# EFFECTS OF HUMIDITY ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF 3D PRINTED PLA FILAMENT

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

by


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I hereby, declared this report entitled "Effects of Humidity on Mechanical Properties and Microstructure of 3D Printed PLA Filament" is the result of my own research except as cited in references.

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# APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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# ABSTRAK

Filamen asid polilaktik (PLA) sensitif terhadap kelembapan kerana sifat higroskopiknya menyebabkan gelembung dan kualiti cetakan yang kurang baik. Ramai pengguna Fused Deposition Modelling (FDM) mengabaikan kawalan kelembapan dan cara penyimpanan filamen yang betul selepas digunakan. Banyak kajian memberi tumpuan kepada kesan parameter proses pada bahagian cetakan 3D; tetapi pengaruh kelembapan pada kualiti percetakan kurang diterokai. Kelembapan boleh mempengaruhi sifat-sifat mekanikal bahagian cetakan 3D kerana kewujudan air boleh mengubah ikatan rantai polimer justeru melemahkan kekuatan mekanikal. Objektif kajian ini adalah untuk mengkajit pengaruh kelembapan pada kekuatan tegangan dan lenturan serta perubahan mikrostruktur. Oleh itu, tiga tetapan bersyarat telah dihasilkan; menggunakan gulungan PLA baru sebagai rujukan, gulungan PLA yang disimpan dalam beg vakum bersama agen pengering, dan gulungan PLA yang disimpan dalam persekitaran terbuka, terdedah kepada kelembapan selama 24 - 150 jam. Filamen ini digunakan untuk menghasilkan spesimen yang mematuhi ASTM D638 – Jenis IV (spesimen tegangan) dan ASTM D790 (spesimen lenturan) untuk diuji pada Mesin Ujian Universal Shimadzu AGS-X (UTM) pada kelajuan 5mm/s, dan 50 mm/s. Spesimen tegangan yang telah patah kemudiannya disalut dan digunakan pada mesin Scaning Electron Microscope (SEM) untuk mengkaji mikrostrukturnya. Keputusan menunjukkan bahawa kelembapan mengurangkan kekuatan tegangan dan lenturan sambil meningkatkan keupayaan untuk patah. Kehadiran kelembapan memplastikkan polimer, memudahkannya untuk dibentuk dan mengurangkan ketegarannya kerana kelembapan mengubah struktur molekul polimer. Imej SEM menunjukkan bahawa kelembapan memperluaskan jurang interlayer, menggalakkan peningkatan dalam keupayaan untuk patah disebabkan oleh peningkatan ruang pengubahsuaian makromolekul. Namun, kami mendapati bahawa filamen terpakai yang disimpan dalam beg vakum bersama beberapa agen pengering menunjukkan kekuatan tegangan yang setara dengan spesimen rujukan. Kesimpulannya, kelembapan mempengaruhi sifat-sifat mekanikal dan harus dikawal untuk kualiti percetakan bahagian PLA yang baik. Sebagai cadangan, semua pengguna percetakan 3D dinasihatkan untuk menyimpan filamen PLA mereka dalam beg vakum bersama agen pengering untuk menggantikan kabinet pengeringan bagi mengawal kelembapan dalam percetakan.

# ABSTRACT

Polylactic acid (PLA) filament is sensitive to humidity due to its hygroscopic properties, resulting in bubbles and poor printing quality of 3D printed parts. Even though it is significant to control the PLA filament's humidity and store it properly after use, many Fused Deposition Modelling (FDM) users ignore this factor. Many studies focus on the effect of process parameters on the 3D printed part; however, the influence of humidity on the printing quality is less explored. Moisture can influence the mechanical properties of 3D printed parts due to the water's existence, which could alter the polymer chain's bonding, resulting in a lower mechanical strength. The objectives of this study are to investigate the influence of humidity on the tensile strength, fracture strength, and the alteration of microstructure caused by moisture. In order to do so, three conditional settings were established; a new PLA roll acts as the reference, used PLA roll stored in the vacuum bag with desiccant, and used PLA roll stored in an open environment, exposed with the humidifier for 24 - 150 hours. These filaments are subsequently used to fabricate specimens that comply with ASTM D638 – Type IV (tensile specimen) and ASTM D790 (flexural specimen) to be tested in the Shimadzu AGS-X Universal Testing Machine (UTM) at the speed of 5mm/s, and 50 mm/s, respectively. The fractured tensile specimen is then sputter-coated and used in the Scanning Electron Microscope (SEM) machine to study its microstructure. The results show that the humidity decreases the tensile and flexural strength while increasing the fracture strain. The presence of moisture causes the polymer to plasticize, increasing its deformability and reducing its rigidity as the moisture alters its molecular structure. The SEM images show that humidity expands the interlayer gap, promoting enhancement in the fracture strain due to increased macromolecules deformation space. Nevertheless, we found that the used PLA filament stored in a vacuum bag with some desiccants shows an equivalent tensile strength with the reference specimen. To conclude, humidity influences the mechanical properties and should be controlled for a good printing quality of PLA parts. As a recommendation, all 3D printing users are advised to store their PLA filament in a vacuum bag with dehumidifying agents to substitute for the drying cabinet to control the humidity in their printing.

# DEDICATION

This humble work is dedicated to my beloved father, mother and siblings.

# ACKNOWLEDGEMENT

Praises and thanks to Allah, the most gracious and the most merciful, for His countless of blessings throughout my journey to complete this final year project successfully.

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| | | |
|---|---|---|
| 3D | - | Three dimensional |
| ABS | - | Acrylonitrile butadiene styrene |
| AM | - | Additive manufacturing |
| ASTM | - | American society for testing and materials |
| CAD | - | Computer-aided design |
| CAM | - | Computer-aided manufacturing |
| C-O | - | Carbon-Oxygen |
| FDM | - | Fused Deposition Modelling |
| FTIR | - | Fourier transform infrared |
| HIPS | - | High-intensity polystyrene |
| ISO | - | International Organization for Standardization |
| Mw | - | Molecular weight |
| N-H | - | Nitrogen-Hydrogen |
| PC | - | Polycarbonate |
| PDLA | - | Poly (D-lactic acid) |
| PDLLA | - | Amorphous poly (D, L-lactic acid) |
| PE | - | Percentage of error |
| PEEK | - | Polyether ether ketone |
| PEI | - | Polyetherimide |
| PET | - | Polyethylene terephthalate |
| PETG | - | Polyethylene terephthalate glycol |
| PLA | - | Polylactic acid |
| PLLA | - | Poly (L-lactic acid) |
| PPSF | - | Polyphenylsulfone |
| PSM | - | Projek Sarjana Muda |
| Pt | - | Platinum |
| ROP | - | Ring opening polymerization |
| RP | - | Rapid prototyping |
| SEM | - | Scanning electron microscope |

| | | |
|---|---|---|
| SLA | - | Stereolithography |
| STL | - | Standard triangle language |
| Tg | - | Glass transition temperature |
| THF | - | Tetrahydrofuran |
| Tm | - | Melting temperature |
| TPU | - | Thermoplastic polyurethane |
| UFM | - | Universal tensile machine |
| UFS | - | Ultimate flexural strength |
| UTS | - | Ultimate tensile strength |

# LIST OF EQUATIONS

# LIST OF SYMBOLS

| | | |
|---|---|---|
| % | - | Percent |
| ° | - | Degree |
| °C | - | Degree Celsius |
| $cm^{-1}$ | - | Centimetre power $^{-1}$ |
| dl/g | - | Decilitre per gram |
| $g/cm^3$ | - | Gram per centimetre cube |
| $g/m^3$ | - | Gram per metre cube |
| g/ml | - | Gram per millilitre |
| g/mol | - | Gram per molecule |
| J/g | - | Joule per gram |
| K | - | Kelvin |
| Kg | - | Kilogram |
| kJ/mol | - | Kilo joule per molecule |
| kN | - | Kilonewton |
| lbs | - | Pounds |
| mg/l | - | Milligram per metre |
| mm | - | Millimetre |
| mm/min | - | Millimetre per minute |
| mm/s | - | Millimetre per second |
| N | - | Newton |
| $N/mm^2$ | - | Newton per millimetre square |
| nm | - | Nano metre |
| $\Delta H°m$ | - | Enthalpy |
| µm | - | Micron metre |

# CHAPTER 1
# INTRODUCTION

This chapter describes the introduction of this research work, including the background, problem statement, objective, scope, and significance of the study. A study on the effect of humidity on the mechanical properties and microstructure of 3D printed PLA filament is carried out in this report.

## 1.1 Background

Additive Manufacturing (AM) or 3D printing is a modern manufacturing technology that has experienced massive growth over the last few years. 3D printing allows physical models and complex geometric structures to be produced with high precision and low cost. Due to the personalized and straightforward manufacturing of functional models, conceptual models, and prototypes, 3D printing has been hugely embraced by the military, automotive, medical, food industry, aircraft, and other allied industries (Mohamed, Masood & Bhowmik, 2015).

According to Zhang, Fan, and Liu (2020), Fused Deposition Modelling (FDM) is one of the mainly utilized AM processes because of its ease and availability of machinery with reasonable costs that employs thermoplastic materials as hot melt adhesive properties. Kwon *et al.* (2020) declared that FDM is among the most prevalent processes owing to its adaptability and low expense. Three-dimensional structures that integrate the primary material in layers via the heated nozzle of the FDM 3D printer are produced in the FDM process. The nozzle's horizontal and vertical directions are entirely funded by the software called computer-aided manufacturing (CAM).

Filaments from thermoplastics such as polycarbonate (PC), acrylonitrile butadiene styrene (ABS), and polylactic acid (PLA) are typically used as the raw material instead of metals in this technology because of their low melting point and its ability to melt continuously under heat and to be re-solidified after the heat is removed (Wang *et al.,* 2017). Consequently, this helps the FDM printer to produce a solid product after the semi-liquid extrusion of the raw material.

Different variables determine the properties of the filament's materials. Humidity is one of the key factors influencing the filament's properties, as shown in Figure 1. For example, if the polylactic acid (PLA) filament has been subjected to heavy moisture for an extended period, the filament has lost tensile strength at the time of printing which allows bubbles to emerge on the surface of the product (Valerga *et al.,* 2018). Additionally, PLA is susceptible to humidity, and changes in its properties are caused by exposure to high humidity. As humidity increases, it has been recorded that the elongation ratio, degradation rate, and average molecular weight decrease (Liu *et al.,* 2017).

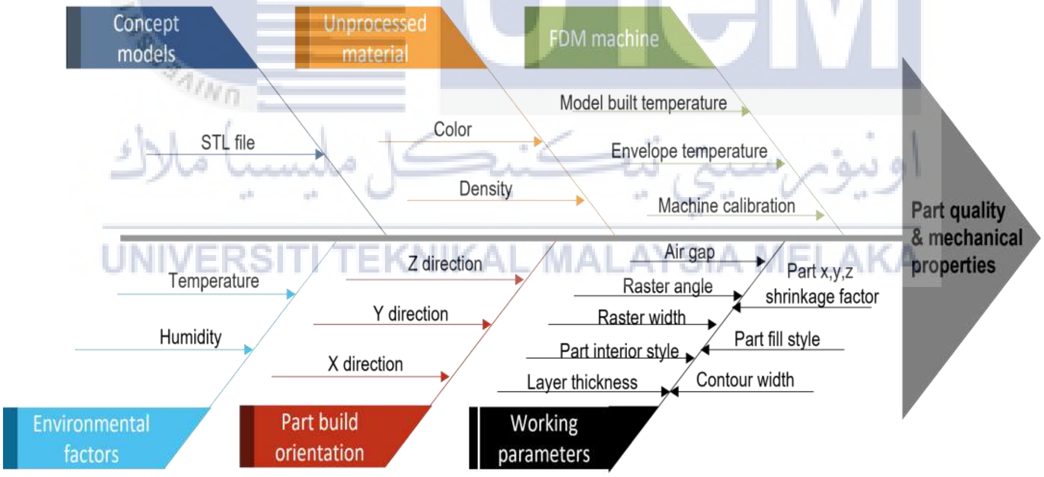


Figure 1.1: The cause-and-effect diagram of FDM process parameters (Mohamed, Masood & Bhowmik, 2015)

In this study, the effect of humidity on the mechanical properties, which includes tensile strength and flexural strength, and microstructure of the PLA printed parts exposed to various humidity environments was investigated.

## 1.2 Problem Statements

Polyesters are widely recognized for absorbing humidity, and the presence of moisture causes severe degradation events. The degradation is mainly caused by the hydrolysis of macromolecular chains, which significantly reduces molecular weight (Titone *et al.,* 2021). According to Mallick *et al.* (2018), polylactic acid (PLA) or polylactide is a biologically degradable and bioactive polyester consisting of building blocks of lactic acid. The filaments of PLA are made of fermented plant starch such as maize, sugarcane, sugar beet pulp, and cassava, making them distinct from other thermoplastics. Lesaffre *et al.* (2017) suggested that PLA is sensitive to such environmental restrictions. Exposure to different natural weather factors such as sunlight, rainfall, and humidity, typically contributes to the aging of the substance, which will affect both the physico-chemical and fire-resistant properties of the material.

Filaments made of PLA possess hygroscopic characteristics that appear to absorb moisture from the air, which contributes to inconsistent and poor printing quality (Dwamena, 2020). Suppose the filaments are stored in a humid environment. In that case, the water vapor tends to be absorbed, and steam is generated during the heating process, resulting in an imperfect product surface at the end of the process. In addition, this will lead to a generation of bubbles on the surface of the printed part. Valerga *et al.* (2018) stated that the filament had reduced tensile strength if the PLA filament is exposed to high humidity for an extended period. Therefore, the filaments must be kept sealed in a vacuum so that the filaments are still in a dry condition to ensure good printing quality. A study on the effect of humidity on the mechanical properties and microstructure of the 3D printed PLA specimens still lacks, which encouraged this study to be carried out. On the other hand, dehumidifying agents like silica gel or desiccant might be able to control the moisture content in the PLA filament. However, it is unknown to what extent it works and how it influences the PLA specimen's mechanical properties compared to the new PLA filament. Therefore, in this study, an attempt to investigate the influence of using these items on the mechanical properties of the PLA specimen is also conducted.

## 1.3 Objectives of Study

The objectives of this study are:

(a) To analyze the tensile strength of the 3D specimens fabricated using the non-exposed and moisture-exposed PLA filaments.

(b) To examine the flexural strength of the 3D parts produced from the non-exposed and moisture-exposed PLA filaments.

(c) To investigate the microstructure of the fractured 3D printed tensile samples using the Scanning Electron Microscope (SEM).

## 1.4 Scope of Study

The scope of this study are as follows:

(a) In this study, a 1.75 mm diameter of the PLA filament (light blue) was used for all conditions.



(b) The humidity level was decided through three conditions as follows:

i. New PLA filament roll, which acts as the reference.

ii. Used PLA filament roll stored in the vacuum bag, with the desiccant.

iii. Used PLA filament roll stored in an open environment, exposed to a humidifier for variant of 24, 48, 72, 96, 120, and 150 hours.

(c) The printing parameters for all conditions were similar, with three replications of each conditional setting.

(d) The FDM machine, FlashForge's Adventurer3, was used to print the samples.

(e) The analysis of the tensile strength (ASTM D638 – Type IV) and flexural test (ASTM D790 of the FDM printed parts were carried out to investigate the influence of humidity on the quality of printing.

(f) The fractured tensile samples which have the closest maximum force value to the average value were used for the analysis of the microstructure using the scanning electron microscope (SEM) due to the limitation of laboratory usage during the Covid-19 pandemic outbreak.

(g) The samples used for SEM analysis were cut into 10 mm and then sputter-coated with 10nm thick of gold-palladium using SC 7620 Mini Sputter Coater machine.

## 1.5 Significance of Study

This study helps to analyse and examine the effect of moisture on PLA mechanical properties and microstructure. If the humidity is found to be affecting the quality and properties of the printed parts, a clear message to emphasize the importance of controlling this factor could be highlighted. Thus, it can improve the printing quality of parts produced from PLA and reduce the PLA waste. The reduction of 3D printing waste can promote sustainable 3D printing since the number of 3D printer users is increasing due to its affordability. In addition, the mechanical properties of the PLA filament, which is stored with desiccant in a vacuum bag, are found to be equivalent to the new PLA filament. This finding shows that the use of dehumidifying agents is sufficient to keep the humidity away from the used PLA filament to substitute drying rack, which is too costly for hobbyists. Therefore, it is hoped that this study could prove the effect of humidity on the printing quality of parts and simultaneously create awareness for all 3D printer users.

## 1.6 Organization of Report

In this study, there are five chapters consisting of introduction, literature review, methodology, result and discussion, conclusion and recommendation. Chapter 1 began with a study background, problem statement, objectives, and scope of the study. Chapter 2 comprised of previous study or research about the FDM process, PLA filaments, the influence of humidity towards the 3D printed parts, and the testing method of the mechanical properties. The methodology to achieve the stated objectives were explained in Chapter 3. Later, Chapter 4 analysed the tensile strength, flexural test and SEM analysis results. Lastly, the conclusion and recommendation about this study were discussed in Chapter 5.