UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

INFLUENCE OF PRE-DRYING THE FILAMENT USING DIFFERENT METHODS ON THE MECHANICAL PROPERTIES AND MICROSTRUCTURE OF PLA, ABS, TPU AND PETG THERMOPLASTIC POLYMERS IN ADDITIVE MANUFACTURING

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Master of Manufacturing Engineering (Quality System Engineering)

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A thesis submitted
in fulfilment of the requirement for the degree of Master of Manufacturing Engineering (Quality System Engineering)

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2022

DECLARATION

I declare that this thesis entitles "Influence of Pre-Drying the Filament Using Different Methods on The Mechanical Properties and Microstructure of PLA, ABS, TPU And PETG Thermoplastic Polymers in Additive Manufacturing" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree

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Date : 17th June 2022

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Quality System Engineering)

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Date : 17th June 2022

DEDICATION

Alhamdulillah, all praise Allah for giving me the chance to complete my master's project through the covid-19 endemic situation.

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ABSTRACT

Additive manufacturing (AM), also known as 3D printing, creates three-dimensional solid items from the CAD file. 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 extruding pre-heated thermoplastic polymers with a nozzle at pre-determined process parameters. Filaments that contain moisture will interrupt the extrusion process, as the mass flow rate and humidity are correlated. Thermoplastic filaments are mostly hygroscopic and absorb moisture when exposed to a humid environment if not stored properly using dry cabinets. As a result, water absorbed in the plastic will rapidly expand, boil, and break as the filament is extruded. Hence, microstructure and mechanical performance can all be affected. Pre-drying the moisture-exposed used filament can theoretically eliminate the moisture, avoid unnecessary interruption during the printing, and simultaneously produce good quality 3D printer parts. In addition, density is a significant physical property related to the porosity of the microstructure. Generally, dense material exhibits a packed microstructure with limited porosity, and the pores in the microstructure are detrimental to the mechanical properties of specimens. Pre-dried filaments could improve the mechanical strength and reduce the porosity of the samples. In this study, a comparative study was made between the undried and pre-dried specimens (SUNLU dryer and oven). This study aimed to investigate two different drying methods of filaments before printing and to observe the influence of adopting those drying approaches on the mechanical properties, microstructure, and polymeric chain bonding. Thermoplastic polymers (ABS, PLA, TPU, PETG) were employed to see how moisture influences the 3D specimens. Hence, three conditions were established: (i) new filaments as the reference, (ii) used filaments stored in the vacuum bag with desiccant, and (iii) used filaments stored in an open environment and exposed to a humidifier for a variant of 48 hours, 96 hours and 150 hours. Shimazu AGS-X Universal Testing Machine (UTM), Scanning Electron Microscope (SEM) machine, densimeter, and Jasco FTIR machine are used. As a result, the tensile and flexural strength were improved after filament drying compared to the undried. Besides, the density was also improved, which was validated by the SEM images that show a smaller interlayer gap was found in the pre-dried specimen. In addition, the microstructure of the pre-dried specimen shows fewer voids, low incomplete fusion, and better layer formation. The chemical chain bonding of the sample was altered by humidity, and the pre-dried filaments showed almost no presence of water (H2O). The absorption of the spectra is high in the O-H group, which was discharged when drying. Further investigations and improvements are needed to evaluate 3D printed part performance based on porosity characterization.

ABSTRAK

Pembuatan tambahan (AM), atau pencetakan 3D mencipta item daripada fail CAD. *Fused Deposition Modeling* (FDM) digunakan secara meluas kerana kepelbagaian dan kosnya yang rendah. FDM menjana struktur 3D dengan menyemperit polimer termoplastik pra-panas dengan muncung. Filamen sarat lembapan mengganggu penyemperitan kerana kadar aliran jisim dan kelembapan dikaitkan. Filamen termoplastik adalah higroskopik dan mengumpul lembapan jika tidak disimpan dalam kabinet kering. Apabila filamen tersemperit, air yang diserap mengembang, mendidih, dan pecah. Oleh itu, struktur mikro dan prestasi mekanikal semuanya boleh terjejas. Pra-pengeringan filamen lama yang terdedah kepada lembapan membantu mengurangkan kelembapan, mengelakkan gangguan pencetakan dan menjana bahagian pencetak 3D berkualiti tinggi. Di samping itu, ketumpatan adalah sifat fizikal penting yang berkaitan dengan keliangan struktur mikro dan kekuatan mekanikal. Secara amnya, bahan padat mempamerkan struktur mikro padat dengan keliangan terhad yang mana liang dalam struktur mikro merosakkan sifat mekanikal spesimen. Filamen pra-kering boleh meningkatkan kekuatan mekanikal, dan mengurangkan keliangan spesimen. Dalam kajian ini, filamen telah dibandingkan antara filamen yang belum kering dan filamen pra-kering (pengering dan ketuhar SUNLU). Tujuan penyelidikan ini adalah untuk menyiasat cara berbeza untuk mengeringkan filamen yang terdedah kepada kelembapan dan kesan penggunaan pendekatan pengeringan tersebut ke atas sifat mekanikal, struktur mikro dan ikatan rantai kimia. ABS, PLA, TPU, PETG digunakan untuk mengkaji kelembapan mempengaruhi spesimen 3D. Oleh itu, tiga keadaan ditetapkan: (i) gulungan filamen baru sebagai rujukan, (ii) gulungan filamen terpakai disimpan dalam beg vakum dengan bahan pengering, dan (iii) gulungan filamen terpakai disimpan dalam persekitaran terbuka dan terdedah kepada pelembap selama 48 hingga 150 Jam. *Shimazu AGS-X Universal Testing Machine* (UTM), *Scanning Electron Microscope (SEM)*, *densimeter* dan *Jasco FT/IR* digunakan. Hasilnya, kekuatan tegangan dan lenturan bertambah baik selepas pengeringan berbanding spesimen yang belum kering. Selain itu, ketumpatan dipertingkatkan, yang disahkan oleh imej SEM, yang menunjukkan jurang *interlayer* yang lebih kecil dalam spesimen yang belum kering, yang pada masa yang sama mengurangkan keliangan. Selain itu, struktur mikro spesimen pra-kering menunjukkan lompang yang lebih sedikit, pelakuran tidak lengkap yang rendah dan pembentukan lapisan yang lebih baik. Ikatan rantai kimia spesimen diubah oleh kelembapan, dan filamen pra-kering menunjukkan hampir tiada kehadiran air (H_2O). Penyerapan spektrum tinggi pada kumpulan OH, yang kumpulan OH bebas apabila pengeringan. Pencirian keliangan diperlukan untuk menilai prestasi bahagian cetakan 3D. Kekasaran permukaan dan ujian mekanikal seperti ujian mampat memerlukan lebih banyak penyelidikan untuk item cetakan 3D yang lebih baik.

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LIST OF ABBREVIATIONS

3D	-	Three Dimensional
ABS	-	Acrylonitrile Butadiene Stryrene
AM	-	Additive manufacturing
ASTM	-	American society for testing and materials
ATR	-	attenuated total reflection
BIS	-	British Standard Institution
BHET	-	Hydraquent
CAD	-	Computer Aided Design
CNN	-	conventional neural network
FDM	-	Fused Deposition Modelling
FTIR	-	Fourier Transform infrared
HIPS	-	High Impact Polystyrene
HS	-	Hard Segment
ISO	-	International Organization for Standardization
IR	-	Infrared
JIS	-	Japanese Institution Standard
NMR	-	Nuclear Magnetic Resonance
PEI	-	Polyetherimide
PLA	-	Poly Lactic Acid

PC	-	Polycarbonate
PEEK	-	Polyether Ether Ketone
SEM	-	Scanning Electron Machine
STL	-	Standard Triangle Language
RH	-	Relative Humidity
Tg	-	Glass Transition Temperature
Tm	-	Melting Temperature
TPU	-	Thermoplastic Polyurethane
TPA	-	Terephalic Acid
UTM	-	Universal Testing Machine
ROP	-	Ring Opening Polymerization
RP	-	Rapid Prototyping

LIST OF EQUATIONS

LIST OF SYMBOLS

cm	-	Centimetre
m	-	Metre
%	-	%
g/cm3	-	Grams per centimetre cube
g/mol	-	Gram per molecule J/g - Joule per gram
mm	-	Millimetre
°C	-	Degree Celsius
K	-	Kelvin
nm	-	Nanometre
mm/min.	-	Millimetre per minute
mm/s	-	Millimetre per second
N	-	Newton
N/mm2	-	Newton per millimetre square
kN	-	Kilo newton
GPa	-	Giga Pascal
MPa	-	Mega Pascal
Jm	-	Joule meter
W/mK	-	Watt per meter Kelvin

CHAPTER 1

INTRODUCTION

1.1 Background

Additive manufacturing has changed the manufacturing and prototyping industries since the late 1980s with 3D printing. As 3D printers have become more accessible and affordable, additive manufacturing has grown significantly in both volume and scope. Low-cost 3D printing is becoming more common. 3D printing can generate tangible items from a geometrical representation by adding material. 3D printing technology was created out of the layer-by-layer production of three-dimensional (3D) structures directly from computer-aided design (CAD) modelling (Tofail et al., 2018). It is expected that introducing 3D printing technology would boost manufacturing speed and reduce prices (Jiménez et al., 2019).

The earliest known material extrusion technology is Fused Deposition Modelling (FDM). FDM was invented in the early 1990s, and the polymer is the primary material used in this process (Stansbury & Idacavage, 2015). FDM is one of the consumer-level additive manufacturing technologies for 3D printing objects. Using FDM, thermoplastic polymers may be turned into solid components. This layer-by-layer technique builds the component by melting and extruding the thermoplastic filament depositing it on the platform, and then hardening and solidifying it. Because of its capacity to produce components with complicated forms without the need for tooling or human intervention, FDM is acquiring a significant edge in manufacturing industries.

FDM process may employ a wide range of polymers. FDM printing suffers from the fact that the quality of a print may be affected by environmental conditions such as humidity. The FDM process generates three-dimensional structures by extruding pre-heated thermoplastic polymers via a nozzle at pre-determined process parameters. Since mass flow rate and humidity are correlated, moisture-containing filaments will halt the extrusion process. According to Chola (2017), water is found in the low viscosity of filaments.

There are a few filaments materials such as PLA, ABS, PETG, TPU and more where these filaments have different properties such as strength, density, flexibility, and more. A few printing challenges that might arise due to unfavourable environmental conditions include warping, poor layer connectivity, and uneven parts (Fang et al., 2020). 3D printing filaments are hygroscopic and the filament absorbs moisture from the air, which alters the elastic modulus, ultimate strength, and fracture toughness. Micro- and macro-scale effects of printing humidity on the characteristics of thermoplastic polyurethane-based filament were studied by Livolsi et al. (2021). A humid atmosphere decreases the ultimate strength and tangent modulus of the 3D printed parts. Due to moisture absorption, mechanical tests by Zaldivar et al. (2018) showed that 3D printed items had significantly lower tensile strength and failure strain.

Therefore, in this study, the influence of pre-drying the filament before printing on the mechanical properties, cross-sectional microstructure, chemical bonding and porosity of the thermoplastic polymers (PLA, TPU, ABS, PETG) was investigated. Hygroscopicity is an undesirable effect in 3D printing filaments. As a result, the filaments will quickly expand, boil, and break as it is extruded because of the moisture absorbed in the plastic. Consequently, the surface quality, layer adhesion, and mechanical performance may be