Nyerges, T., Couclelis, H., & McMaster, R. (2011). The SAGE Handbook of GIS and Society. City Road,London: SAGE Publication LTD.

Pandey, P., Reddy, N., & Dhande, S. (2003). Improvement Of Surface Finish By Staircase Machining In Fused Deposition Modelling. Journal of Material Processing Technology, 323-331.

Pomell, J., Silvonen, A., Lagus, N., Kim, H., Partanen, J., & Kiviluoma, P. &. (2015, MAY). Adaptive Selective Laser Sintering Testing Device For Process Research In 3d Printing. pp. 180-185.

Santhakumar, J., Maggirwar, R., & Golla, S. (2016, September). Enhancing Impact Strength of Fused Deposition Modeling Built Parts using Polycarbonate Material. Indian Journal of Science and Technology, 9(34), 1-6. doi:10.17485/ijst/2016/v9i34/100983

Shahi, & Singh, B. (2016, April). Advanced Manufacturing Techniques (3D Printing). International Journal of Mechanical And Production Engineering, 4(4).

Sing, S. L., An, J., Yeong, W. Y., & Wiria. (2015, April 21). Laser and Electron-Beam Powder-Bed Additive Manufacturing of Metallic Implants: A Review on Processes, Materials and Designs. Journal Of Orthopaedic Research, 369-385.

Surange, V. G., & Gharat, P. V. (2016, March). 3D Printing Process Using Fused Deposition Modelling (FDM). International Research Journal of Engineering and Technology (IRJET), 3(3), 1403-1406.

Vasudevarao, B., Natarajan, D. P., & Henderson, M. (n.d.). Sensitivity of Rapid Prototyping surface finish to process parameter variation.

Yap, Y. L., Wang, C., & Sing, S. L. (2017, October). Material Jetting Additive Manufacturing: An Experimental Study Using Designed Metrological Benchmarks. Precision Engineering, 50, pp. 275-285.

Yasa, E., & Kruth, J. (2011). Application of Laser Re-Melting on Selective Laser Melting Parts. Advances in Production Engineering and Management, 6(4), 259-270.

Yasa, E., & Kurth, J. (2011, Application Of Laser Re-Melting On Selective). Application of Laser Re-melting On Selective Laser Melting Parts. Journal Advances in Production Engineering & Management, 6(4), 259-270.

Zhou, J., Herscovici, d., & Chen, C. (1999). Parametric Process Optimization to Improve Accuracy of Rapid Prototyped Stereolithography Parts. International Journal of Machine Tool and Manufac

APPENDIX A: Material Testing Result Table

Tensile test result table

Material	No. Speci-men	Max. Force (N)	Tensile Strength (MPA)	Tensile Strain (mm/mm)	Modulus Elasticity (MPa)	Yield Stress (MPa)	Yield Strain (mm/mm)	Failure Stress (MPa)	Failure Strain (mm/mm)
ABS	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	Average								
	Std. Dev								
	R-squared								
PLA	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	Average								
	Std. Dev								
	R-squared								

Flexural test result table

Material	Specimen	Max Load (N)	Extension At Maximum (mm)	Flex-ural Modulus (MPa)	Yield Strength (MPa)	Yield Strain (mm/mm)	Flexural Strength (MPa)	Flexural Strain (mm/mm)	Stress Failure (MPa)	Strain Failure (mm/mm)
ABS	1.									
	2.									
	3.									
	4.									
	5.									
	6.									
	7.									
	8.									
	9.									
	10.									
	11.									
	12.									
	13.									
	14.									
	15.									
	Average									
	Std.Dev									
	R-Squared									
PLA	1.									
	2.									
	3.									
	4.									
	5.									
	6.									
	7.									
	8.									
	9.									
	10.									
	11.									
	12.									
	13.									
	14.									
	15.									
	Average									
	Std.Dev									
	R-Squared									

Impact test result table

Material	Specimen	Cross sectional area(m^2)	Type of Failure	Energy of Impact(J)	Impact Strength (kJ/m^2)
	1				
	2				
	3				
	4				
	5				
	6				
	7				
	8				
	9				
ABS	10				
	11				
	12				
	13				
	14				
	15				
	Average				
	Std.Dev				
	R-Squared				
	1				
	2				
	3				
	4				
	5				
	6				
	7				
	8				
	9				
PLA	10				
	11				
	12				
	13				
	14				
	15				
	Average				
	Std.Dev				
	R-Squared				

APPENDIX B: Tensile Test Specimen

A) ABS Tensile Specimen

Specimen Before Testing	Specimen After Testing	Result		
		Tensile Strength, MPa	Yield, Strength, MPA	Modulus Elasticity
		36.19	30.28	782.37
		34.19	30.00	738.37

		36.26	31.00	816.56
		35.70	33.5	737.29
		34.63	31.02	802.99

		35.33	30.76	785.6
		35.37	34.24	720.7
		35.37	33.6	720.7
		33.98	31.87	758.9

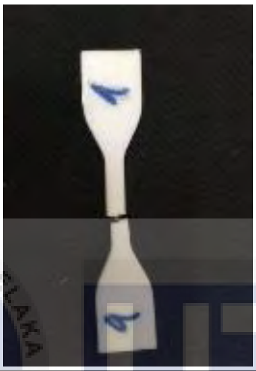
		35.74	32.00	808.85
		34.08	31.24	770.68
		33.62	31.50	777.0
		33.53	31.32	712.39

		34.41	32.17	766.48
		34.05	31.02	790.85

B) PLA Tensile Specimen

Specimen Before Testing	Specimen After Testing	Result		
		Tensile Strength, MPa	Yield, Strength, MPA	Modulus Elasticity
		38.43	35.00	862.88
		37.69	33.00	869.60
		35.78	32.47	841.61

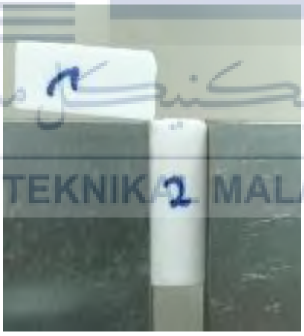
		37.61	34.13	881.68
		37.71	34.12	866.7
		36.50	33.00	880.96
		36.41	32.88	877.8

		38.12	34.00	868.2
		37.33	32.51	709.24
		35.58	33.17	804.75
		36.53	33.61	825.27

		36.69	33.1	869.81
		39.06	35.96	898.23
		39.15	35.12	899.9
		39.15	35.12	899.9

APPENDIX C: Impact Test Specimen

A) ABS Impact Specimen

Specimen Before Testing	Specimen After Testing	Result		
		Type of Failure	Energy of Impact(J)	Impact Strength (KJ/m2)
		Hinge Break	0.78	11.39019
		Hinge Break	0.84	12.26636
		Complete Break	0.81	11.82827

		Hinge Break	0.78	11.39019
		Complete Break	0.81	11.82827
		Hinge Break	0.76	11.09813
		Hinge Break	0.83	12.12033

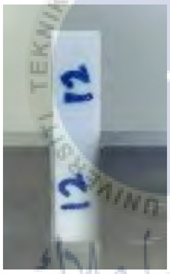
		Hinge Break	0.87	12.70444
		Complete Break	0.69	10.07593
		Hinge Break	0.71	10.36799
		Hinge Break	0.76	11.09813

		Hinge Break	0.74	10.80607
		Hinge Break	0.86	12.55841
		Hinge Break	0.95	13.87266
		Hinge Break	0.76	11.09813

B) PLA Impact Specimen

Specimen Before Testing	Specimen After Testing	Result		
		Type of Failure	Energy of Impact(J)	Impact Strength (KJ/m2)
		Complete Break	0.20	2.920561
		Complete Break	0.28	4.088785
		Complete Break	0.30	4.380841
		Complete Break	0.20	2.920561

		Complete Break	0.17	2.482477
		Complete Break	0.23	3.358645
		Complete Break	0.29	4.234813
		Complete Break	0.19	2.774533
		Complete Break	0.16	2.336449

		Complete Break	0.20	2.920561
		Complete Break	0.30	4.380841
		Complete Break	0.21	3.066589
		Complete Break	0.20	2.920561
		Complete Break	0.27	3.942757

		Complete Break	0.22	3.212617

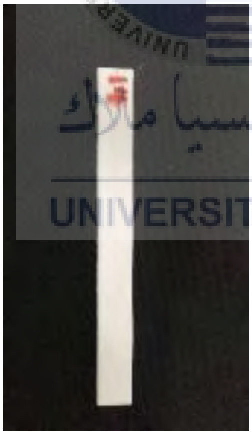
APPENDIX D: Flexural Test Specimen

A) ABS Flexural Specimen

Specimen Before Testing	Specimen After Testing	Result		
		Flexural Strength, MPa	Yield, Strength, MPA	Modulus Elasticity
		53.29	46.3	1919.36
		53.52	45.81	1897.27
		54.22	44.62	1950.90

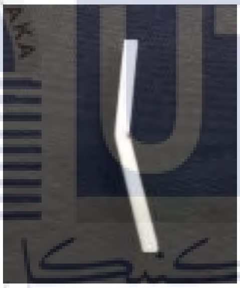
		54.04	44.78	1945.73
		51.19	43.78	1836.15
		53.49	45.37	1846.05
		53.52	44.41	1953.24

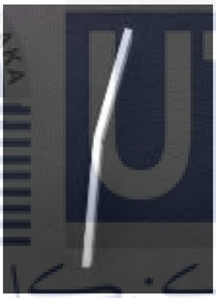
		53.20	44.04	1924.73
		53.44	45.12	1947.22
		54.48	46.34	1940.99
		52.91	45.89	1892.97

		53.19	45.57	1980.10
		51.30	43.14	1884.47
		52.44	45.31	1894.01
		52.97	44.21	1914.52

B) PLA Flexural Specimen

Specimen Before Testing	Specimen After Testing	Result		
		Flexural Strength, MPa	Yield, Strength, MPA	Modulus Elasticity
		66.16	58.7	2846.39
		72.42	64.5	2972.34
		69.11	61.8	2872.37
		71.05	64.2	3165.12

		70.67	64.1	2946.52
		70.49	62.3	3023.32
		65.49	57.9	2542.77
		66.09	57.5	2659.62
		69.19	63.3	2872.39

		64.27	47.5	2547.12
		68.15	62.5	2982.15
		72.51	65.4	3097.61
		66.60	58.3	2664.12
		67.50	61.7	2966.04

		68.11	61.7	2768.28