MECHANICAL PROPERTIES OF SPECIMENS 3D-PRINTED RECYCLED POLYLACTIC ACID (UTeM)

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "Mechanical properties of specimen 3D-printed recycled Polylactic acid" is the result of my own work except as cited in the references

Signature : ______________________________

Name : Mohd Firdaus Bin Abdul Hamid

Date : 28 August 2020

SUPERVISOR'S DECLARATION

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

Signature :__________________

Name of Supervisor :__________________

Date :__________________

DEDICATION

To my beloved mother and father

ABSTRACT

Polylactic acid (PLA) filament is affordable yet can be consider costly for research purposes. A lot of prototype need to be printed for testing or evaluation in a project. This study focusing on recyclability of PLA that widely used in 3D-printing. A filament extruder had been fabricated to extrude the recycled PLA filament. A set of five specimens was printed from each PLA and recycled PLA filament using fused deposition modelling (FDM) 3D printing process. The objective of this study is to investigate the mechanical properties of 3D-printed part using original PLA and recycled PLA filament. The experiment using ASTM D638 type IV standard of procedure to evaluate the tensile strength properties. Comparison is made on the PLA of original and recycled to see if the recycled PLA having large difference or not. The final result shows that the recycled PLA specimens differ within 3%-30% in term of tensile properties. The obtained result shows that recycled PLA filament can be used in 3D-printing process.

ABSTRAK

Filamen asid polilaktik (PLA) berpatutan namun boleh dianggap mahal untuk tujuan penyelidikan. Banyak prototaip perlu dicetak untuk ujian atau penilaian dalam sesuatu projek. Kajian ini memfokuskan pada kebolehkitar semula PLA yang banyak digunakan dalam percetakan 3D. Pengekstrusi filamen telah dibuat untuk mengeluarkan filamen PLA yang dikitar semula. Satu set lima spesimen dicetak dari setiap PLA dan filamen PLA yang dikitar semula menggunakan proses pencetakan 3D pemodelan pemendapan (FDM). Objektif kajian ini adalah untuk mengkaji sifat mekanikal bahagian bercetak 3D menggunakan filamen PLA asli dan kitar semula PLA. Eksperimen menggunakan prosedur standard ASTM D638 jenis IV untuk menilai sifat kekuatan tegangan. Perbandingan dibuat pada PLA yang asal dan dikitar semula untuk melihat apakah PLA yang dikitar semula mempunyai perbezaan yang besar atau tidak. Hasil akhir menunjukkan bahawa spesimen PLA yang dikitar semula berbeza dalam 3% -30% dari segi sifat tegangan. Hasil yang diperoleh menunjukkan bahawa filamen PLA kitar semula dapat digunakan dalam proses pencetakan 3D.

ACKNOWLEDGEMENT

I would like to give a huge appreciation to my supervisor Dr. Shafizal for guiding my final year project from beginning until the ending. I am honored doing a project under his surveillance as he never hesitate to give advice and motivation to complete the project. I am very in debt to his patience and acceptance while leading me in this project.

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CAD	Computer-Aided Drawing
PLA	Poly Lactic Acid
FDM	Fused Deposition Modelling
FFF	Fused Filament Fabrication
ABS	Acrylonitrile Butadiene Styrene
PC	Poly Carbon
PA	Poly Amide
ROP	Ring Opening Polymerization
AM	Additive Manufacturing
ASTM	American Society Testing and Material
SEM	Scanning Electron Microscopy
UTM	Universal Testing Machine

LIST OF SYMBOL

L_b	Load at Break
δ_b	Elongation at Break
A	Cross-sectional Area
σ	Tensile Stress
E	Young Modulus
ε	Tensile Strain

CHAPTER 1

INTRODUCTION

1.1 Project Background

3D-printer is a machine that capable to develop a three-dimensional object involving Additive Manufacturing (AM) process adding pre-heated filament or heated liquid etc. layer by layer fabricate a computer-aided design (CAD) model. For this case, Poly Lactic Acid (PLA) filament is used as the additive material. There are several materials that commonly used as the additive material in Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF) methods such as Acrylonitrile Butadiene Styrene (ABS), Poly Carbonate (PC), and Poly Amide (PA) filaments (Dudek, 2013)

PLA is a thermoplastic polymer that extracted from sugar cane or corn starch. It is belonged to a biodegradable polymer group as depicted in Fig. 1.1 that encouraged to be used for product with short life-span such as engineering application, packaging, and surgery (Avérous and Pollet, 2012). PLA has been researched tremendously because it can considered as a substitute for synthetic plastic materials where commonly use in food packaging (Farah et, al, 2016).

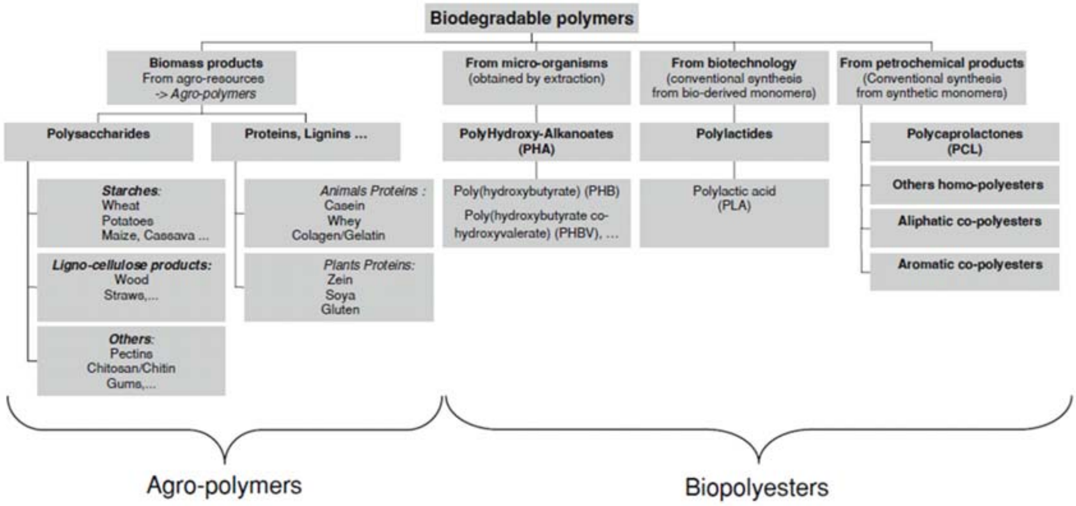

Figure 1.1: Classification of the main biodegradable polymer

(Source: Avérous and Pollet, 2012)

1.2 Problem Statement

PLA filament is affordable and inexpensive filament among other material in 3D-printing process yet can be consider costly for research purposes. A lot of prototype need to be printed for testing or evaluation in a project. Moreover, unexpected incident may happen during the process and produce numerous waste. This waste can be generated from failed prints and unwanted product that need to be print along as support point/platform during 3D-printing process.

The only solution to reduce the cost is recycling the used PLA. An unused 3D-printed product and waste can be reuse by turning it back into a filament by extruding process where it is compressed in a heated barrel, melted and forced through a die (Rosato, 2012). Hence, this is a good approach in reducing raw material usage proportionally reducing environment impact which is crucial nowadays (Reddy et. al, 2013).

Recycling PLA for 3D-printing application can lower the harmfulness on environment yet the degradation in mechanical properties has become the problem (Zhao X.G. et. al, 2018). The effects of recycled PLA significantly decrease in terms of mechanical properties between the third times mechanically recycled PLA and the PLA (Lanzotti et al, 2018).

In term of thermal properties, the melting point of first time recycled PLA slightly decrease which can be explained by the presence of shorter PLA chains due to chain scission (Fonseca Valero et. al, 2014).

1.3 Objective

The objectives of this project are:

i. To extrude the recycled PLA filament using extruding process.
ii. To investigate the mechanical properties of recycled PLA filament using experimental methods.
iii. To investigate the sustainability of the recycled PLA filament usage in 3D-printing process.

1.4 Scope

The scope of this project that need to be achieved as fulfilling the objective by using additive manufacturing for fabricate the specimen i.e. 3D-printing process using FDM methods. Besides that, the recycled PLA filament must perform same conventional 3D-printing process to make the type of process constant and get a reliable result.

Secondly, the recycled PLA filament need to be extruded first before going through 3D-printing process. This can be done by using extruder machine to process waste/rejected PLA materials into filaments through heating process.

The recycle PLA's product must do a comparison between the PLA's product in terms of mechanical properties to get the result and can be proposed the suitable application accordingly. This mechanical properties must be evaluated by using tensile test and analyze the result from the recycled PLA filament.

1.5 Methodology

There are many methods have been used to complete this study about characterize the mechanical properties of PLA. Started with the modelling the specimen for experimental analysis with SolidWorks software based on ASTM standard design by referring related articles and journals.

For fabrication, an Anet A8 model of 3D-printer have been used as the fabricator. The 3D-printer will fabricate the specimens precisely according to the model in SolidWorks. Then for the recycling process, an extruder machine have been fabricated to extrude the waste from PLA into a filament form. The extruded filament then going fabrication process which is 3D-printing process into specimen for tensile testing.

For experiment result, a tensile test have been done by using Instron universal testing machine at lab. The result for PLA and recycled PLA will be used to compare the difference between them.

1.6 Project Outline

There are six chapters in this project. Chapter one is about the introduction of the project, problem statement, objective and project outline.

Chapter two is literature review of this project. This chapter collects the references to support the idea or reasoning relevant to the subject which are PLA material and 3D-printing process. In this chapter, there were discussion about definition and properties of PLA and further explanation of 3D-printing process.

Chapter three will be discussing about the methodology of this project including the preparation before experimenting the properties of PLA and recycled PLA such as design of the project (Gantt chart) and design of the experiment. This chapter will also elaborate about standard procedure to obtain the experimental data by experimenting the PLA.

Chapter four focusing on results. The result from experiments will be collected in this chapter before any discussion or conclusion will be made in next chapter.

Chapter five is discussion of the project analysis. The result get from both PLA and recycled PLA will be compared and discussed. Any findings during the analysis will be discussed in details.

Lastly, chapter six is conclusion and recommendation. This chapter concluded the finding in this project and suggest several recommendation for future research related to this subject.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

All related article and journal needed to be study to support the concept idea behind this study and the experimental methodology which is expressed in this chapter.

In this chapter, literature review about the PLA and its recyclability which is a favorite material to be studied as its inspiring potential to replicate conventional petrochemical-based polymers as a biomaterial which is a better version in widespread applications (Farah et al, 2016) will be discussed. Besides, 3D-printing process and fused deposition modelling method also will be mentioned.

2.2 Poly Lactic Acid (PLA) and its recyclability

PLA is Bio polyesters and a chiral molecule which can be produced by different ways such as chemically synthesized or biologically (Avérous and Pollet, 2012) which produces a specific of grades for specific uses. Nowadays, PLA in produced by ring-opening polymerization of lactide as shown in figure 2.1 which is derived from agricultural source such as corn and sugarcane to process the glucose by fermentation.

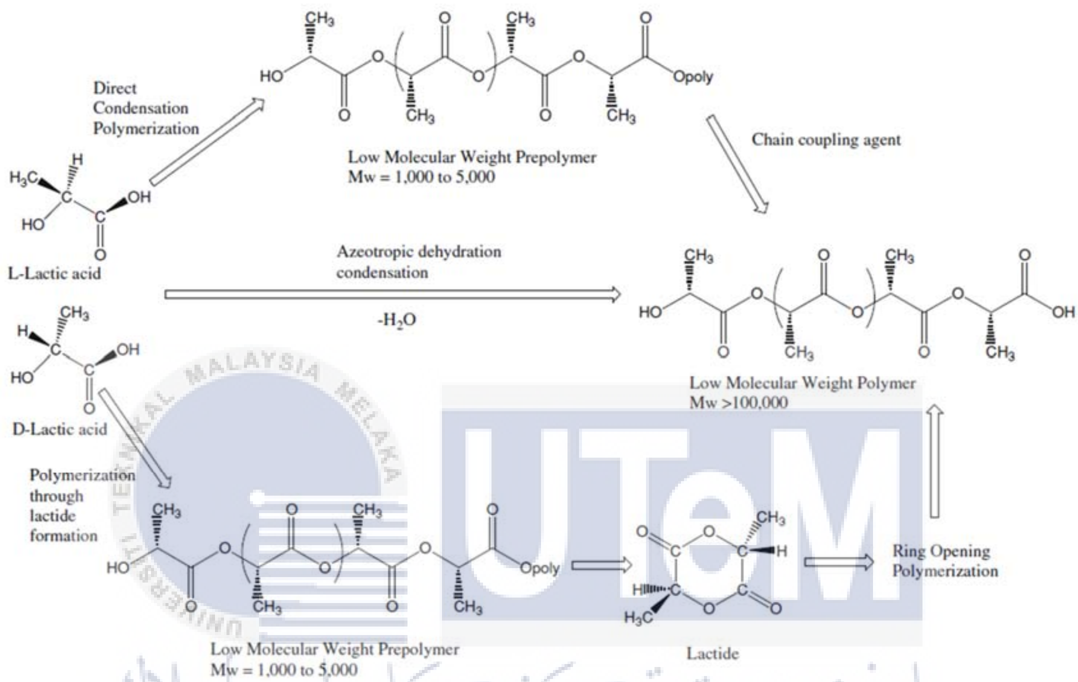

Figure 2.1: Chemical structure of PLA and ROP method for obtaining high molecular weight. (Source: Avérous and Pollet, 2012)

Many advantages can be benefitted from PLA which are inexpensive due to large availability in market, lower environmental effect than Polystyrene but similar optical and mechanical properties, and suitable for food and medical packaging (Auras et al, 2010).

PLA is a recyclable thermoplastic material but it is not strong enough when recycle although going through physical treatment and copolymerizing (Msibia et al, 2018). Many researchers study to strengthened to mechanical properties of PLA such as produce bio composites formulated of PLA with Pecan Nutshell Powder (Alvarez-Chavez et al, 2017) but resulting decreased tensile strength and extruding bioplastic composites of Starch/PLA/Agave bagasse fiber (Aranda-Garcia et al, 2015) resulting increased tensile strength.

Table 2.1: Mechanical Properties of PLA, 3D-printing grade
(Source: Zhao et.al, 2018)

Property	Unit	Value
Tensile Modulus	MPa	1572.43 ± 27.16
Tensile Strength	MPa	30.21 ± 0.89
Yield Strength	MPa	27.69 ± 0.77
Elongation at Break	%	2.74 ± 0.53
Flexural Modulus	MPa	2423.73 ± 56.42
Flexural Strength	MPa	64.48 ± 2.49

Mechanical properties of recycled PLA fabricate with AM, the tensile strength decreased 10.9%, Shear strength increased by 6.8%, and hardness decreased 2.4%. In short, the differences were similar but there was more variability in the result that need to elaborate more in further study in this area of recycling 3D-printed filament (Anderson, 2017)

By understanding the mentioned studies above, PLA is recyclable but certainly decreasing in values of tensile strength without additive substance. In this study, there isn't any additive substance in the recycled PLA.

2.3 3D-Printing

3D-printing process which also known as AM process is involving a heated material process into solid structure by adding layer by layer according to the model designated by CAD software with relatively low cost and easy to use compare to conventional subtractive manufacturing (Berman, 2013).

As the name AM suggest, Kietzmann (2015) said, the product builds from bottom to top similar to combining simple Lego blocks and simplify the complex understanding of 3D-printing process with the 3D-printing mantra, “if you can draw it, you can print it”.

This statement supported by Lipson and Kurman (2013) understanding by saying, a 3D-printer convert digital information into a physical object based on instruction from a computer-aided design file by processing thermoplastic resin with low operational cost without tooling and mold which means there are no limitation to fabricate the drawing where there is no need extra space for grinding, cutting, drilling, turning or milling process at the product.

There are several aspect in advantages of AM over conventional manufacturing such as quality. The quality of AM in term of design can’t be denied as the technology has been evolved since 1984. The other view of quality that can be doubted is the materials. Many scientists/researchers have study to enhance the mechanical and physical properties of each materials that available in the market also to improve the stability, degradation, process ability, aging and recyclability for wider application and high security and safety (Farah et. al, 2016).

The other advantages of AM is flexibility in number of production. The variation of targeted number for production is essential exclusively for medium and small scale industry. They can design several variant of model/goods efficiently without consuming high labour skill and wages, extra mold and jigs setup and preparation time before manufacture process started (Attaran. M, 2017).

There are many types of 3D-printer which are differentiate by the method of the process (Pandey, 2014):

- Stereo lithography (SLA).
- Digital Light Processing (DLP).
- Fused Deposition Modelling (FDM).
- Selective Laser Sintering (SLS).
- Selective Laser Melting (SLM).
- Electronic Beam Melting (EBM).
- Laminated Object Manufacturing (LOM).
- Binder Jetting (BJ).

Each of these methods have pros and cons and suitability of several parameters need consideration before making a method selection. The parameters are machine and/or material selection, design considerations and software limitations, application and post-processing considerations (Edgar and Tint, 2015)

Mentioned by Fernandes (2019), in AM typically involve producing components from raw materials that may be present as filament, powder or solid blocks. As declared in scope section, FDM method is selected because PLA material compatible as the additive material in form of filament similarly with ABS, PC and PA (Pandey, 2014).

The difference between AM and subtractive manufacturing is the ways of production but the result in term of strength is still the same. According to Ezeh (2018), after conducting statistical analysis by referring researched data, it come to the conclusion that AM characterization by fatigue performance is similar to the one that manufactured using conventional (subtractive manufacturing) and well-establish technologies.

2.4 Fused Deposition Modelling (FDM)

FDM rapid prototyping system can produce relatively complicated parts based on CAD model. The processes that involve in FDM are a filament is fed through heated nozzle and become semi-liquid and deposited onto the bed or on going constructed layer. The nozzle or head moves in X-Y directions and deposited the heated material a complete layer before continuing the same X-Y direction for the next layer (Z-direction). After completed the model, it is not requires hardening process because the nozzle attached with a fan which is directly blow to the newly-deposited material and harden the material occasionally (Dudek, 2013).

Same as the other type of methods, there are size restriction for the product to be printed. The size of product logically smaller than the size of the printer casing. For bigger product, it requires additional time to assemble the parts that have been printed separately (Attaran. M, 2017).

2.5 Summary of Literature review

The literature reviews listed above are referral for this study. The definitions stated are related to the study. Many data and methodology are taken based on the reviews. There are multiple of articles suggest the same ways to research the properties of recycled PLA.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will elaborate the detail about design, fabricate and analyze the specimen. The practice in this study refer previous researched article and journal that have been made entire the globe. Declaring the methodology is important for having a smooth study or research, especially in engineering and science field. A smooth study can prevent unexpected and miscellaneous error.

In this chapter, the methodology of this study will be divided into three major parts which are designing process, fabricate, and analyze method.

3.2 Gantt Chart

Gantt chart shows in Table 3.1 is the project schedule for PSM 1. It is encouraged to accomplish every task stated in each row in the table within the estimated time assign as shown in column side in the table. For the PSM 1, it is estimated complete by 15th week from the PSM registration.

Table 3.1: Gantt chart for PSM 1

Undergraduate Project 1															
Activity	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-Understanding the title, Objective and Problem statement of study															
-Chapter 1; Introduction															
-Submission the draft															
Submit progress report															
-Chapter 2: Literature review															
-Submission the draft															
-Chapter 3: Methodology															
-Submission the draft															
Chapter 4: Summary															
Submission Final report															
Project seminar															

Table 3.2 shows the Gantt chart for PSM 2. It is encouraged to accomplish every task stated in each row in the table within the estimated time assign as shown in column side in the table.

Table 3.2: Gantt chart for PSM 2

Undergraduate Project 2															
Activity	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-Chapter 4; Result and Analysis															
-Submission the draft															
Submit progress report															
-Chapter 5: Conclusion and Recommendation															
-Submission the draft															
Preparing Final draft															
Submission Final report															
Project seminar															

3.3 General Experiment Setup

PLA is categorized as plastic material (Ezeh et al, 2018). The mechanical characterization of PLA which is tensile test need to be conducted follow to the standardized test procedure specialized for plastic, ASTM D638. In this experiment, a standard specimen's geometry Type IV is used for this characterization process (ASTM Standard D638, 2014).

Firstly, to make comparison we need to characterize the PLA's 3D-printed specimens. Then characterize the recycled PLA's 3D-printed specimens. For preparing the recycled PLA filament, the PLA filament going through several process which are shredding, drying and extrude processes. Then, fabricate these two filaments using 3D-printer becoming specimens for testing. After this, the characterization process takes place as mentioned above which is the objective of the study. The comparison parameters in this study is tensile strength properties.

The design of experiment shown in 3.1 in flow chart approach for better understanding which is simplifying all the processes included in this study such as preparation of the specimens before the experiment, during experiment, and post-experiment analysis.

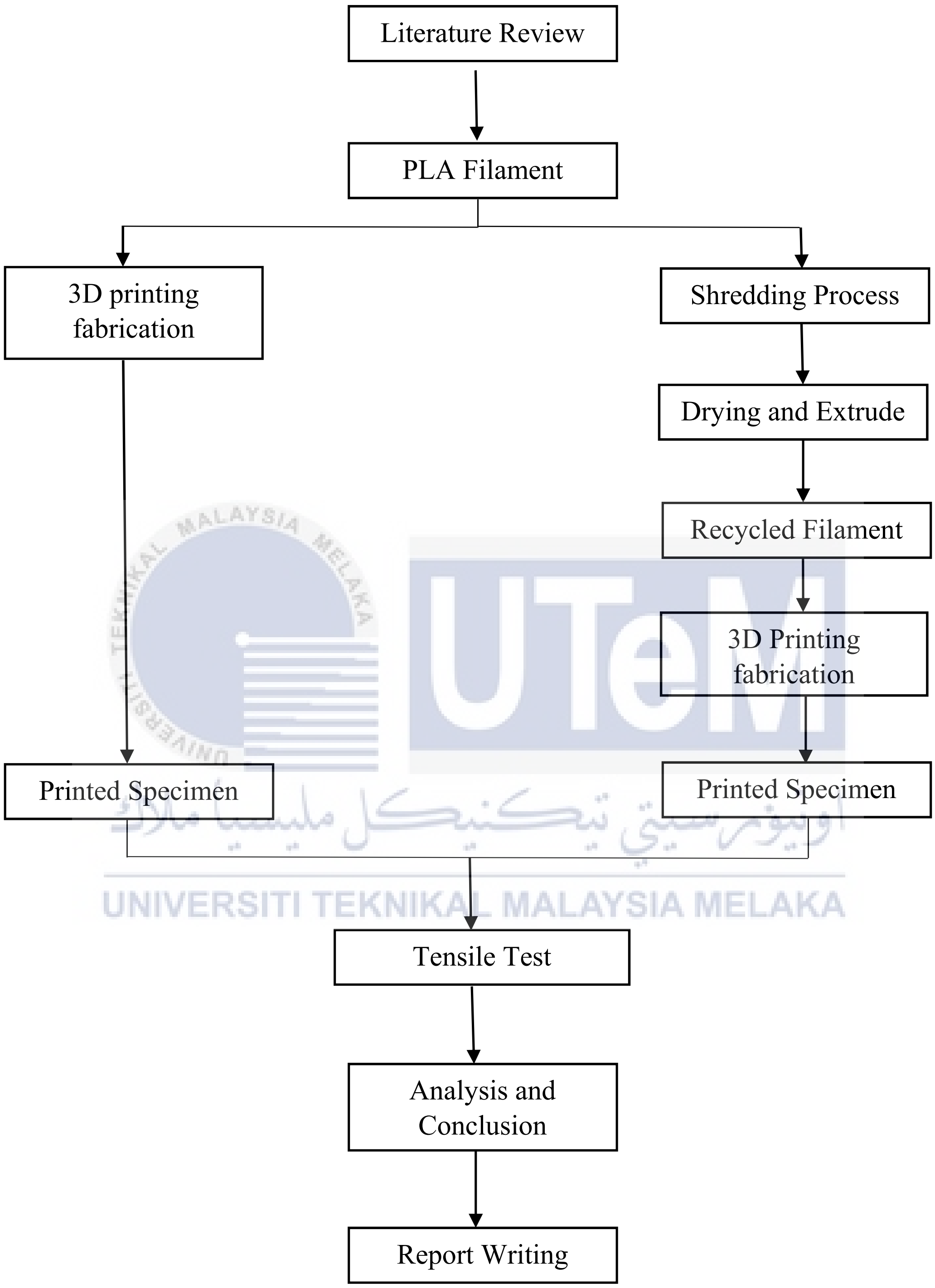

Figure 3.1: Flow chart of the experiment.

3.3.1 Designing the Specimen

The evaluation of 3D-printed PLA test specimen is conducted by referring ASTM D638 standard procedure. There are five types of specimen design in ASTM D638. Researchers usually testing PLA material on Type I standard. In this study, the PLA test specimen conducted following Type IV design as the Type IV also having slightly similar result as simulation compare to Type I (Kumar and Narayan, 2019).

Solidworks software is used for designing the model specimens as specified in ASTM D638 Type IV standard as shown in Fig. 3.2 and Table 3.2 then saved in .stl file format. Next, the model in .stl file imported to Cura (3D-printing software) to set the parameters for printing the specimens.

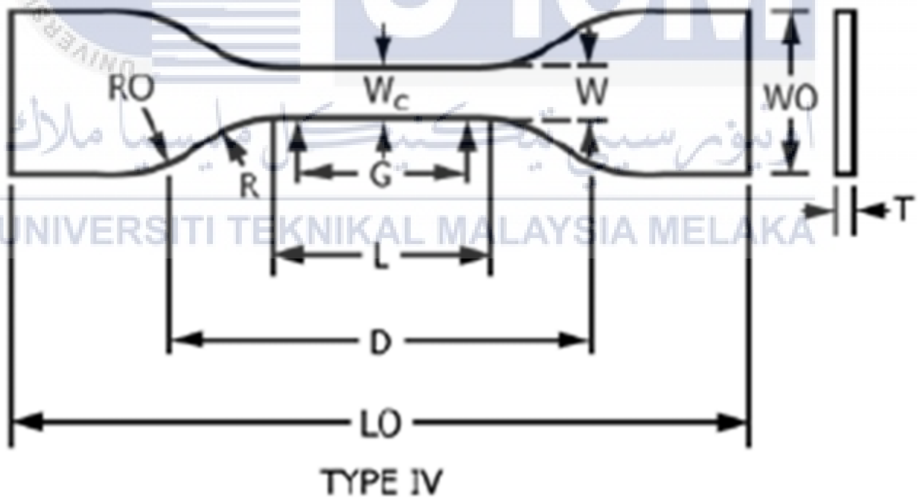

Figure 3.2: Specimen’s geometry for ASTM D638
(Source: ASTM Standard D638, 2014)

Table 3.3: Detailed dimension for Specimen.

(Source: ASTM Standard D638, 2014)

Dimension (refer Figure 3.2)	Values (mm)
T – Thickness	4
W – Width of narrow section	6
L – Length of narrow section	33
WO – Width overall	19
LO – Length overall	115
G – Gage length	25
D – Distance between grips	65
R – radius of fillet	14
RO – Outer radius	25

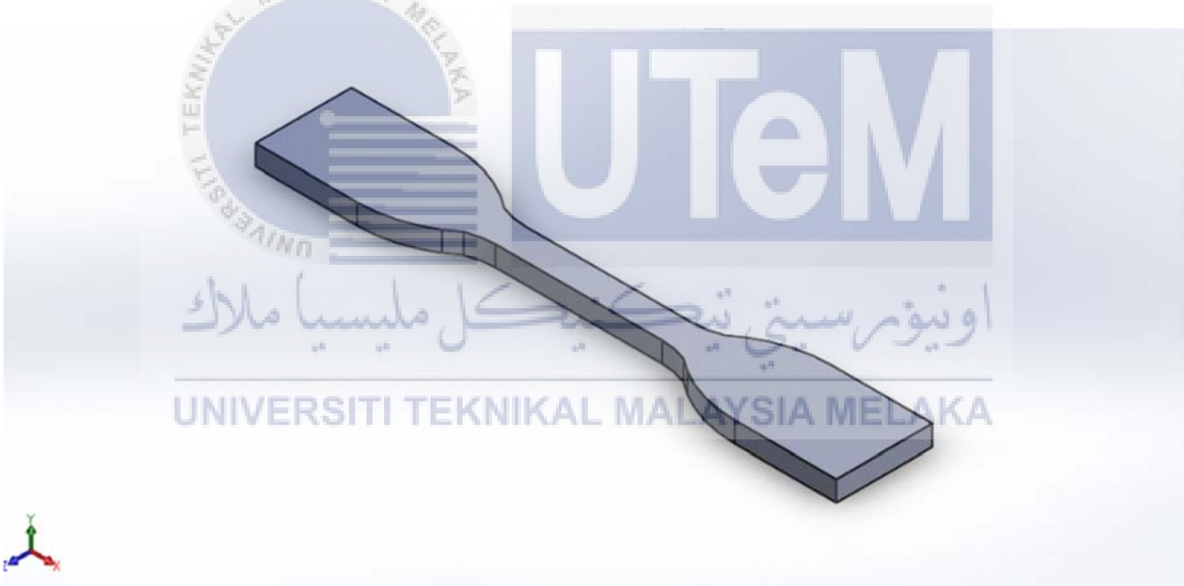

Figure 3.3: Modelling Specimen in SolidWorks Software.

3.3.2 Detailed Dimension

In this design, it can be conclude that the smallest cross-sectional area is the critical point to fracture first which is the narrow section. Hence, the extensometer will be placed at both end of narrow section to take reading of the strain. This study will be focusing only at the narrow section. For the bulky section, it is only for grasping (fixed ends). The differences of these two section needed to be made for prohibited fracture outside the extensometer range.

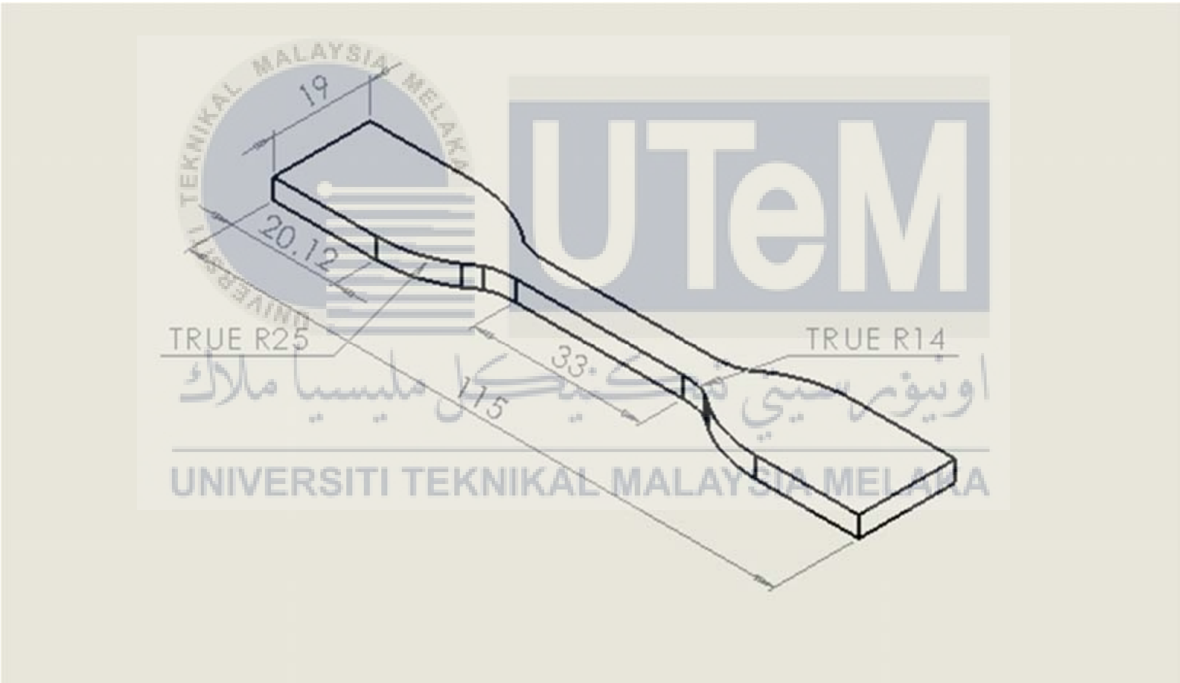

Figure 3.4: Detailed Dimension of Specimen model.

3.3.3 Fabrication of the Specimen

The imported .stl file format then opened on Cura software as depicted in Fig. 3.6. Next, the printing parameter are set as shown in table 3.2 in Cura software. For making this fabrication faster, the parameter set to print 5 specimens at once .Then, save the setting in .gcode file format which is a language that can be read by Anet A8 3D printer as shown in Fig. 3.5 as the additive manufacturing fabrication process can be done easily. The printed specimen can be seen in Fig. 3.7.

Table 3.4: 3D Printing parameters.

Parameters	Unit	Values
Layer Height	mm	0.3
Shell Thickness	mm	1.6
Fill Density	%	100
Print Speed	mm/s	80
Printing Temperature	°C	200
Bed Temperature	°C	60
Filament Flow	%	100

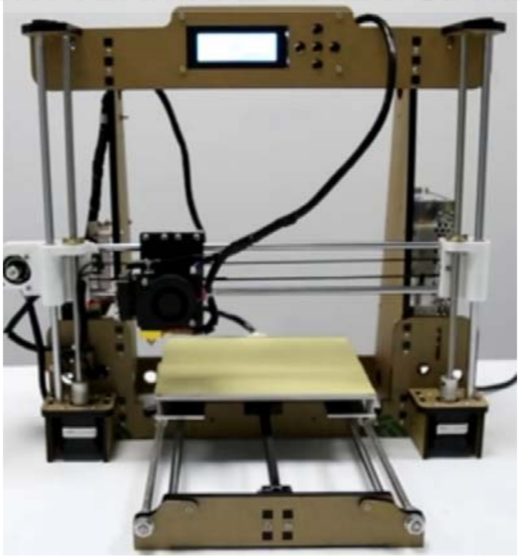

Figure 3.5: Anet A8 3D-Printer.

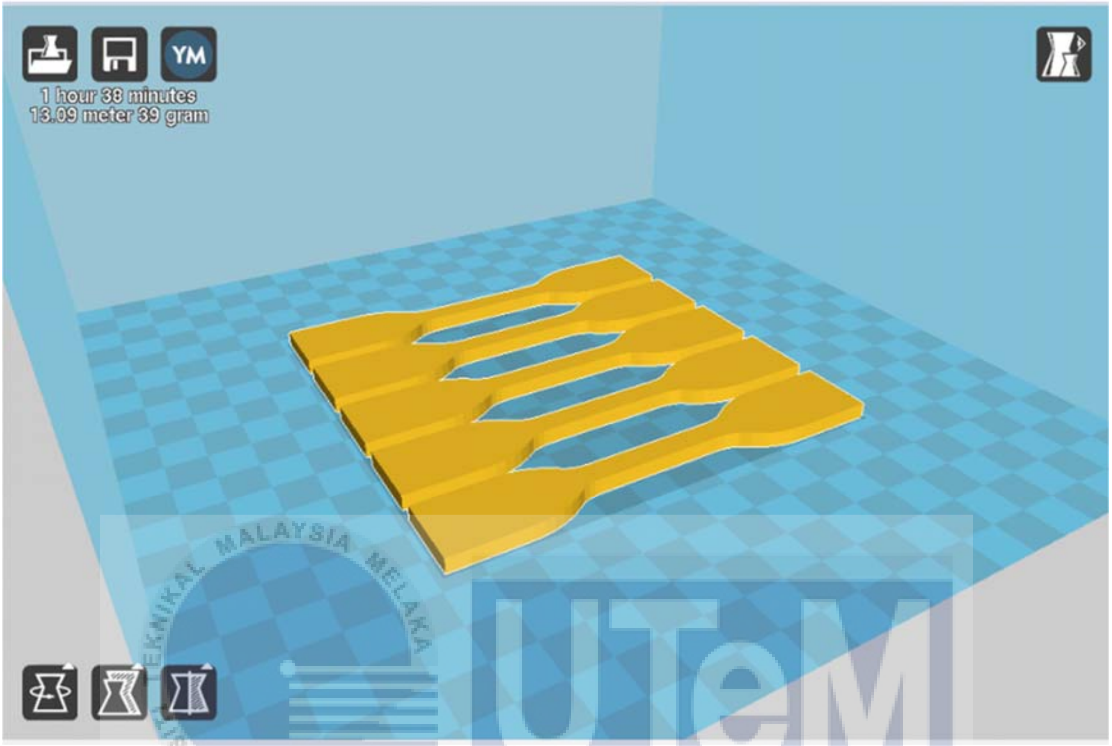

Figure 3.6: Setting printing parameters in Cura Software.


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Figure 3.7: Printed Specimen.

3.3.4 PLA Recycle Process

PLA recycle consists of two processes. Shredding process and extrude into filament. The recycling of PLA doesn’t involve strengthening substance or treatment. It is just shredded PLA which later being heated at certain degree Celsius and extruded into filaments.

For shredding process, several 3D-printed PLA product that having no uses and waste are taken as the recycle material in this study. The process started with collecting the materials and shred them into small pieces such as powders and pellets. The next steps will use extruder machine to extrude shredded material with temperature set at 180-240°C into filament shape (Zhao et. al, 2018). Then die with diameter of 1.75mm and filament extruded need to have constant diameter along its length for making it compatible with the 3D-printer.

3.3.5 Tensile Test

The objectives of this experiment are to obtain the Tensile Stress, Modulus of Elasticity and tensile strain by recording the stress at rupture and elongation at break (Gamez-Perez et al, 2011). As to achieve the objective, several apparatus and testing machine, Instron 3369 Universal Testing Machine (UTM) as depicted in Figure 3.8 need to be prepared and follow the standard procedure which is ASTM D638

Figure 3.8: Instron 3369 UTM.

The apparatus and testing machine required are:

i. Instron 3369 UTM.
ii. Fixed and self-aligning grips.
iii. Specimens.
iv. Crosshead extension indicator.
v. Computer using Instron software.

Referring the standard, each stage of testing needed to be repeated five times and the average from these five results is taken as a single result. Furthermore, the speed of testing value is 5 mm/min (Nominal strain rate at start). From each complete experiment, the experimental data that collected are Load at Break, L_b and Elongation at break, δ_b.

The tensile strain, ε can be calculated by dividing the δ_b by the initial distance of the gauges position, L_o = 25mm. Then we can calculate the tensile stress, σ using the equation,

$$\sigma = \frac{L_b}{A} \tag{2.1}$$

Where A = cross-sectional area of narrow section.

After obtaining the tensile stress, we can calculate the Modulus of Elasticity, E by using the Hooke's Law equation,

$$E = \frac{\sigma}{\varepsilon} \tag{2.2}$$

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the diameter reading from extruding recycled PLA and the result of mechanical characterization analysis will be discussed. An experiment has been conducted to determine the tensile strength by following ASTM D638 using Instron UTM. The experiment has been follow ASTM D638 standard.

4.2 Result

The diameter reading of the recycled filament have been recorded in table 4.1. in increasing the reliability of the result, five sets of filament were extruded in 1 meter length. The reading take place at 5 different spots which are at its 0.1, 0.3, 0.5, 0.7, 0.9 meter. The average diameter from all sets is representing the performance of the extruder machine.

Table 4.1: Diameter reading of the extruded recycled PLA filament.

Sets	0.1	0.3	0.5	0.7	0.9	Average
1	1.60	1.25	1.55	1.65	1.65	1.54
2	1.70	1.50	1.65	1.65	1.50	1.60
3	1.45	1.75	1.60	1.55	1.60	1.59
4	1.55	1.65	1.60	1.70	1.60	1.62
5	1.75	1.70	1.80	1.75	1.75	1.75
					Ave.	1.62

For analysis, the experimental data were collected from Instron software and computer which is computer-generated connected to Instron UTM machine during experiment. It is observed that all the specimens followed similar pattern. The experiment was repeated five times as per ASTM D638 requirement to get accurate result.

Figure 4.1 shows the experimental data for the original PLA specimens and figure 4.1 shows the experimental data for recycled PLA specimens. Both computer-generated result include a tensile stress against tensile strain graph and followed with several tensile strength properties such as maximum load, maximum deformation, elongation at break, and modulus elasticity. The graph also shows the pattern of each specimens that can concluded other mechanical properties such as ductility. Further explanation of the obtained data were prepared at the discussion section.

Figure 4.1: Data from Instron Machine for original PLA

Figure 4.2: Data from Instron machine for recycled PLA

4.3 DISCUSSSION

The reliability and accuracy of the obtained data can be validated by comparing to studies with similar parameter settings. From the experiment data, the results are slightly similar to the article result in term of maximum load, deformation, strain value, and Elastic Modulus value.

Table 4.2: Experimental result original PLA

Specimen	Maximum Load, L (N)	Maximum Deformation, δ (mm)	Elongation at break, ε (%)	Elastic Modulus, E (N/m^2)
1	1202.46	1.2153	4.86	1787.78
2	1237.60	1.4485	5.79	1908.08
3	1341.94	1.4314	5.73	1949.33
4	1235.60	1.5066	6.03	1842.51
5	1244.16	1.2977	5.19	1830.07
Average	1252.35	1.3799	5.52	1863.55

Table 4.3: Tensile test value from article.

(Source: Kumar and Narayan, 2019)

Specimen	Maximum Load (N)	Maximum Deformation (mm)	Elongation at break (%)	Elastic Modulus (N/m^2)
1	1489.53	2.2600	5.65	1865.52
2	1391.02	2.3100	5.78	1816.07
3	1317.03	2.2430	5.61	1792.79
4	1428.67	2.4940	6.24	1714.58
5	1421.48	2.3050	5.76	1822.14
Average	1409.55	2.3224	5.81	1802.22

The percentage difference of original PLA for every parameters are:

- Max load is 11.2% lower.
- Max deformation is 40.6% lower.
- The strain value is 5.0% lower; and
- The elastic modulus is 3.4% lower than Kumar and Narayan (2019) results.

Referring the recycled PLA specimen data, the decreases value of the tensile properties can be compare with the original PLA specimen as shown in table 4.4. By using article produced by Zenkiewicz. M, et.al (2009), the validity of the comparison can be justified.

Table 4.4: Comparison between original PLA and recycled PLA.

Parameter	Original PLA	Recycled PLA	Difference percentage (%)	Difference percentage (%) from Zenkiewicsz. M, et.al (2009).
Max. tensile stress	52.18 MPa	49.38 MPa	5.37	5.20
Tensile stress at break	44.20 MPa	46.35 MPa	4.86	8.30
Tensile strain at yield	0.031	0.030	3.23	2.40
Tensile strain at break	0.055	0.038	30.90	10.20

The percentage error of this result compare to the article for every parameters are:

- Max tensile stress is 3.27% higher.
- Tensile stress at break is 41.45% lower.
- The tensile strain at yield is 34.58% higher; and
- The tensile strain at break is 202.94%% higher than Zenkiewicz. M, et.al (2009) conclusion.

By referring the finding by Zenkiewicz. M et al. (2009), the comparison only made up to two cycles of recycle while the article repeated the cycle up to ten cycles. The percentage difference between recycled and original PLA found in this study lies within the range prepared by the article except for the tensile strain at break which is beyond the article findings value.

The value decreasing may cause by 3D-printing process, which introduces more thermal changes experienced by the PLA itself. Referring figure 4.1 and 4.2, the graph show the ductility more on the original PLA. As PLA have been recycled and extruded, it become stiffer and more brittle. Zenkiewicz. M et al. (2009) also concluded that the mechanical properties of recycled PLA exhibit slight changes for one recycle process and become larger as the number of the recycle process increases.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the objectives of this project had been fulfilled. This project report is divided into five chapters which are introduction, literature review, methodology, result and discussion, and conclusion and recommendation.

The recycled filament had been extruded successfully using extruder machine with average diameter of 1.62 mm instead of standard diameter 1.75 mm. The suitable temperature for extruder machine is 205°celcius for getting the best form of filament. The filament then can be printed into specimen using 3D-printer which means it is sustainable for 3D-printing process. For the analysis, the recycled PLA properties can be compared as having a decrease value of the most parameters from the original PLA properties. The maximum tensile stress 5.37% lower, tensile stress at break 4.86% higher, tensile strain at yield 3.23% lower, tensile strain at break 30.9% lower, elongation at break 28.3% lower, and young's modulus 4.387% lower than original PLA.

5.2 Recommendation

During this project, there are several recommendation for the development in term of diameter consistency of the recycled filament which are the design or processing concept of the extruder machine can be optimized to reduce the problem during printing the filament. The Anet A8 3d-printer having 1.75mm input filament hole with upper tolerance of +0.02mm which means the filament cannot be feed in or getting stuck if any point of the filament having diameter larger than 1.75mm. This incidents occur many times during fabrication the recycled PLA specimens which delayed the progress of the study.

Another recommendation is to modify the input filament hole at the 3D-printer to accept the inconsistency of the filament diameter for making the recycled filament sustainable for 3D-printing process.

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