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

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This report is submitted
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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.

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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).

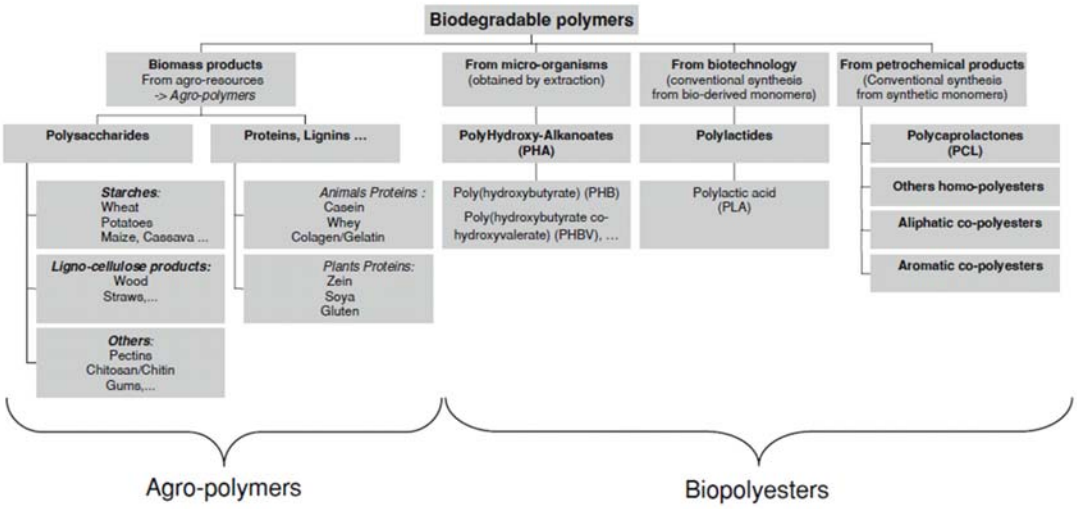

Figure 1.1: Classification of the main biodegradable polymer

(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.

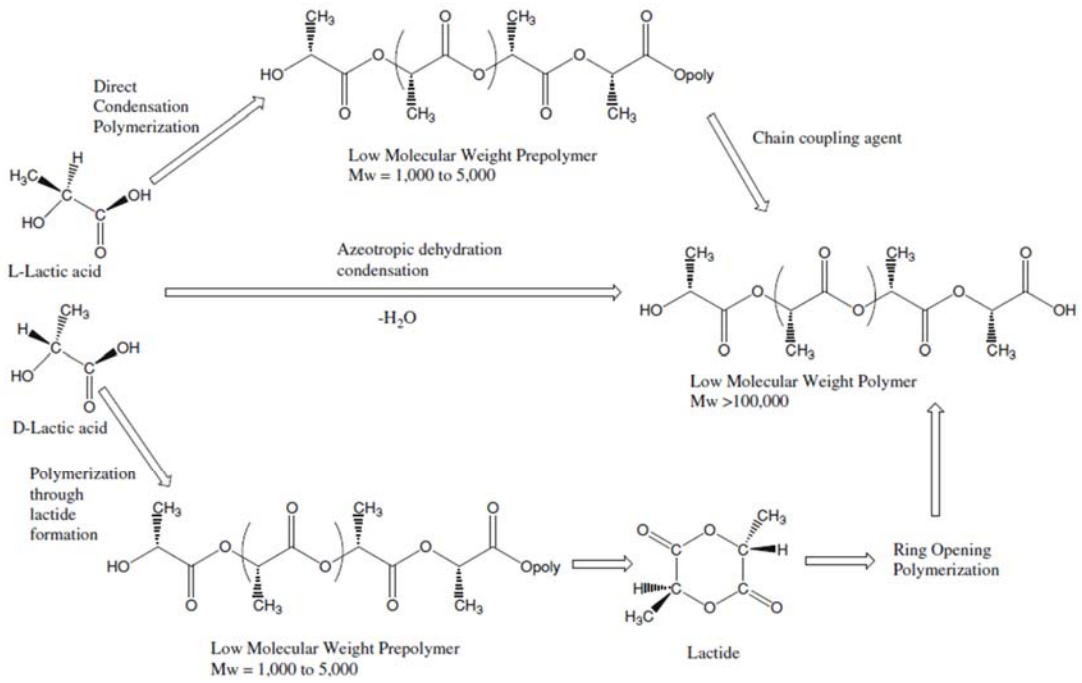

Figure 2.1: Chemical structure of PLA and ROP method for obtaining high molecular weight. (Source: Avérous and Pollet, 2012)

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).