A COMPARATIVE STUDY OF SURFACE ROUGHNESS, TENSILE STRENGTH, MICROSTRUCTURE, AND POROSITY OF THE UN-DRIED AND PRE-DRIED PETG/TPU FDM FILAMENTS

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

by

SITI AISHAH BINTI BAKRULAZI

B051810204

970916-04-5282

FACULTY OF MANUFACTURING ENGINEERING

2022

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **A COMPARATIVE STUDY OF SURFACE ROUGHNESS, TENSILE STRENGTH, MICROSTRUCTURE, AND POROSITY OF THE UN-DRIED AND PRE-DRIED PETG/TPU FDM FILAMENTS**

Sesi Pengajian: **2021/2022 Semester II**

Saya **SITI AISHAH BINTI BAKRULAZI (970916-04-5282)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

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

☑ TIDAK TERHAD

Disahkan oleh:

Alamat Tetap:
Km 18, Kampung Serkam Anak Air,
77300, Merlimau, Melaka.

Cop Rasmi:
DR RAHIMAH BINTI HJ ABDUL HAMID
Senior Lecturer
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka

Tarikh: 30/6/2022

Tarikh: 30/6/2022

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled "A Comparative Study of Surface Roughness, Tensile Strength, Microstructure, And Porosity of The Un-Dried and Pre-Dried PETG/TPU FDM Filaments" is the result of my own research except as cited in references.

Signature : ……………………………………….

Author's Name : SITI AISHAH BINTI BAKRULAZI

Date : 30/6/2022

APPROVAL

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

……………………………………………………………

(DR RAHIMAH BINTI ABD HAMID)

ABSTRAK

PETG dan filamen TPU adalah higroskopik, menyebabkan buih dan kualiti cetakan yang lemah dalam bahagian cetakan 3D. Mengeringkan filamen sebelum mencetak boleh menghilangkan lembapan dan meningkatkan kualiti permukaan, memulihkan prestasi asalnya dan menghalang liang-liang. Kesan kelembapan terhadap kualiti cetakan 3D printing kurang di terokai. Kelembapan boleh mengubah kekuatan tegangan dan topografi permukaan dengan menyebabkan kekasaran dan keliangan bahagian bercetak 3D. Kajian ini menggunakan ANOVA untuk menganalisis kekasaran permukaan bahagian PETG dan TPU cetakan 3D. Sampel pra-kering mempunyai permukaan yang lebih licin daripada sampel yang belum kering. TPU lebih kasar daripada PETG kerana ia mempunyai kekasaran permukaan yang lebih tinggi. Kajian ini mengukur kekuatan tegangan bahagian PETG dan TPU cetakan 3D pra-kering menggunakan Mesin Pengujian Universal dan mendapati ia lebih kuat daripada sampel yang tidak kering. Kekuatan tegangan meningkat dengan pengeringan. Kajian ini menilai struktur mikro keratan rentas bahagian cetakan 3D yang patah menggunakan SEM. Sampel yang tidak kering mempunyai jurang antara lapisan yang lebih besar, liang manik, dan corak resapan yang tidak lengkap disebabkan oleh kelembapan. Sampel pra-kering mempunyai lebih sedikit liang manik dan jurang antara lapisan. PETG mempunyai jurang interlayer kurang daripada TPU. Kajian ini juga menggunakan Prinsip Archimedes untuk mengukur keliangan kepingan PETG dan TPU cetakan 3D. Sampel yang belum kering lebih berliang daripada sampel pra-kering kerana perbezaan ketumpatan antara PETG dan TPU. Sampel yang belum kering berliang dan kurang tumpat. TPU telap dan ia Kurang tumpat daripada PETG. Untuk berbuat demikian, tiga tetapan bersyarat telah diwujudkan; (i) gulungan PETG dan TPU baharu bertindak sebagai rujukan, (ii) gulungan PETG dan TPU terpakai disimpan dalam beg vakum dengan gel silika untuk 50 gram, dan (iii) gulungan PETG dan TPU terpakai disimpan dalam persekitaran terbuka, terdedah dengan pelembap selama 48 jam, 96 jam dan 150 jam. Kertas kerja ini membentangkan penyiasatan komprehensif pertama tentang penilaian kekasaran permukaan, kekuatan tegangan, struktur mikro, dan keliangan filamen PETG/TPU FDM lembap pra-pengeringan. Akibatnya, kaedah pengeringan meningkatkan kekuatan tegangan, kekasaran permukaan dan topografi permukaan, serta mengurangkan keliangan bahagian cetakan 3D. Kajian lanjut diperlukan mengenai analisis FTIR, yang boleh menganalisis komposisi kimia zarah mikro dan nano, dan ujian mampat, yang boleh mengenal pasti modulus keanjalan, had berkadar, titik hasil mampatan, kekuatan hasil mampatan, dan kekuatan mampatan.

ABSTRACT

PETG and TPU filament are hygroscopic, causing bubbles and poor printing quality in 3D printed parts. Drying the filament before printing may remove moisture and improve surface quality, restoring its original performance and preventing pores. The effect of humidity on the quality of 3D printing is less explored. Moisture can alter the tensile strength and surface topography by causing roughness and porosity of 3D printed parts. This study used ANOVA to analyse the surface roughness of 3D printed PETG and TPU parts. Pre-dried samples have a smoother surface than un-dried samples. TPU is rougher than PETG because has higher surface roughness. This study measured the tensile strength of pre-dried 3D printed PETG and TPU parts using a Universal Testing Machine and found they are stronger than un-dried samples. Tensile strength increased with drying. This study evaluates the cross-sectional microstructure of fractured 3D printed parts using SEM. Un-dried samples have larger interlayer gaps, inter-bead pores, and an incomplete diffusion pattern due to dampness. Pre-dried sample had fewer inter-bead pores and interlayer gaps. PETG has less interlayer gaps than TPU. This study also used the Archimedes Principle to measure the porosity of 3D printed PETG and TPU pieces. Un-dried samples are more porous than pre-dried samples due to the density difference between PETG and TPU. Un-dried samples are porous and less dense. TPU is permeable and it is less dense than PETG. In order to do so, three conditional settings were established; (i) a new PETG and TPU roll acts as the reference, (ii) used PETG and TPU roll stored in the vacuum bag with silica gel for 50 grams, and (iii) used PETG and TPU roll stored in an open environment, exposed with the humidifier for 48 hours, 96 hours and 150 hours. This paper presents the first comprehensive investigation on evaluation of surface roughness, tensile strength, microstructure, and porosity of the pre-drying humidified PETG/TPU FDM filament. As a result, the drying method is improving the tensile strength, surface roughness and surface topography, as well as reduce the porosity of the 3D printed parts. Further research is needed on FTIR analysis, which can analyse the chemical composition of micro and nanoscale particles, and compress tests, which can identify the modulus of elasticity, proportional limit, compressive yield point, compressive yield strength, and compressive strength.

DEDICATION

Only
my beloved father, Bakrulazi bin Osman
my true loved mother, Rasidah binti Mohd Said
my siblings, Nurhidayah binti Bakrulazi and Siti Hawa binti Bakrulazi
for giving me moral support, money, cooperation, encouragement, and also understandings
Thank You So Much and Love You All Forever

ACKNOWLEDGEMENT

All praise and thanks to Allah s.w.t, the Almighty, for showering me with His mercy, grace, and blessing. He gave me the strength and the willpower I needed to finish my final year project without any problems.

In this opportunity, I would like to express my sincere thanks and gratitude towards Dr Rahimah binti Abdul Hamid, who has given their full effort in guiding me to achieve my goals, guidance, understanding, patience, and endless support to complete this project. It has been a pleasure to have her as my supervisor.

I would like to thank Encik Nor Akramin bin Mohamad, Chairman of JK PSM Committee, for his valuable guidance and training. His excitement for this undertaking motivated me greatly, and it helped me succeed. He also provides materials that are used as a key reference for this study as well as for addressing and clearing all doubts while doing the project.

Last but not least, my appreciation is also to my parents, siblings, fellow friends and individuals who are directly or indirectly involved giving supports and advises throughout the completion this project. I lack valuable words to thank everyone, but my heart is still full of gratitude. Thank you very much.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	-	Two Dimensional
3D	-	Three Dimensional
ABS	-	Acrylonitrile Butadiene Styrene
AC	-	Alternating Current
AM	-	Additive Manufacturing
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Materials
Au	-	Gold
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CNF	-	Cellulose Nanofiber
CO2	-	Carbon Dioxide
FDM	-	Fused Deposition Modelling
FKP	-	Fakulti Kejuruteraan Pembuatan
H2O	-	Hydrogen
LCD	-	Liquid Crystal Display
Pd	-	Palladium
Pt	-	Platinum
PET	-	Polyethylene Terephthalate
PETG	-	Polyethylene Terephthalate Glycol
PLA	-	Polylactic Acid
PSM	-	Projek Sarjana Muda
RH	-	Relative Humidity
SEM	-	Scanning Electron Microscope
STL	-	Stereolithography
Tg	-	Glass Transition Temperature
TPU	-	Thermoplastic Polyurethane
ULTEM	-	Polyetherimide
UTeM	-	Universiti Teknikal Malaysia Melaka
UTS	-	Ultimate Tensile Strength

LIST OF SYMBOLS

°C	-	Degree Celsius
°F	-	Degree Fahrenheit
°	-	Degree
%	-	Percent
g	-	Gram
g/cm^3	-	Gram per Centimetre Cubic
kg	-	Kilogram
kN	-	Kilo Newton
lbs	-	Pounds
m	-	Metre
mm	-	Millimetre
mm/min	-	Millimetre per Minute
mm/s	-	Millimetre per Second
MPa	-	Megapascals
N	-	Newton
N/mm^2	-	Newton per Square Millimeter
nm	-	Nanometre
ρw	-	Density of distilled water
Ra	-	Arithmetic Average
rpm	-	Revolution per Minute
W	-	Watt
W_a	-	Weight in air
W_w	-	Weight in water
Zi	-	Standard Deviation
µm	-	Micrometre

CHAPTER 1

INTRODUCTION

This chapter describes the introduction of this work, including the background, problem statement, objective, and scope of the study. An investigation of the effect of humidity on the surface roughness, tensile strength, microstructure and density of the pre-dried 3D printed PETG and TPU filament is carried out in this report.

1.1 Background

3D printing, also known as Additive Manufacturing (AM) is a technique of creating three-dimensional (3D) solid items from a computer-aided design (CAD) file. Objects are built in the additive process by laying successive layers of material until the object is finished. When compared to traditional production methods, 3D printing allows the creation of complex shapes with less material. According to Kwon et al. (2020), Fused Deposition Modelling (FDM) is one of the most widely used AM techniques because of its versatility and inexpensive cost. The FDM process creates 3D structures by layering thermoplastic polymers materials using the heated nozzle of an FDM 3D printer at pre-determined process parameters. The filament is heated and deposited in layers to create a three-dimensional component based on a CAD file.

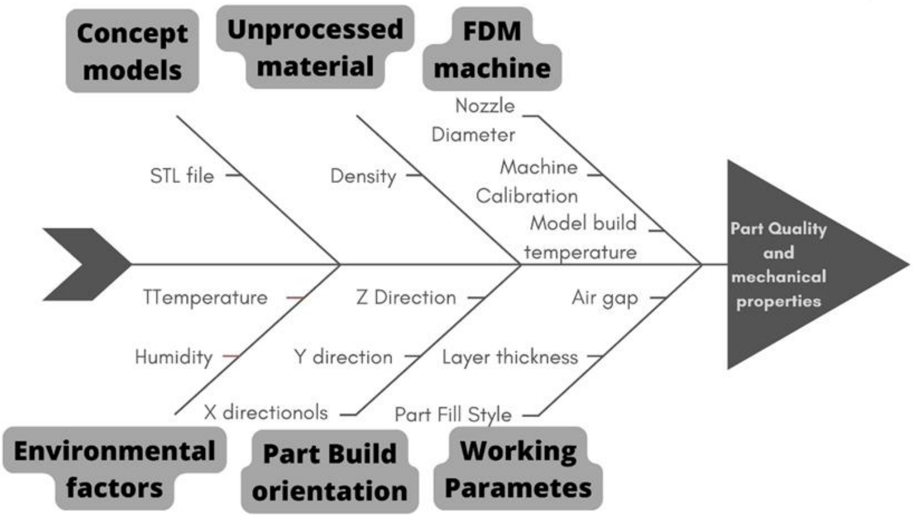

Figure 1.1: Cause and Effect Diagram of FDM Process Parameters

Figure 1.1. shows the cause and effects diagram for FDM that influencing the part quality and its mechanical properties, including environmental factors, build orientation, working parameters, concept models, raw materials, and the machine. Humidity is one of the causes, categorized under environmental factors that could influence the final output of the 3D printed parts. However, a research work investigating on humidity is still lacking as their studies are focusing on other factors, especially process parameters. Thermoplastic filament is sensitive to humidity unless the procedures are standardized and the place where the filament is created has a significant impact on the results (Valerga et al. 2018). Thermoplastic filaments like Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG), and Thermoplastic Polyurethane (TPU) are hygroscopic and tend to absorb moisture when expose to a humid environment which simultaneously affects the quality of the printed parts. PETG is an amorphous plastic resin manufactured by injection moulding or sheet extrusion and is used as a filament material for specimen manufacturing. PETG offers excellent strength, low shrinkage, and strong chemical printing capabilities (R. Srinivasan, 2020).

Drying the filament before printing has a tendency to reduce or eliminate the absorbed moisture, and improve the printing process. The popping or cracking sounds that might occur during extrusion can be avoided by drying the filament. Other than that, the drying process helps to improve the quality of the surface roughness, the tensile strength, and the microstructure of the fractured sample. It also helps to reduce the porosity, which is that will be discussed in more detail in this study. The term "pre-dried" refers to the filament after it has been dried. For the purposes of this investigation, the dehydrator known as a SUNLU Dryer was utilised in order to achieve a pre-dried filament.

In this study, the influence of humidity on the surface topography, which includes the surface roughness, porosity and microstructure of PETG and TPU printed parts initially exposed to various humidity conditions and subsequently un-dried using a dehydrator before printing, was investigated. A comparison between the un-drying and pre-drying filaments was also executed to study the effectiveness of drying.

1.2 Problem Statement

Humidity refers to the amount of water that permeates a body or vapour in the atmosphere. Humidity or moisture of 3D printed filaments was the main problem throughout this study, as it affected the quality of 3D printing. Kwon et al. (2020) highlighted that humidity changes the properties of the filament and lowers the quality of 3D-printed things. For this reason, it is important to keep the filament supply at the same humidity level. It also happens because the thermoplastic filament absorbs moisture quickly once the seal is broken. Furthermore, moisture is the biggest enemy when using a 3D printer. It can ruin the filament by causing a rough or grainy surface on finished prints and filament popping, cracking, or hissing sound while printing (Asesar, 2015). Because of the moisture in the environment, the surface roughness of pre-dried filaments differs. Likewise, drying the filament before printing can help prevent printing bubbles and nozzle blockage (Dwamena, 2020). According to Valerga et al. (2018) the appearance of bubbles will have an impact on the findings of both surface quality and tensile strength as a result of the increase in relative humidity. When performing 3D printing, the filament should be stored in a dry environment, such as a dry cabinet, or the used filament should be sealed in a vacuum bag.

Besides that, porosity is caused by water breaking the polymeric chemical chain, causing the polymer composition to be amorphous, with a more porous structure. Wet filaments have less strength than dry ones and break more easily as H_2O molecules break polymer bonds and diminish resistance, causing their impact resistance to drop. Thermoplastic material with a double bond in the chemical structure tends to combine with water, as water molecules have one oxygen atom covalently bound to two hydrogen atoms. Polymers with hydrogen-bonding groups will soak up water. Moreover, the more water the filament is exposed to, the porous it becomes. Leite (2016) stated that the increase in porosity would decrease the material's mechanical properties. PETG is more hygroscopic than ABS and PLA, which means it collects more moisture from the environment and deteriorates faster if left out in the open environment. Besides, TPU is the least hygroscopic of the other polymers and is also the most sensitive to improper storage. To preserve filament in good condition, it is recommended to store the used filament in appropriate storage such as a dehydrator and drying cabinet. Humidity problems will reduce part printing quality; therefore, drying the filament may help to reduce moisture and hence enhance printing part quality. Thus, in this study, a hypothesis is that drying the filament before printing can eliminate water and increase the printed surface topography of parts. The assumption made will be proven and discussed as the findings of this work.

1.3 Objective of Study

The objectives of this study are as stated below:

a) To analyze the surface roughness (R_a) of the pre-dried 3D printed PETG and TPU parts using ANOVA.

b) To measure the tensile strength of the pre-dried 3D printed PETG and TPU parts using a Universal Testing Machine.

c) To evaluate the cross-sectional microstructure of the fractured tensile specimen of the pre-dried 3D printed parts using the SEM machine.

d) To examine the porosity of the pre-dried 3D printed PETG and TPU parts using the Archimedes Principle.

1.4 Scope of Study

The scopes of this study are:

a) In this study, a 1.75mm diameter of the PETG and TPU filament was used for all conditions.

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

   i. New PETG and TPU filament roll, which acts as the reference.

   ii. Used PETG and TPU filament roll stored in an open environment, exposed to a humidifier for 48, 96, and 150 hours.

   iii. Used PETG and TPU filament roll stored in the vacuum bag, with the silica gels for 50 g.

c) The PETG and TPU are exposed to the humidifier in an open environment for a few hours and then dry by using the SUNLU FilaDryer S1 dehydrator.

d) The FDM machine, Ender 3 V2, was used to print the samples.

e) Shimadzu Universal Testing Machine is used for the tensile test with a 20kN load and testing speed of 5 mm/min.

f) Mitutoyo SJ-301 surface roughness tester is used in this study, and the variation of data is analysed using Analysis of Variance (ANOVA).

g) The porosity of printed part 3D printing is examined using densimeter, which adopted the Archimedes principle due to the limitation of the porosity equipment at the laboratory.