INVESTIGATING THE EFFECT OF WALL LINE NUMBERS ON THE MECHANICAL PERFORMANCE OF DEVELOPED RPET/HDPE COMPOSITE FILAMENT IN FDM 3D PRINTING

ASLAM HADI BIN HAMZAH

MASTER OF SCIENCE IN MANUFACTURING ENGINEERING

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Faculty of Industrial & Manufacturing Technology & Engineering

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Aslam Hadi Bin Hamzah

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A thesis submitted
in fulfillment of the requirements for the degree of
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2025

DECLARATION

I declare that this thesis entitled "Investigating the Effect of Wall Line Numbers on the Mechanical Performance of Developed rPET/HDPE Composite Filament in FDM 3D Printing" 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 candidature of any other degree.

Signature	:	....
Name	:	Aslam Hadi Bin Hamzah
Date	:	24th February 2025

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 Science in Manufacturing Engineering.

Signature : ....

Supervisor Name : Ir. Ts. Dr. Lailatul Harina Binti Paijan

Date : 24th February 2025

DEDICATION

All the praises and thanks to Allah S.W.T for His Guidance and Enlightenment.

This thesis is dedicated to my beloved parents and my siblings,

Also to my hardworking and knowledgeable supervisor and co-supervisor,

Thank you very much for your understanding and encouragement.

ABSTRACT

Fused Deposition Modelling (FDM) is considered as the most common 3D printing technique for manufacturing 3D models. The mechanical properties of 3D-printed parts using FDM process can be affected with different printing parameters. However, the investigation on printing parameters of wall line count influencing mechanical properties is limited. In addition, waste plastic bottles contribute to plastic pollution, affecting humans and the environment, and by upcycling into 3D printing material, it can create a sustainable environment, which protect natural resources. For that reason, plastic bottles are recycled and developed as a potential bioplastic for 3D printing applications, known as recycled Polyethylene Terephthalate (rPET). Therefore, this study aims to fabricate 3D filament using blended rPET + High Density Polyethylene (HDPE) with two composition ratios of 1:99 and 5:99, respectively. The 3D filaments were produced with different ratios of rPET:HDPE through single screw extrusion process. Then, the thermal properties for 3D filament were characterised using differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) to determine the thermal temperature of rPET and observe any shifts due to blending with HDPE. Meanwhile, the mechanical properties were analyzed using tensile, flexural, and impact strength to evaluate how the addition of rPET affects strength and overall performance of material, especially in the context of FDM 3D printing. The thermal properties of 3D filaments were analyzed to understand the melting temperature of blended materials for 3D printing process. After thermal analysis, surface morphology was conducted to observe surface quality on the 3D filaments. Next, the 3D filaments were used to manufacture 3D-printed samples using FDM process with varying wall counts of 5, 10, and 15 layers for evaluating the mechanical properties. Based on the result, it is found that the addition of 5 % rPET produced higher melting temperature at 132.1 ℃ compared to 131.1 ℃, exhibited by the 1 % rPET. It can be observed with the increase of rPET from 1 % to 5 % exhibits 0.76 % increment in melting temperature. However, the degradation temperature shows a 0.42 % reduction with increasing in rPET. From the surface morphology observation, the addition of 1 % and 5 % rPET of 3D filaments exhibits a smooth and uniform surface. The mechanical properties demonstrate that the 5 % rPET with 10 wall line counts exhibits the best mechanical properties. It was found that 5 % rPET with 10 wall line counts exhibits two times higher tensile strength at 28.34 MPa compared to the 1 % rPET with 5 wall line counts, which resulted at 14.32 MPa. From the fracture surface image under microscopy observation, it shows ductile characteristic with the 10 wall line counts sample, revealing fibrous strand of the fracture after tensile test, which supported by the tensile strength. Overall, the result shows that the addition of 5 % rPET into HDPE was comparable with PLA, indicating the 3D filament using rPET and HDPE with 10 wall line counts produce the best result and feasible for FDM process, with significantly contributing for the sustainability of the environment.

SIASATAN rPET CAMPURAN DENGAN HDPE TERHADAP SIFAT MEKANIKAL UNTUK PROSES FDM

ABSTRAK

Pemodelan Pemendapan Bersatu (FDM) dianggap sebagai teknik pencetakan 3D yang paling biasa untuk pembuatan model 3D. Sifat mekanikal bahagian cetakan 3D menggunakan proses FDM boleh dipengaruhi dengan parameter pencetakan yang berbeza. Walau bagaimanapun, penyiasatan ke atas parameter pencetakan kiraan garisan dinding yang mempengaruhi sifat mekanikal adalah terhad. Di samping itu, botol plastik sisa menyumbang kepada pencemaran plastik, menjejaskan manusia dan alam sekitar, dan dengan mengitar semula ke dalam bahan cetakan 3D, ia boleh mewujudkan persekitaran yang mampan, yang melindungi sumber semula jadi. Atas sebab itu, botol plastik dikitar semula dan dibangunkan sebagai bioplastik yang berpotensi untuk aplikasi percetakan 3D, yang dikenali sebagai Polyethylene Terephthalate (rPET) kitar semula. Oleh itu, kajian ini bertujuan untuk menghasilkan filamen 3D menggunakan rPET campuran + Polietilena Ketumpatan Tinggi (HDPE) dengan dua nisbah komposisi masing-masing 1:99 dan 5:99. Filamen 3D dihasilkan dengan nisbah rPET:HDPE yang berbeza melalui proses penyemperitan skru tunggal. Kemudian, sifat terma untuk filamen 3D telah dicirikan menggunakan kalorimetri pengimbasan pembezaan (DSC) dan analisis termogravimetrik (TGA) untuk menentukan suhu terma rPET dan memerhati sebarang anjakan akibat pengadunan dengan HDPE. Sementara itu, sifat mekanikal dianalisis menggunakan kekuatan tegangan, lenturan dan hentaman untuk menilai bagaimana penambahan rPET mempengaruhi kekuatan dan prestasi keseluruhan bahan, terutamanya dalam konteks percetakan 3D FDM. Sifat terma filamen 3D dianalisis untuk memahami suhu lebur bahan campuran untuk proses pencetakan 3D. Sifat terma filamen 3D dianalisis untuk memahami suhu lebur bahan campuran untuk proses pencetakan 3D. Selepas analisis haba, morfologi permukaan telah dijalankan untuk melihat kualiti permukaan pada filamen 3D. Seterusnya, filamen 3D digunakan untuk mengeluarkan sampel cetakan 3D menggunakan proses FDM dengan bilangan dinding yang berbeza-beza 5, 10, dan 15 lapisan untuk menilai sifat mekanikal. Berdasarkan keputusan, didapati penambahan 5% rPET menghasilkan suhu lebur yang lebih tinggi pada 132.1 ℃ berbanding 131.1 ℃ bagi 1% rPET. Peningkatan rPET daripada 1% ke 5% menunjukkan kenaikan suhu lebur sebanyak 0.76%. Walau bagaimanapun, suhu degradasi menunjukkan penurunan sebanyak 0.42% dengan peningkatan kandungan rPET. Daripada pemerhatian morfologi permukaan, penambahan 1% dan 5% rPET pada filamen 3D mempamerkan permukaan yang licin dan seragam. Sifat mekanikal menunjukkan bahawa 5% rPET dengan 10 kiraan garisan dinding memberikan sifat mekanikal terbaik. Ditemui bahawa 5% rPET dengan 10 kiraan garisan dinding menunjukkan kekuatan tegangan dua kali ganda iaitu 28.34 MPa berbanding 1% rPET dengan 5 kiraan garisan dinding yang mencatatkan 14.32 MPa. Dari imej permukaan patah di bawah pemerhatian mikroskop, ia menunjukkan ciri mulur pada sampel dengan 10 kiraan garisan dinding, memperlihatkan untaian gentian patah selepas ujian tegangan, yang disokong oleh kekuatan tegangan tersebut. Secara keseluruhan, keputusan menunjukkan penambahan 5% rPET ke dalam HDPE adalah setanding dengan PLA, menunjukkan filamen 3D menggunakan rPET dan HDPE dengan 10 kiraan garisan dinding menghasilkan keputusan terbaik dan sesuai untuk proses FDM, serta memberi sumbangan penting kepada kelestarian alam sekitar.

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LIST OF ABBREVIATIONS

UTeM	-	Universiti Teknikal Malaysia Melaka
3D	-	Three Dimensional
2D	-	Two Dimensional
rPET	-	Recycled Polyethylene Terephthalate
PET	-	Polyethylene Terephthalate
HDPE	-	High-Density Polyethylene
rHDPE	-	Recycled High-Density Polyethylene
PLA		Polylactic Acid
FDM	-	Fused Deposition Modelling
FFF	-	Fused Filament Fabrication
DSC	-	Differential Scanning Calorimetry
TGA	-	Thermogravimetric Analysis
FE-SEM	-	Field Emission Scanning Electron Microscopy
AM	-	Additive Manufacturing
SLA	-	Stereolithography
SLS	-	Selective Laser Sintering
SLM	-	Selective Laser Melting
CAD	-	Computer Aided Design
ABS	-	Acrylonitrile Butadiene Styrene
TPU	-	Thermoplastic Polyurethane
PP	-	Polypropylene
PETG	-	Polyethylene Terephthalate Glycol
ASA	-	Acrylonitrile Styrene Acrylate
PEEK	-	Polyether Ether Ketone

PEI	-	Polyetherimide
PBS	-	Poly (butylene succinate)
PC	-	Polycarbonate
ASTM	-	American Society for Testing and Materials
UTS	-	Ultimate Tensile Strength
PE-g-MA	-	Polyethylene-grafted-maleic anhydride
SEBS	-	Styrene-Ethylene-Butylene-Styrene

LIST OF SYMBOLS

+	-	Plus
°C	-	Degree Celsius
%	-	Percentage
°	-	Angle
mm	-	Millimeter
mm/s	-	Millimeter per Second
g/cm^3	-	Grams per Cubic Centimeter
rpm	-	Revolutions per Minute
°C/min	-	Degree Celsius per Minute
mg	-	Milligram
m ℓ/min	-	Milliliter per Minute
mm/min	-	Millimeter per Minute
N	-	Newton
MPa	-	Megapascals
GPa	-	Gigapascals
kJ/m^2	-	Kilojoules per Square Meter
wt.%	-	Weight percent

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LIST OF PUBLICATIONS/INNOVATIONS

List of Journal Publication

1. **A. H. Hamzah**, L. H. Paijan, M. H. A. Bakar, M. F. Mamat, N. A. Maidin, and S. I. Musa, 2024, Effect of Wall Line Count on the Mechanical Properties of FDM 3D-printed PLA Parts, Malaysian Journal of Microscopy, Vol 20, No 2, pp 1-11. **(Published-Scopus Indexed Q4)**

2. **A. H. Hamzah**, L. H. Paijan, and M. H. A. Bakar, 2025, Effect of Wall Line Count on the Mechanical Properties and Wear Performance of FDM 3D- Printed Recycled PET Parts, MYTRIBOS International Symposium. **(Submitted-Scopus Indexed Q3)**

List of Innovation and Competitions

1. L. H. Paijan and **A. H. Hamzah**, 2024, Investigation of Recycled PET based on Mechanical Properties through FDM Process, Material Lecture Competition 2024 – National Level. **(Third Place)**

2. **A. H. Hamzah**, L. H. Paijan, M. H. A. Bakar, M. F. Mamat, and N. Ab. Wahab, 2023, Private Eye 3D Scanner, Jejak Inovasi UTeM. **(Gold Award)**

3. L. H. Paijan, M. H. A. Bakar, M. F. Mamat, N. Ab. Wahab, and **A. H. Hamzah**, 2023, Tracker 3D Scanner, International Research & Innovative Technology Competition (i-RITEC 2023) UTHM. **(Gold Award)**

4. L. H. Paijan, **A. H. Hamzah**, and A. Q. Shamsuri, 2024, Techno Sight 3D Scanner, International Innovative Research & Industrial Dialogue (IIRID 24) UTeM. **(Gold Award)**

5. **A. H. Hamzah**, A. Q. Shamsuri, N. A. M. Yusof, L. H. Paijan, and M. F. Mamat, 2024, Tech Vision 3D Scanner, Johor International Innovation Invention Competition and Symposium (JIICaS 2024), UiTM Pasir Gudang. **(Gold Award)**

6. L. H. Paijan, **A. H. Hamzah**, and A. Q. Shamsuri, 2024, QuantumSight 3D, Hari Inovasi Negeri Melaka, UTeM. **(Gold Award)**

7. L. H. Paijan, **A. H. Hamzah**, and A. Q. Shamsuri, 2024, Private Eye 3D Scanner (PE3DS), Infineon Week FYP Innovation Competition, UTeM. **(Consolation Prize)**

8. **A. H. Hamzah**, L. H. Paijan, A. Q. Shamsuri, 2024, Hyper Vision 3D Scanner, Texas Instrument – UTeM Innovation Competition (TUIC 2024), UTeM. **(Certificate of Participant)**

9. **A. H. Hamzah**, and L. H. Paijan, 2024, Effect of Wall Line Count on the Mechanical Properties of FDM 3D-printed PLA Parts, 32nd Scientific Conference of Microscopy Society of Malaysia (SCMSM2024). **(Travel Grant Award)**

CHAPTER 1

INTRODUCTION

1.1 Background

3D printing, also known as additive manufacturing, is a revolutionary technology that enables the creation of three-dimensional objects from digital designs. Among various types of 3D printing process, Fused Deposition Modeling (FDM) is the most commonly known additive manufacturing process that creates layer by layer using thermoplastic materials. In this process, a filament is fed into a heated nozzle, where it melts and extruded into thin strands follwing a predetermined path onto the build platform. The material maintains the intended shape as it cools and hardens, while the newly deposited layer will thermally bonds with the previous one. Moreover, due to its low cost and user friendly, FDM is widely used in medical, engineering, and other industries (Kumari et al., 2024). Based on the current technology, the 3D printing industry is currently expanding. Although 3D printing technology is expanding, there are critical concerns related to 3D printing parameters that need to be considered, which can affect mechanical properties (Zubrzycki et al., 2022). However, the influence of wall line count still remains limited in this area, despite the possibilities of affecting mechanical properties of 3D printed parts. Several studies highlighted that the changes in printing parameters such as layer height, infill density, and nozzle temperature can affect the mechanical properties of 3D-printed parts (Bhushan et al., 2024). Other than that, the investigation of using recycled bottles (Polyethylene Terephthalate) as filament material for 3D printing is significantly lacking. Therefore, this research aims to investigate the effect of varying wall line count based on the mechanical properties with the comparison of blended material consisting of recycled Polyethylene Terephthalate (rPET) with High Density Polyethylene (HDPE) and Polylactic