STUDY THE EFFECT OF MECHANICAL PROPERTIES ON THE IMMERSED EXTREMELY AGED FS3300PA PA-12 POWDER IN SEA WATER ON YZY 0 DEGREE ORIENTATION

ARIF BIN ABDUL RANI
B092110153

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (BMKM) WITH HONOURS

2024

Faculty of Mechanical Technology and Engineering

STUDY THE EFFECT OF MECHANICAL PROPERTIES ON THE IMMERSED EXTREMELY AGED FS3300PA PA-12 POWDER IN SEA WATER ON YZY 0 DEGREE ORIENTATION

Arif Bin Abdul Rani

Bachelor of Mechanical Engineering Technology (BMKM) with Honours

2024

STUDY THE EFFECT OF MECHANICAL PROPERTIES ON THE IMMERSED EXTREMELY AGED FS3300PA PA-12 POWDER IN SEA WATER ON YZY 0 DEGREE ORIENTATION

ARIF BIN ABDUL RANI

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this choosen item entitled "Study The Effect Of Mechanical Properties On The Immersed Extremely Aged FS3300PA PA-12 Powder In Seawater On YZY 0 Degree Orientation" is the result of my own research except as cited in the references. The choosen item has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : ARIF BIN ABDUL RANI

Date : 10 JANUARY 2025

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of BMKM Engineering Technology (specialisation) with Honours.

Signature :

Supervisor Name : Ts. Ahmad Nizam Bin Jamaludin

Date : 10 January 2025

DEDICATION

Completing my degree is a journey marked by challenges, growth, and invaluable support. To my beloved parents, your unwavering encouragement and sacrifices have been the cornerstone of my success. I want to thank my mother Sharifah Binti Sulaiman for the endless love and belief in me that have fueled my determination even in the toughest time. Many thanks to my dad Abdul Rani Bin Shahid, your wisdom and guidance have shaped my path and instilled in me the resilience to overcome obstacles. They both deserve my gratitude for all of the sacrifices they made for me when I was a student at this institution and for the assistance they provided in the form of guidance, funding, and encouragement as I prepared this report. Not to forget, I want to thank MARA for the generous sponsorship of my studies. Your belief in my potential not only alleviated the financial burden of pursuing higher education but also provided me with the encouragement and motivation to excel in my studies. for This report will be dedicated to them. Next, I'd want to thank everyone who helped me with this final year project, especially Ts. Ahmad Nizam bin Jamaludin, my supervisor, Ts. Mohd Idain Fahmy Bin Rosley and my friends. To my dearest love Hafizatul Aini, thank you for always being there during the storm of stress and sadness, especially when studies overwhelm me. Your contiuous support and comforting presence mean the world to me. Also, a big thanks to my Sahabat Hiking circle; Hadi, Haziq, Fahmi, Muiz, Fareen, Nana for making my study journey a magnificent adventure by exploring the beauty of nature. Each hike, each breathtaking view, and each moment of shared laughter has etched unforgettable memories in my heart. Thank you for being the extraordinary friends who turned my academic path into a beautiful, scenic journey of growth and discovery.

ABSTRACT

This research investigates the impacts of prolonged seawater immersion on the mechanical characteristics, dimensional stability, and water absorption of Polyamide-12 (PA-12) FS3300PA components made with Selective Laser Sintering (SLS) 3D printing method. The study also aimed to examine the influence of layer thickness, laser power, and sintering orientation on the mechanical properties of aged PA-12. The specimens were separated into 10 groups: nine for aged powder and one for virgin powder as a baseline. With various layer thicknesses (0.07 mm, 0.12 mm, and 0.15 mm), laser power (65 W, 70 W, and 75 W), and orientations (YZY 0°, YZY 90°, and XYY 0°), the nine groups of aged powder were sintered. The performance of virgin and extremely aged PA-12 powders were compared before and after 1000 hours of seawater immersion. The results show that thinner layers and higher laser power resulted in stronger mechanical properties, greater water absorption, hence decreasing dimensional stability. Aged powder demonstrated higher tensile strength than virgin powder, while Young’s modulus and elongation at break achieved similarity between both. Mechanical performance was also affected by the sintering orientation; XYY 0° and YZY 90° produced better stiffness and tensile strength in comparison to YZY 0°. However, due to equipment malfunction, fracture behavior analysis to study the fracture morphologies using Scanning Electron Microscopy (SEM) could not be completed.

ABSTRAK

Penyelidikan ini menyiasat kesan rendaman air laut yang berpanjangan ke atas ciri mekanikal, kestabilan dimensi dan kadar penyerapan air komponen Polyamide-12 (PA-12) FS3300PA yang dibuat dengan kaedah pencetakan 3D Selective Laser Sintering (SLS). Kajian ini juga bertujuan untuk mengkaji pengaruh ketebalan lapisan, kuasa laser, dan orientasi pensinteran terhadap sifat mekanikal PA-12 yang dikitar semula. Spesimen dipisahkan kepada 10 kumpulan: sembilan untuk serbuk terpakai dan satu untuk serbuk baru sebagai garis dasar. Dengan pelbagai ketebalan lapisan (0.07 mm, 0.12 mm dan 0.15 mm), kuasa laser (65 W, 70 W dan 75 W), dan orientasi (YZY 0°, YZY 90° dan XYY 0°), sembilan kumpulan serbuk terpakai telah disinter. Prestasi serbuk PA-12 baru dan terpakai dibandingkan sebelum dan selepas 1000 jam rendaman air laut. Keputusan menunjukkan bahawa lapisan yang lebih nipis dan kuasa laser yang lebih tinggi menghasilkan sifat mekanikal yang lebih kuat, penyerapan air yang lebih besar, seterusnya mengurangkan kestabilan dimensi. Serbuk tua menunjukkan kekuatan tegangan yang lebih tinggi daripada serbuk dara, manakala modulus Young dan pemanjangan semasa putus mencapai persamaan antara kedua-duanya. Prestasi mekanikal juga dipengaruhi oleh orientasi pensinteran; XYY 0° dan YZY 90° menghasilkan kekukuhan dan kekuatan tegangan yang lebih baik berbanding dengan YZY 0°. Walau bagaimanapun, disebabkan oleh kerosakan peralatan, analisis sampel untuk mengkaji morfologi patah menggunakan Scanning Electron Microscopy (SEM) tidak dapat diselesaikan.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. Thank you also to the Majlis Amanah Rakyat (MARA) for the financial assistance.

My utmost appreciation goes to my main supervisor, Ts. Ahmad Nizam Bin Jamaludin, Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. Also, to my co-supervisor, Ts. Idain Fahmy Bin Rosley, Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey.

Last but not least, from the bottom of my heart a gratitude to my beloved parents, Sharifah Binti Sulaiman and Abdul Rani bin Shahid, for their encouragements and who have been the pillar of strength in all my endeavors. My support also to my siblings, for their patience and understanding. Finally, thank you to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE **TITLE** **PAGE**

LIST OF SYMBOLS AND ABBREVIATIONS

BMKM	-	Bachelor of Mechanical Engineering Technology
PA-12	-	Polyamide 12 Material
MOHE	-	Malaysian Ministry of Higher Education
PBF	-	Powder Bed Fusion
SLS	-	Selective Laser Sintering
3D	-	3 Dimension
PA6	-	Polyamide 6 Material
MoS2	-	Molybdenum Disulfide
UV	-	Ultraviolet
GFRP	-	Glass Fiber Reinforced Polymer
MPa	-	Mega Pascal
PET	-	Polyetherene Terephthalate
PP	-	Polypropylene
FTIR	-	Fourier-transform Infrared Spectroscopy
DSC	-	Differential Scanning Microscopy
AM	-	Additive Manufacturing
CAD	-	Computer Aided Design
FEM	-	Fenite Element Method
LCD	-	Liquid Crystal Display
EHT	-	Electron High Tension
mm	-	milimeter
%	-	Percent

°C	-	Degree Celcius
g	-	Gram
KJ/m^3	-	KiloJoule per meter cube
°	-	Degree

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

FS3300 PA-12 powder is a high-performance polyamide 12 (PA-12) material designed specifically for use in powder bed fusion (PBF) additive manufacturing processes. Renowned for its versatility and reliability, FS3300 PA-12 powder has gained significant traction across various industries due to its exceptional mechanical properties and ease of processing. With a particle size distribution optimized for uniform laser sintering, FS3300 PA-12 powder enables the production of intricate, dimensionally stable components with superior surface finish.

For long term industrial use, the main obstacle in utilizing FS3300 PA-12 virgin powder for additive manufacturing is the high cost. It is important to look for cost-effective alternatives because of this heavy financial burden, specifically by recycling the old powder. However, the implementation of recycling complicates the material setup process, raising concerns about the consistency and quality of the finished product.

Hence, this study will systematically examine how the mechanical properties of virgin and ageing PA-12 powder parts, including their tensile strength, flexural modulus, and water stability, change after being immersed in seawater for an extended period of 1000 hours in order to provide specific insights into the practicability of HydroQS housing part development.

1.2 Problem Statement

FS3300PA PA-12 powder is widely used in industrial applications due to its excellent mechanical properties, surface quality, and chemical resistance. However, the primary challenge in using the FS3300 PA-12 virgin powder for additive manufacturing is its expensive cost of RM500 per kilogram. The Farsoon SS402P machine requires 60 kilograms of powder to run at full capacity, so the cost of materials alone may be too expensive for long-term industrial use. Due to this significant price burden, it is necessary to investigate more affordable options, especially recycling the old powder. But when recycling is integrated, the material setup process gets more complicated, which raises questions about the final product's consistency and quality.

In order to close this crucial gap, this study will methodically investigate how the mechanical characteristics of FS3300PA PA-12 powder (virgin and ageing) parts change after immersed in seawater for an extended period of time which to be exact is 1000 hours, including their tensile strength, flexural modulus, and impact resistance. For the purpose to provide specific insights into how the orientation of printed parts affects the fabrication of housing for Hydro Quality Survey System (HydroQS), the study focuses on the YZY 0-degree orientation, which represents a common printing configuration for many additive manufacturing processes.

Understanding the mechanical behavior of FS3300PA PA-12 powder parts in seawater, particularly in the YZY 0-degree orientation, is necessary for informing design decisions, material selection, and performance expectations before fabricating parts. This research will contribute valuable knowledge in developing a HydroQS product.

1.3 Research Objective

1. To study the weight stability and water absorption of the virgin and extremely aging powder PA-12 based on YZY 0-degree orientation by using different laser power (65-watt, 70-watt & 75-watt) and layer thickness (0.09mm, 0.12mm and 0.15mm) before and after soak in seawater.
2. To study the mechanical properties of the virgin and extremely aging powder PA-12 based on YZY 0-degree orientation by using different laser power (65-watt, 70-watt & 75-watt) and layer thickness (0.09mm, 0.12mm and 0.15mm) before and after soak in seawater.
3. To study the fracture behavior of the virgin and extremely aging powder PA-12 based on YZY 0-degree orientation by using different laser power (65-watt, 70-watt & 75-watt) and layer thickness (0.09mm, 0.12mm and 0.15mm) before and after soak in seawater.

1.4 Scope of Research

The scope of this research are as follows:

1. Measure the weight changes of the sintered virgin and aged samples (ASTM D5947) before and after immersing in seawaster by using a scientific weighing scale.
2. Conduct a tensile testing to measure the mechanical properties based on ASTM D638-III using Universal Test Machine (UTM).
3. Implement a Scanning Electron Micoscope (SEM) process to study the fracture behaviour of tested product.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is mainly focused on detailing the information of relevant studies about FS3300 PA-12, characteristics, mechanial properties and behaviour in various conditions. Besides, this chapter will also provide a comprehensive overview of existing knowledge and research related to PA-12 material and its application in industry. Through a literature review, researchers can identify gaps, debates, and areas where further investigation is needed. It helps pinpoint what has already been studied and what remains unexplored. Beyond summarizing sources, a good literature review critically evaluates and synthesizes information. It analyzes the strengths and weaknesses of existing studies, providing a clear picture of the state of knowledge on the subject. The sources of information are collected from books, the journals, and any previous studies that have been done which are related to this field, in such a way that they can help to identify problems, generate ideas, and perform any improvement for the analysis later.

2.2 PA-12 Applications in Various Industries

Polyamide 12 (PA12) is commonly utilized in selective laser sintering processes, known for its processability and mechanical properties, chemical resistance, and durability (Du Maire et al., 2023). It is perfect for under-the-hood applications like fuel lines, brake hoses, and cable sheathing because it can tolerate extreme weather conditions, such as exposure to fuels, oils, and high temperatures. Because PA-12 is lightweight, it helps reduce overall vehicle weight, which increases fuel efficiency. Reliability under mechanical stress is ensured by its flexibility and impact resistance. “These materials hold significant potential as alternative choices for vehicle parts, contributing to lighter vehicles and reduced fuel consumption. PA12 stands out due to its excellent mechanical and physical properties, making it well-suited for automotive applications.” (Kondo et al., 2022)

For sports equipment applications, Polyamide 12 (PA 12) is a great choice because of its special blend of qualities, which include toughness, flexibility, and resistance to abrasion and impact. Because it is lightweight and strong at the same time, this thermoplastic material is perfect for sports equipment that needs to be robust and easy to use, like protective gear, shoe soles, and other molded components. For instance, a study by (Goodridge et al., 2012) highlights that PA-12 materials maintain excellent performance under repetitive loading conditions, which is essential for sports gear such as protective helmets, footwear, and racket strings. Additionally, PA-12's ability to absorb shocks and vibrations contributes to enhanced safety and comfort for athletes, further cementing its relevance in sports applications.

2.3 Polyamide 12 Mechanical Properties

Polyamide 12 (PA 12) is a thermoplastic polymer known for its excellent mechanical properties, including high tensile strength, flexibility, and impact resistance. FS3300 PA-12 powder is designed specifically for use in selective laser sintering (SLS) processes in additive manufacturing. “PA12 is known for its toughness, strength, impact resistance, and fracture resistance under deformation” (Petousis et al., 2022). The ability of FS3300 PA-12 powder to produce parts with high dimensional accuracy and fine detail resolution is one of its primary features. “The results showed that the composition of 100% virgin PA-12 material appeared to be stiffer, with lower plastic deformation at maximum tensile stress and smoother surface roughness."(Rafi Omar et al., 2022). This study examines the effects of significant Selective Laser Sintering (SLS) 3D printer parameters on the material strength of PA-12. Various virgin materials, reheat materials, and recycled materials were used for the PA-12 material compositions. The tensile strength, surface roughness, and surface morphology were tested. Figure 1 below shows the comparison of tensile properties between PA11 and PA12 which indicates PA12 has higher Ultimate Strength and Young Modulus when compared to PA11.

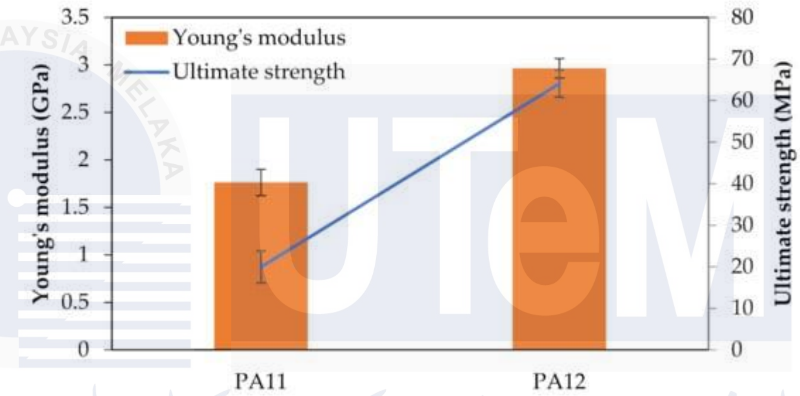


Figure 1: Comparison of tensile properties between PA11 and PA12.

2.3.1 Elasticity behaviour of PA-12

Polyamide 12 (PA-12) exhibits notable elasticity, making it a desirable material for applications requiring flexibility and resilience. Its elastic properties stem from its molecular structure, which allows it to undergo deformation under stress and return to its original shape once the stress is removed. In the context of SLS 3D printing, PA-12's elasticity contributes to its ability to absorb impact and resist breakage, even under repeated bending or stretching. This characteristic is particularly beneficial in producing durable parts that require a combination of strength and flexibility. The study by (Kadkhodaei et al., 2023) found that the elastic response of SLS-produced Polyamide 12 is nonlinear and shows negligible dependency on printing orientation but is significantly affected by strain rate. The proposed rate-dependent Mooney–Rivlin hyperelastic models accurately captured the material behavior, with the cyclic responses stabilizing after a few initial cycles.

2.3.2 Impact Resistance

Impact resistance is another important mechanical property for materials subjected to sudden or shock loads. Polyamide 12 exhibits excellent impact resistance owing to its molecular structure and material properties. Recent studies have underscored its remarkable ability to absorb energy during impact events, making it suitable for applications requiring resilience against mechanical stress. “PA-12 demonstrates excellent chemical resistance, aging resistance, low moisture absorption, close-molding tolerance, and, importantly, outstanding impact resistance.” (Bahrami et al., 2021). The study also found that PA12 has the identical excellent mechanical properties as PA6 and 66, including hardness, tensile strength, fatigue and impact resistance, a low coefficient of friction, and resistance to aromatic hydrocarbons.

2.4 Polyamide 12

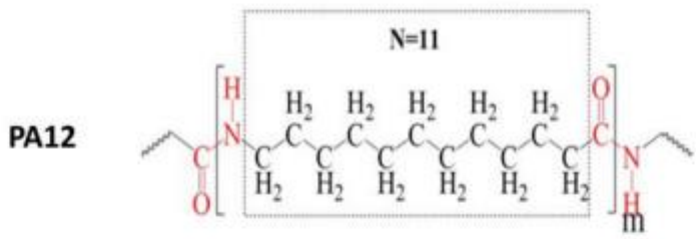


Figure 2: Chemical Structure of PA12

Figure 2 above shows the chemical structure of Polyamide 12, often known as nylon 12, a strong and flexible plastic material valued for its robustness, longevity, and resistance to chemicals and wear. Its specific characteristics come from a specific type of oil-based chemical that takes the form of complex, chain-like structures.

2.4.1 Virgin PA-12 Powder

Virgin PA-12 powder is a form of polyamide 12 (Nylon 12) polymer powder that has not been heated or sintered, neither has it undergone any prior processing cycles. This material is suitable for a variety of applications, especially in additive manufacturing processes like selective laser sintering (SLS) and other 3D printing methods since it is manufactured through a regulated manufacturing process that ensures high purity and uniformity. “Part with 100 percentage virgin material had higher tensile strength and a smoother surface due to the high adhered powder content and the right melting point.” (Rafi Omar et al., 2022). Because of this, virgin powder is perfect for precision and high-performance applications. However, due to its expensive cost of RM500/kg, there comes another alternative which to consider a recycled material of PA-12 for sintering process.

2.4.2 Extremely Ageing PA-12 Powder

Recycled PA-12 powder is a Nylon 12 polymer powder that has been used in additive manufacturing techniques for one or more cycles before being reclaimed for reuse. Recycled PA-12 powders allowing the reuse of extra powder from earlier print runs, provides an affordable and environmentally friendly alternative for additive manufacturing. A study from (Di He et al., 2022) discovered that recycled PA12 powder from the selective laser sintering process reduces life cycle global warming potential by up to 26% for automotive fuel-line clips and 42% for SLS parts.

2.4.3 Comparison of Virgin and Ageing PA-12 Powder

Recycled PA-12 powder is different from virgin powder in several ways. The recycled powder shows variations in material properties as particle size/shape distributions, surface morphology, microstructures, thermo-chemical, flowability and mechanical strength when compared to raw powders(Yang et al., 2023). When compared to parts made using aged or recycled powder, parts formed with virgin PA-12 powder often have better mechanical qualities, surface finish, and dimensional precision. Figure 2 below shows the result of study by (Yang et al., 2023) which is the comparison of cross-sectional SLS printed parts using virgin powder (a) and 3-times reused powder (b). The sintered part using aged powders, in general has decreased dimensional accuracy of around 5%− 10% compared to virgin powders. Figure 3 also shows the texture defect discovered by (Yang et al., 2023) which indicating the presence of "orange peel" texture when parts were printed using a recycled PA-12 powder.

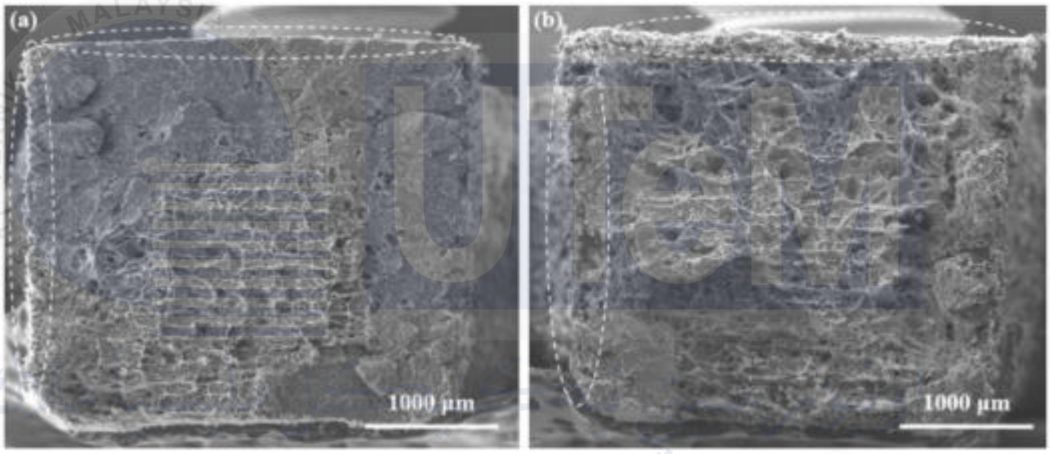


Figure 3: Cross-section of SLS printed parts using (a) new powders, and (b) 3-times reused powders (Yang et al., 2023)

Figure 4: SLS printed parts with (a) using aged powder and (b) using virgin powder (Yang et al., 2023)

2.5 Factors Contributing to Aging and Degradation in Polyamides

Polyamide aging and degradation, particularly PA-12, are caused by a variety of environmental factors including temperature, humidity, UV radiation, and chemical exposure. Heat, oxygen, and moisture exposure are important variables since they can all interact with the polymer matrix and cause chemical changes. A study done by (Wudy & Drummer, et al.,2020.) explored the aging behavior of PA-12 during laser sintering processes. The high process temperatures and long building times in laser sintering lead to chemical and physical aging mechanisms in the polymeric feed material.

2.5.1 Thermal Degradation Process

Thermal degradation occurs when a material is exposed to high temperatures and reduces its physical, chemical, or mechanical properties. For Polyamide 12 (PA 12), thermal degradation can occur when it is exposed to temperatures exceeding its stability range, typically above 180°C. As a result of the polymer chains breaking, this degradation shows up as discoloration, a decrease in mechanical strength, and a decrease in molecular weight. A study by (Wudy et al., 2014) explored different ambient conditions (ambient air, nitrogen, and vacuum) caused the degradation in mehanical properties of Polyamide 12. Moreover, (Amstutz et al., 2021) also examined the effects of temperature and water absorption on PA-12 properties. The tested medical tubes showed reduced Young's Modulus and yield stress with increasing temperature and water absorption.

2.5.2 Oxidative Degradation Process

Polyamide 12 (PA 12) oxidative degradation occurs when the polymer reacts with oxygen, causing the molecular structure to break down. This process usually begins with the formation of free radicals, which then react with oxygen to produce peroxides and hydroperoxides. Chain scission and cross-linking are the results of these unstable compounds breaking down even further into smaller molecules. Oxidative deterioration causes embrittlement, discoloration, and a considerable loss of mechanical properties over time. (Zheng et al., 2024) investigated that prolonged exposure to high temperatures and oxygen significantly speeds up the degradation process, causing noticeable changes to the structural and mechanical properties of the polymer.

2.5.3 Hydrolytic Degradation Process

Hydrolytic degradation of polyamide 12 (PA12) involves the breakdown of its polymer chains through a reaction with water. This process typically leads to a reduction in molecular weight, changes in physical properties, and ultimately the deterioration of the material's performance. Findings of a study by (Brette et al., 2024) stated the hydrolytic degradation of various polyamides, including PA12, by aging them in oxygen-free water at high temperatures. According to the study, the polymer undergoes chain scission as a result of hydrolysis, which increases crystallinity and reduces mechanical strength and molecular weight. "The hydrolysis process involves water molecules attacking the amide bonds in the polymer chain, leading to chain scission." (Zheng et al., 2024).

The ageing and degrading mechanisms described above have a significant impact on the mechanical properties of PA-12 over time. Thermal, oxidative, and hydrolytic breakdown processes cause a material's tensile strength, elasticity, and overall durability to decrease.(Zheng et al., 2024) revealed that that the cumulative effect of these degradation mechanisms could potentially compromise the structural integrity of PA-12 parts, resulting in a progressive loss of mechanical performance. This degradation necessitates the creation of techniques to increase the PA-12 powders' stability and reusability in SLS as well as careful monitoring and control of processing parameters.

Understanding how PA-12 ages and degrades is important for maximizing its useful life and performance in additive manufacturing applications. Time-related processes such as hydrolytic, oxidative, and thermal deterioration cause the material's mechanical properties to deteriorate. To improve PA-12's sustainability and reliability for industrial use, these problems must be addressed with improved material formulations, processing techniques, and environmental controls.

2.6 Effect of Seawater Exposure on Polymer Materials

Given the widespread application of polymeric materials in marine environments, their exposure to seawater is an important field of this research. The distinct combination of salts, organic substances, and microorganisms found in seawater can significantly impact the longevity and functionality of polymers. Polyamide 12 (PA-12) is a polymeric material that is frequently subjected to these kinds of conditions. It is a polymer that is widely utilized in underwater pipelines, cables, and structural components. A study by (Zhang & Deng, 2022) explores the influences of seawater content and temperature on the properties of GFRP composites. Results showed that increasing seawater content from 0% to 9.09% at 298 K led to significant reductions in Young's modulus, shear modulus, and bulk modulus of material.

2.6.1 Chemical Changes of Polymer Induced by Seawater Exposure

The exposure of polymer materials to seawater causes a variety of chemical changes that can have a significant impact on their mechanical properties and longevity. The interaction of seawater constituents with the polymer matrix, including water, salts, and microorganisms, is the main cause of these changes. Research from (Puglisi et al., 2023) explored that seawater is rich in microorganisms, including bacteria, fungi, and algae, which can colonize the surface of polymers. These microorganisms can produce enzymes that degrade the polymer chains, a process known as biodeterioration. For instance, certain bacteria can produce enzymes that break down polyesters and polyurethanes, leading to surface pitting and a decrease in mechanical integrity.

2.6.2 Physical Degradation of Polymer Due to Seawater Immersion

Physical degradation of polymer materials due to seawater immersion primarily involves the absorption of water, leading to changes in mechanical properties, chemical structure, and overall durability. A study by (Zhang & Deng, 2022) investigated the impact of seawater on GFRP composites using molecular dynamics simulations. They discovered that mechanical properties like bulk modulus, shear modulus, and Young's modulus significantly decreased with increasing seawater content and temperature. In particular, these properties decreased by 46.72%, 53.46%, and 41.75%, respectively, at a temperature of 298 K and a seawater content of 9.09%. The interaction between the composite material and seawater molecules is blamed for this degradation, which results in a weakening of the fiber-matrix interface and an increase in microcracking.

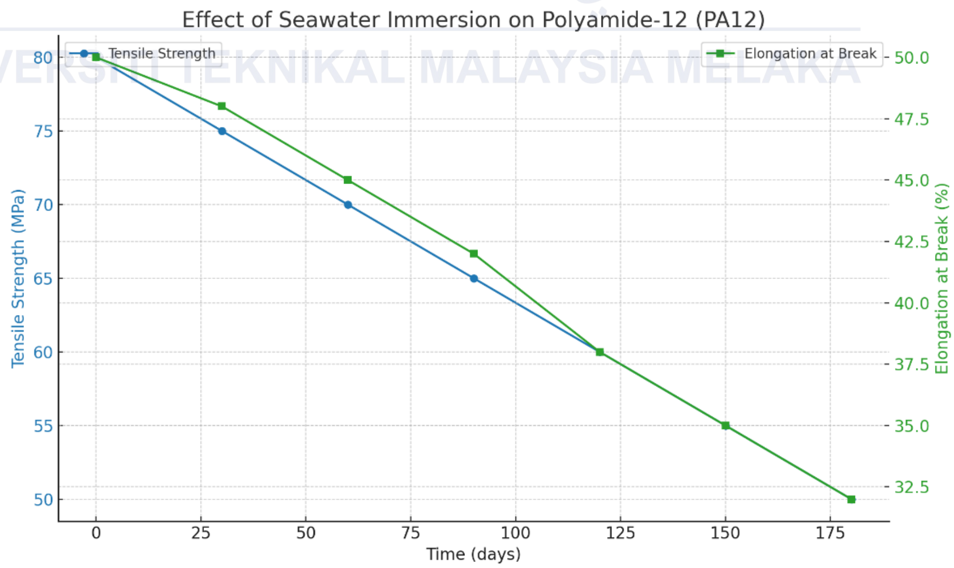


Figure 5: Effect of Seawater Immersion on Polyamide 12 (PA-12)

From the figure above, studies explored after the seawater immersion over a period of 180 days on PA-12, the tensile strength decreased from 80 MPa to 50 MPa. Moreover, the elongation at break is also being decreased over time from 50% to 32%.

2.6.3 Environmental Degradation of PA-12 in Marine Conditions.

Environmental degradation of PA-12 (polyamide 12), commonly known as nylon 12, in marine conditions is an important concern due to its widespread use in various applications such as marine ropes, fishing nets, and aquaculture equipment. The remarkable mechanical properties, chemical resistance, and longevity of polyamide 12 (PA-12) make it a popular material for subsea and offshore infrastructure. However, the unique challenges presented by the maritime environment could have a significant impact on the integrity and longevity of PA-12. According to (Oluwoye et al., 2023) the primary factors influencing PA-12 breakdown in marine environments are salinity, temperature fluctuations, UV radiation, and microbial activity which could affect its mechanical properties and decreasing its elasticity and tensile strength.

Moreover, (Oluwoye et al., 2023) discuss the application of diverse analytical techniques to assess the degradation of PA-12 in marine environments. Techniques like Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and scanning electron microscopy (SEM) are used to characterize the chemical and physical changes in the polymer. These methods provide insights into the extent of degradation and help identify the precise mechanisms through which PA-12 degrades in marine environments. By using these analytical techniques, researchers may be able to improve the material's resistance to external stresses and thereby increase the service life of PA-12-derived components in offshore environments.

In conclusion, the degradation of PA-12 in marine environments is a complex process influenced by several ocean-specific factors. For long-term maritime infrastructure safety and effectiveness, this knowledge is important.

2.7 Advances in Additive Manufacturing of PA-12

PA-12 is a common engineering thermoplastic that has advanced additive manufacturing (AM) tremendously recently because of its beneficial properties, which include strong mechanical strength and chemical resistance. (Picard et al., 2020) provide a comprehensive overview of recent developments in this field, highlighting the challenges and opportunities presented by innovative AM techniques. Among the significant developments that have been highlighted is the optimization of process parameters that improve the mechanical characteristics and surface finish of PA-12 parts. By optimising variables such as temperature, layer thickness, and build orientation, scientists have produced PA-12 components with superior performance characteristics compared to those produced using conventional manufacturing methods.

Another important area of progress highlighted by (Picard et al., 2020) and (Vidakis et al., 2021) are the development of novel PA-12 powder formulations that improve the printability and final properties of AM parts. These formulations often contain additives that improve flowability while lowering the possibility of defects like warping or incomplete fusion. For example, it has been shown that the addition of particles significantly enhances the mechanical and thermal properties of PA-12, opening up new applications in industries requiring high-performance materials. This breakthrough in material science is important because it has a direct bearing on the adaptability and dependability of PA-12 in AM.

Despite these advancements, (Picard et al., 2020) still list a number of challenges that need to be solved in order to use AM with PA-12 effectively. There are still major challenges, like the expensive raw material costs and the need for post-processing to achieve the desired surface finishes. Furthermore, the recycling and repurposing of PA-12 powders in the AM process still presents unresolved environmental and economic problems. Nonetheless, these obstacles might be addressed with further research and development in this area, boosting the applicability and efficiency of PA-12 in additive manufacturing.

2.8.1 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is a well-known additive manufacturing (AM) method that fuses powdered material into a solid structure layer by layer using a high-power laser. Initially, a small coating of powdered material is applied to a build platform, usually a thermoplastic polymer such as polyamide (PA12). In order to fuse the particles together, the laser selectively sinters the powder using a cross-sectional design from a digital CAD model. The platform lowers after each layer is sintered, allowing for the application of a fresh layer of powder to be applied until the part is completed. The ability to manufacture complicated geometries without the requirement for support structures is one of SLS's main advantages because the unsintered powder acts as support during the build process.

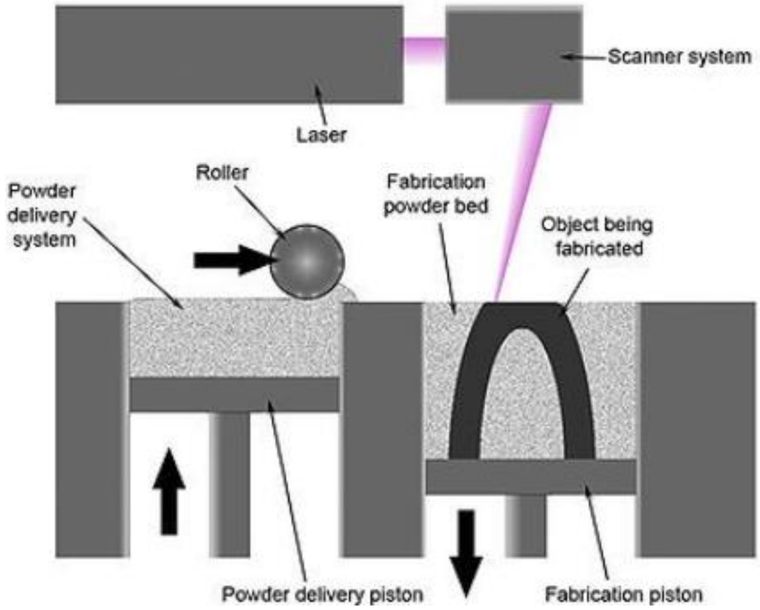


Figure 6: Overview of Selective Laser Sintering Process

The ability of SLS to produce parts with superior mechanical properties and high detail resolution makes it especially valuable. Prototyping and low-volume production are two common uses for the process in the aerospace, automotive, and medical device industries. Good tensile strength, impact resistance, and thermal stability are typical properties of SLS parts. However, compared to other AM techniques, the surface finish of SLS parts can be rougher, and for some applications, post-processing steps like polishing or coating might be necessary.

Based on study from (Lupone et al., 2022), Selective laser sintering (SLS) is a polymer additive technique that offers advantages over other methods. Unlike some processes, SLS does not need support structures during part building, as the surrounding unfused powder supports the part. It also eliminates the need for a binder, reducing toxicity concerns for medical applications. While SLS may not match the resolution of stereolithography, it produces tougher and more stable parts, with the potential for improved resolution through micro-LS systems. The main advantage of SLS lies in its ability to process a wide range of materials, making it suitable for research across various materials, including metals and ceramics.

Moreover, (Wei Han et al., 2022) also explores the optimization of SLS process parameters to enhance the mechanical properties and surface quality of PA12 parts. The study found that by fine-tuning parameters such as laser power, scan speed, and layer thickness, significant improvements in part quality could be achieved. This research provides valuable insights into how precise control of the SLS process can lead to better-performing final products.

To sum up, Selective Laser Sintering remains a crucial technology in additive manufacturing due to its ability to produce complex, high-quality parts. Recent studies have focused on optimizing process parameters, exploring sustainable practices through material recycling, and enhancing material properties with nanocomposites.

2.8.2 Farsoon SS402P

In this study, a Selective Laser Sintering (SLS) process will be implemented by using Farsoon SS402P. The SS402P is a 3D printer produced by Farsoon, a manufacturer based in China. It utilizes powder feedstock and Selective Laser Sintering technology to create thermoplastic parts. It comes with a 350 × 350 x 430 mm construction volume.

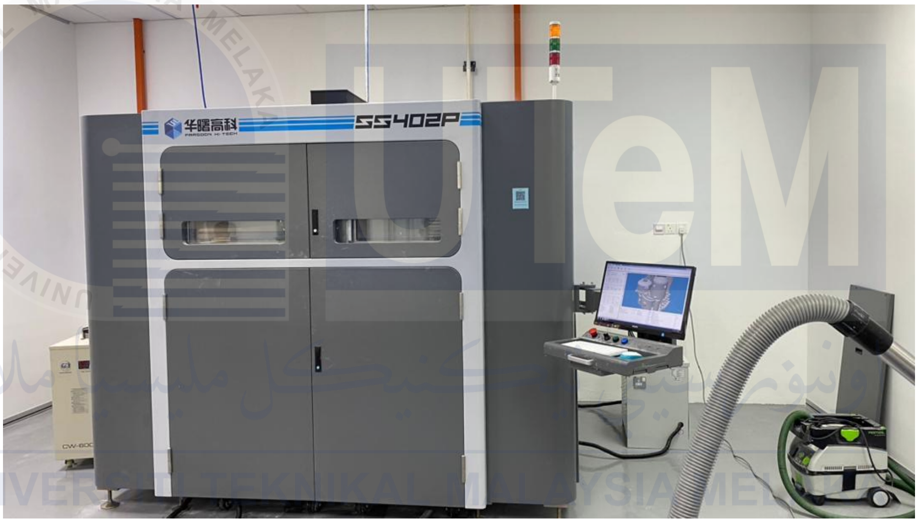


Figure 7: Farsoon SS402P SLS machine

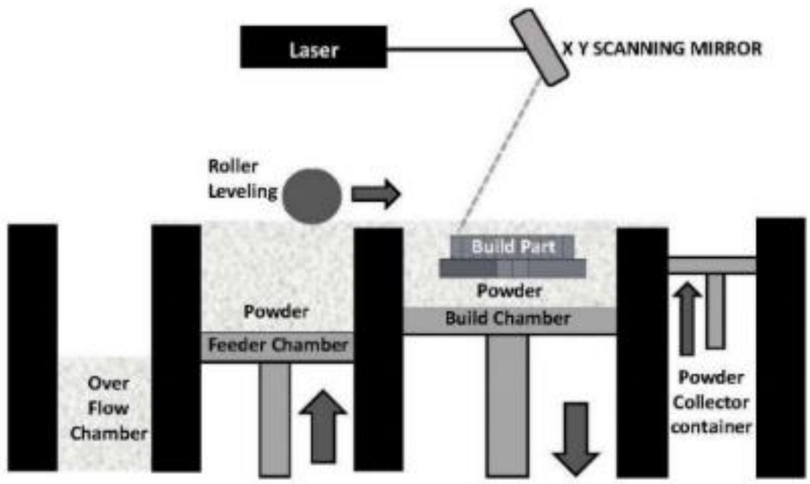


Figure 8: SLS Process for Farsoon SS202P (Rafi Omar et al., 2022)

2.8.3 Orientation Effect on Mechanical Properties

The orientation effect influences the printed part's overall quality as well as the requirement for post-processing. The amount of support material required can be determined by the orientation of a part, which in turn impacts surface damage potential and ease of removal. Incorrect orientation can result in warping or distortion. Moreover, orientation influences the thermal stresses that develop during the sintering process. In order to attain the appropriate balance between structural integrity, surface quality, and dimensional accuracy in SLS, part orientation optimization is therefore essential. This will ultimately affect the final product's performance and appearance.

Research from (Malashin et al., 2024) investigated that the orientation effect on mechanical properties in selective laser sintering (SLS) produced components is significant. Printing orientation influences characteristics like tensile strength, yield point force, and maximum load, with parts printed on edges showing lower values compared to standard orientations. Additionally, elongation at break tends to be approximately 6% lower for edge-printed details. Understanding these correlations between printing parameters and mechanical characteristics is crucial for optimizing additive manufacturing techniques and achieving desired material properties. Figure 8 below shows the stress strain curves of printed PA12 for X, Y and Z build orientation. The study concludes among 3 different orientations, the specimen printed in Y orientation has the highest percentage elongation at break.

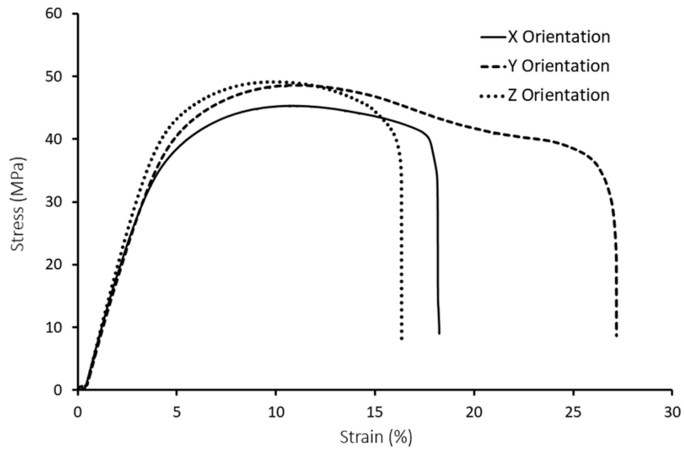


Figure 9: Stress strain curves of printed PA12 for X, Y and Z build orientations (O'Connor et al., 2018)

Moreover, (Malashin et al., 2024a) also reveals samples printed at different angles exhibit varying mechanical characteristics, with parts printed on edges showing lower elongation at break. The investigation underscores the importance of considering printing direction for designing components in SLS manufacturing. On top of that, a study by (Razaviye et al., 2022) investigated that Young's modulus of 0° and 90°oriented parts are significantly higher than those of 30° and 45° ones.

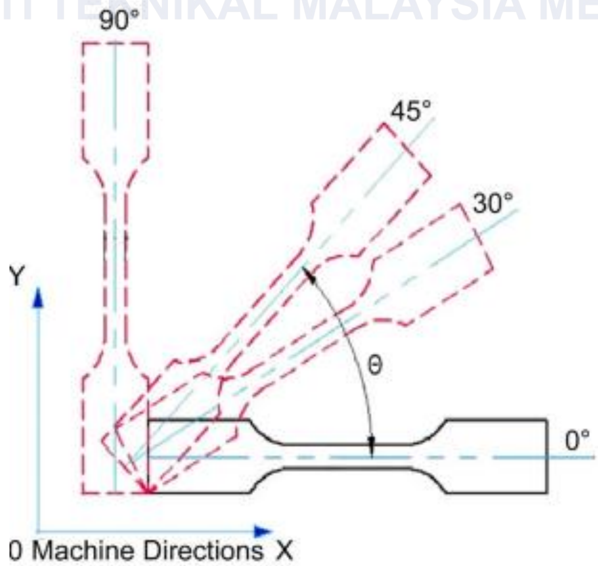


Figure 10: Overview of Sintering parts in different orientations (Razaviye et al., 2022)

2.8.4 Laser Power Effect to PA12 Mechanical Properties

The mechanical properties of the final parts produced using PA12 are significantly influenced by the laser power settings of the SLS machine. While higher laser power generally enhances part density and mechanical strength, it can also introduce challenges such as surface roughness and thermal stresses. According to (Razaviye et al., 2022), laser power and scan speed have the highest effect on the printed parts strength. Figure 10 studied by (O'Connor et al., 2018) below explained that higher laser power gives higher level of strength (Mpa) for the printed specimen. In previous study by (El Magri et al., 2022) also investigated that the tensile strength increases from 19.41 MPa to 25.65 MPa when the laser power is increased from LP: 75% to LP: 95% in the case of the 0° orientation, as attached on Figure 11.

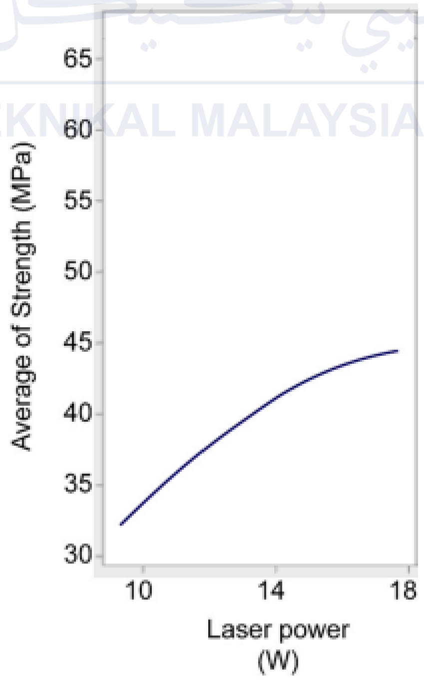


Figure 11: Effect of laser power to specimen stregth (Razaviye et al., 2022)

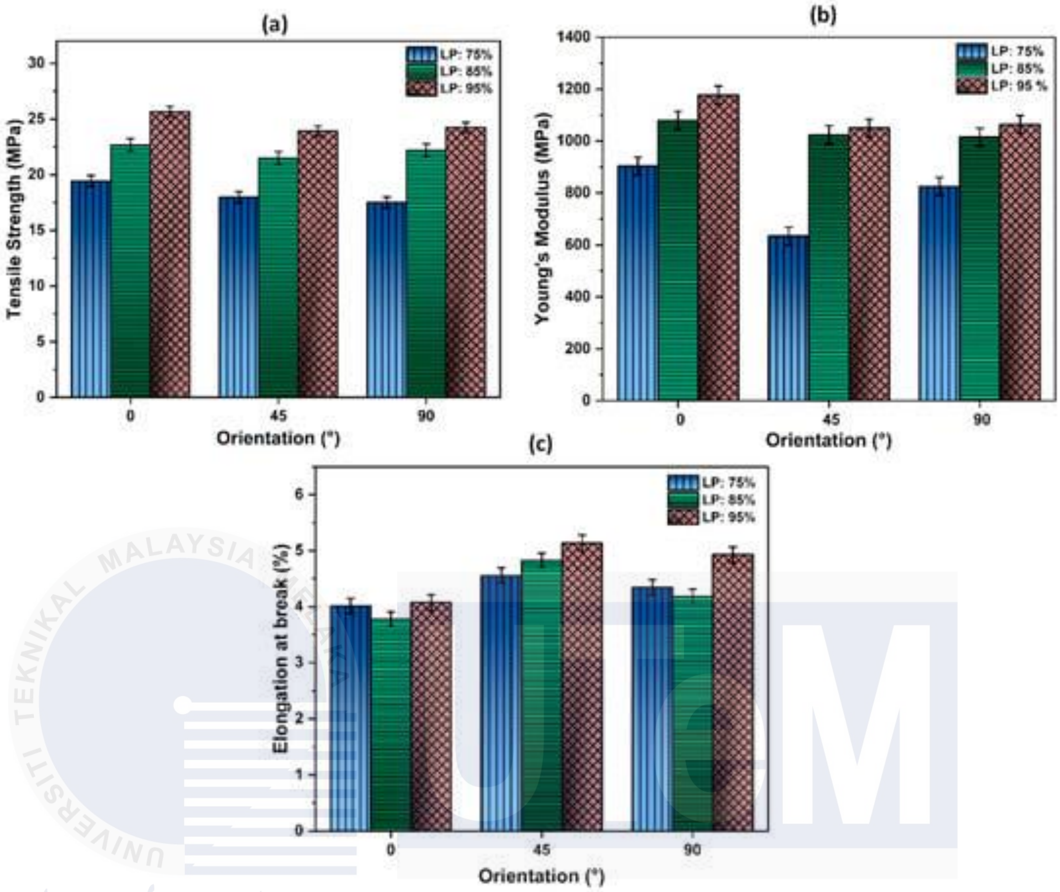


Figure 12: (a) Laser power and plane orientaion effect to (a) Tensile Strength (b) Young's Modulus (c) Elongation at Break (El Magri et al., 2022)

2.8.5 Layer Thickness Effect to PA12 Mechanical Properties

The layer thickness in Selective Laser Sintering (SLS) is an important parameter that affects the mechanical characteristics of PA-12 components. Layer by layer, a laser selectively fuses powdered material to create three-dimensional objects in SLS. The layer thickness has an impact on the printed components' mechanical qualities, surface quality, and resolution.

By referring to (Malashin et al., 2024) study result, Table 1 shows the results for sample made of polyamide 2200 with printing orientations at 0 degree to edge. The table interpret that the thinner the layer (H, cm), the higher value of tensile properties of the specimen.

Table 1: Results for samples with printing orientations at 0∘ (Malashin et al., 2024)

Ψ, °	№	H, cm	B, cm	A_0, cm^2	F_{ts}, N	σ_{pl}, MPa	$F_{0.2}$, N	$\sigma_{0.2}$, MPa	F_{max}, N	σ_{ts}, MPa	ε, %
0	1	0.57	10.25	5.84	28	4.79	42.8	7.33	78.4	13.42	8.8
	2	0.57	10.3	5.87	30.5	5.20	43.4	7.39	73.3	12.49	7.1
	3	0.57	10.25	5.84	26.4	4.52	43.1	7.38	73.6	12.60	5.9
	4	0.57	10.25	5.84	33.1	5.67	47.8	8.18	84.5	14.46	7.7

2.9 HydroQS

Hydro Quality Survey System (HydroQS), a tool used in Sungai Melaka, Malaysia, to measure and examine the quality of the local water. The project attempts to deal with the persistent problems of water pollution in the river and is being carried out in association with Perbadanan Pembangunan Sungai dan Pantai Melaka (PPSPM). The objective of this project is to create a hydrodynamic housing for the Hydro Quality Survey System (HydroQS). The literature review emphasizes the serious issues with Sungai Melaka's water quality and highlights the importance of appropriate management techniques and real-time monitoring. Agricultural, industrial, and residential activities have been recognized as the sources of the pollution levels in the river by numerous studies. The problem has not been adequately addressed by the local government's implementation of measures like trash trapping boats and community participation programs.

The researchers want to create a strong and lightweight housing for the HydroQS using recycled aged polyamide PA-12 powder and Selective Laser Sintering (SLS) to reduce costs and environmental effect. “The selection of Nylon 12 or PA-12 are because it has good material properties such as hardness, tensile strength, and resistance to abrasion, are similar to those of Nylon 6 and Nylon 66” (Idain, et al., 2024). This research will contribute to in the creation of an extensive system for monitoring water quality, which will provide important information for making decisions that will protect the environment and promote sustainable development. As attached in figure 12 is a simple overview of how HydroQS system funtioning.

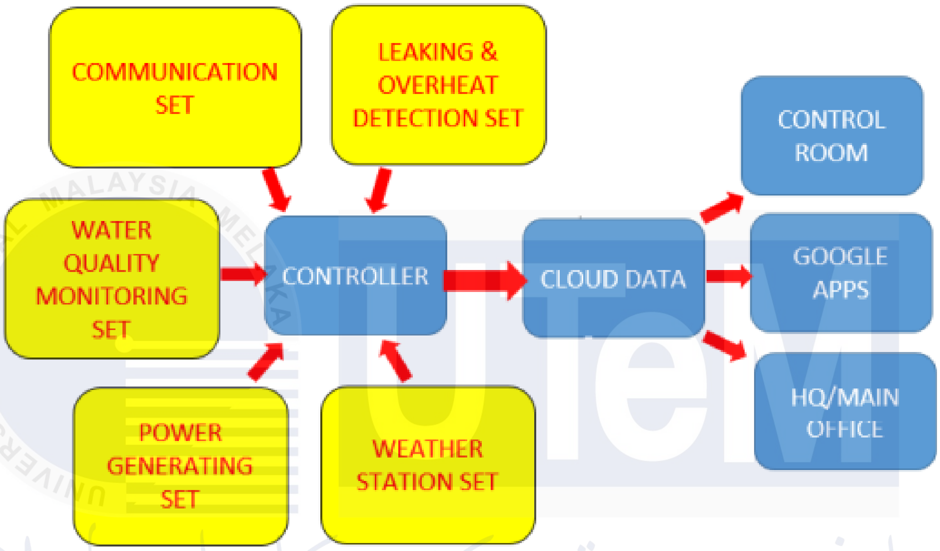


Figure 13: HydroQS System Functioning

CHAPTER 3

METHODOLOGY

3.1 Introduction

It is necessary to understand how environmental factors affect the mechanical properties of advanced materials in order to apply them in challenging environments. The purpose of this study was to investigate the mechanical characteristics of FS3300PA PA-12 sample produced at different parameters, following a prolonged immersion in seawater. For the purpose to provide specific insights into how the orientation of printed parts affects the fabrication of housing for Hydro Quality Survey System (HydroQS), the study focused on the YZY 0-degree orientation, which represents a common printing configuration for many additive manufacturing processes. The methodology of this study aimed to analyze the weight stability, mechanical properties PA-12 after prolonged immersion in seawater and the fracture behaviour after undergoing tensile test.

3.2 Flow Chart Process

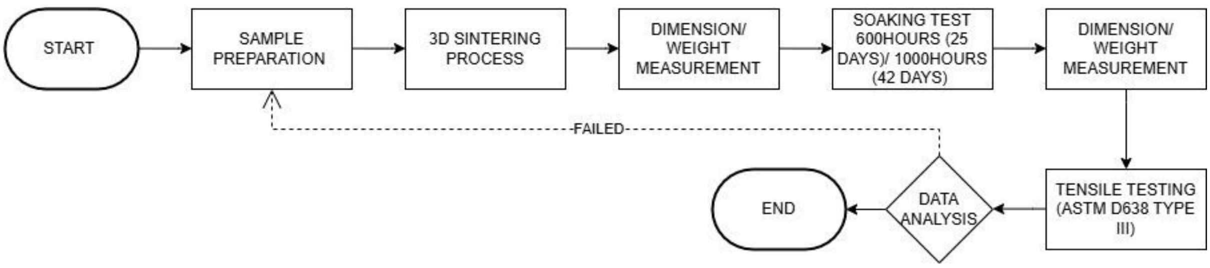


Figure 14: Flowchart of PSM 2

The methodology of the flowchart describes a systematic process for preparing and testing these materials, with a focus on the performance of 3D-printed samples after being submerged in seawater.

The process began with sample preparation, after which the sample is designed with a YZY 0-degree orientation. In this part, the process of parameter setup like laser power and layer thickness have been implemented. The virgin and recycled powder also were prepared before the sintering process. The samples then were designed using Solidwork.

Then a 3D sintering process was executed to create measurable test specimens that adhere to the requirements. After measuring all the specimens using Vernier Caliper for the dimension stability objective, the samples are then immersed in seawater for 1000 hours to simulate environmental conditions that could affect their mechanical properties.

After being submerged in seawater, the samples were subjected to three distinct tensile testing according to ASTM D638 Type III: elongation, tensile, and flexural strength tests. These tests evaluate multiple aspects of the material's mechanical performance: Tests for tensile strength gauge resistance to breaking under tension; tests for flexural strength gauge resistance to deformation under load; and tests for elongation determine ductility.

The data obtained are then analysed to get definitive insights into the material's performance including the elongation at break, tensile strength and young’s modulus. These parameters provide insights into the material's ability to withstand stress, its ductility, and stiffness.

3.3 Research Design

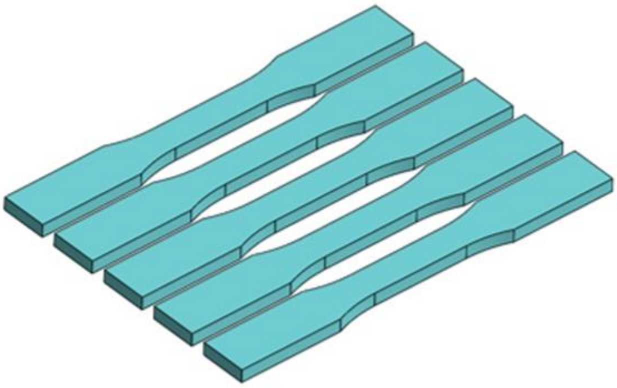


Figure 15: Printed samples oriented in YZY 0 ° plane

Tensile strength testing is a fundamental engineering and materials science test that is widely utilized in a range of manufacturing processes, including injection molding, machining, and industrial-grade 3D printing (additive manufacturing). In terms of 3D printing, the test offers information about the mechanical properties and quality of a material to ascertain how it will respond to loads.

A frequently used design for testing 3D-printed material mechanical properties is shaped like dog bones. Tensile testing uses a dog bone with two opposing shoulders joined by a smaller cross section. Each end of the specimen is held in a tensile testing machine, which applies tension until it breaks. In a tensile test, this narrower cross section is meant to be a predictable point of failure. The shape of the cross section might be either circular or rectangular.

3.4 Proposed Methodology

This study utilized a methodical approach to examine how immersion in seawater affects the mechanical characteristics, fracture behavior, dimensional stability, and water absorption of sintered PA-12 samples. Three main steps were involved in the methodology: sample preparation, testing and analysis.

First, using selective laser sintering (SLS) in a YZY 0-degree orientation, samples for PA-12 have been fabricated at different laser power (65, 70, and 75 watts) and layer thicknesses (0.09, 0.12, and 0.15 mm). The samples are then classified into two separate states of material degradation: extremely aged and virgin. A scientific weighing scale was used to test the samples' weight stability and changes due to water absorption both before and after they are soaked in seawater for 1000 hours of time. This will make it practicable to evaluate the material's reaction to immersion in seawater as well as its capacity for weight changes and water absorption.

After that, tensile testing was performed on the samples using a Universal Test Machine (UTM) in coordination with ASTM D638-III to assess their mechanical properties. Important mechanical characteristics like tensile strength, elongation at break, and Young's modulus can then be determined through this. The effect of seawater on the mechanical performance of the material can be evaluated by contrasting the outcomes of the virgin and severely aged samples before and after seawater immersion. Lastly, Scanning Electron Microscopy (SEM) will be used to examine the fracture behavior of the samples. This method will clarify the mechanism behind the observed failure modes and offer in-depth insights into the fracture surfaces. By combining these findings with the mechanical test results, a thorough understanding of the material's response to seawater exposure can be gained.

3.5 Experimental Setup

To fully investigate the effects of mechanical properties on extremely aged FS3300PA PA-12 powder submerged in seawater in the YZY 0° orientation, a well-organized experimental setup was needed. First, the powder known as FS3300PA PA-12 was selected for the study because of its potential for environmental degradation and extensive industrial use. To ensure consistency and dependability, defined testing techniques such as impact, tensile, and hardness testing are then employed to evaluate the mechanical properties of the powder. The immersion process in seawater has also been closely monitored and controlled, with variables like temperature, salinity, and exposure time being closely watched and adjusted in order to replicate real-world conditions.

The next focus of the experimental setup will be characterize the mechanical behavior of the immersed FS3300PA PA-12 powder through a series of systematic tests. This will involve subjecting the specimens to varying levels of mechanical stress in order to track their response in terms of hardness, impact resistance, and tensile strength. Specifically, the YZY 0° orientation has been chosen to make it easier to understand directional variations in mechanical properties and to be consistent with common industrial applications. Throughout the experimentation process, data have been collected and statistically analyzed in order to quantify the degree of degradation and identify any correlations between mechanical properties and immersion conditions. This study aims to give important insights into the behavior of FS3300PA PA-12 powder under harsh environmental conditions by following a strict experimental methodology. This will help with informed decision-making in developing HydroQS device housing.

3.5.1 Equipment

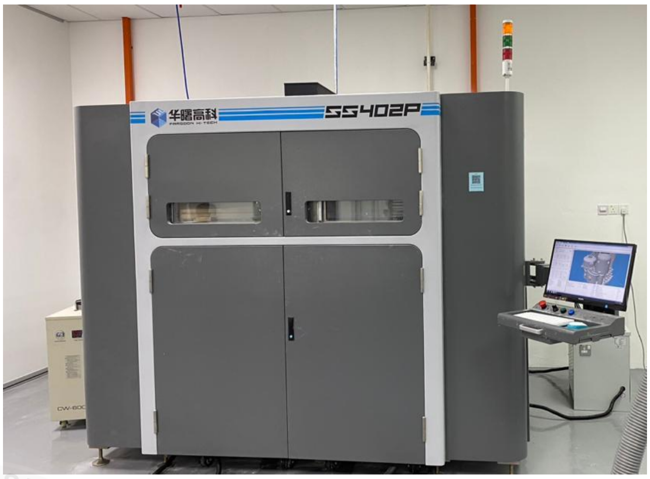


Figure 16: Farsoon SS402P SLS Machine

In this study, Farsoon SS402P was used to develop a Selective Laser Sintering (SLS) technique. China-based Farsoon is the manufacturer of the SS402P 3D printer. To generate thermoplastic parts, it makes use of Selective Laser Sintering technology and powder feedstock. The building volume is 350 × 350 x 430 mm.

Figure 17: Scientific Weighing Scale

A scientific weighing scale, also known as an analytical balance or precision balance, is an instrument designed to measure the mass of objects with a high degree of accuracy and precision. Scientific scale was used where it measured very small mass increments, often to the nearest 0.1 mg (0.0001 g) or better, which is essential for scientific experiments and quality control processes.

Figure 18: Universal Testing Machine (UTM)

In this study, a Universal Testing Machine (UTM) was used to test the mechanical properties of PA12 specimen after immersed in seawater. UTM measures how much force is needed to deform or break the material, in order to understand its strength, elasticity, and overall performance under different conditions.

Figure 19: Scanning Electron Microscopes (SEM)

Using SEM to analyze 3D printed samples provides invaluable insights into the material properties and quality of the printed parts. SEM equipment helps in this research by examining surface morphology, conducting elemental analysis, and performing detailed defect and failure analyses.

3.6 Parameters

Table 2: PA-12 Mechanical Properties Based on Manufacturer (Rafi Omar et al., 2022)

Properties	Value
Density	0.95 g/cm^3
Tensile Strength	48.1 MPa
Impact Strength	3.6 KJ/m^3

The mechanical properties of virgin PA-12 material as confirmed by the manufacturer are displayed in Table 2**.** The specimen preparation for SLS (Selective Laser Sintering) involved careful consideration of various parameters to examine their impact on the mechanical properties of printed parts.

Orientation at YZY 0 Degrees

The orientation "YZY 0 degrees" refers to the specific positioning of the part in the build chamber. The part is oriented with its major axis along the Y-axis. Then layers are constructed along the Z-axis. The part's orientation angle in relation to the horizontal plane is zero degrees, meaning it is aligned parallel to the base plane of the build platform. According to (Rafi Omar et al., 2022), orientation is also an influencing factor to increase the printed part tensile strength.

Table 3: SLS 3D Printer Settings Parameter

Properties	Value
Orientation	YZY 0-degree
Laser Power	65-Watt, 70-Watt, 75-Watt
Layer Thickness	0.09mm, 0.12mm, 0.15mm

The table above is the settings parameter of SLS 3D Printer used in specimen printing process. The settings parameters in Selective Laser Sintering (SLS) are important in fabricating high-quality products. These parameters significantly influence the mechanical properties, dimensional accuracy, surface finish, and overall performance of the printed parts. Adequate laser power ensures proper sintering of the powder particles, leading to well-fused layers. Using thinner layers improves the resolution and surface finish of the parts. This fine resolution allows for better detail and more precise mechanical properties, as each layer is more accurately sintered.

3.7 Sample Preparation

The operation setup consisted of three stages: pre-processing (figure A-B), 3D printing (figure C-F), and post-processing (figure G-I). The four main chambers of the SLS 3D printer are the feeder chamber, building chamber, collector chamber, and powder overflow chamber with figure leveling roller.

Initially, the material weight and volume were determined using Materialise Magics software, taking into consideration the quantity of the component that required printing. At the start of the 3D printing process, the SLS 3D printer's primary constant parameters were set.

Afterwards, as illustrated in figure 12 (G-I), the material block was taken out of the SLS machine building chamber and moved to the sieve machine during the post-processing stage. Figure 12 (J) displays every completed specimen that was prepared for examination. The Farsoon model FS4092P SLS 3D printer, depicted in Figure 12, was utilised to fabricate every specimen, with a maximum usable area measuring 350x350x400mm.

Figure 20: SLS 3D Printing Process

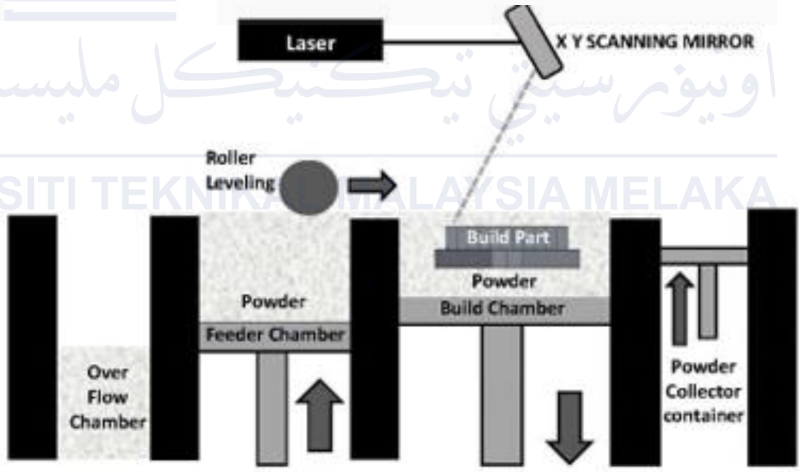
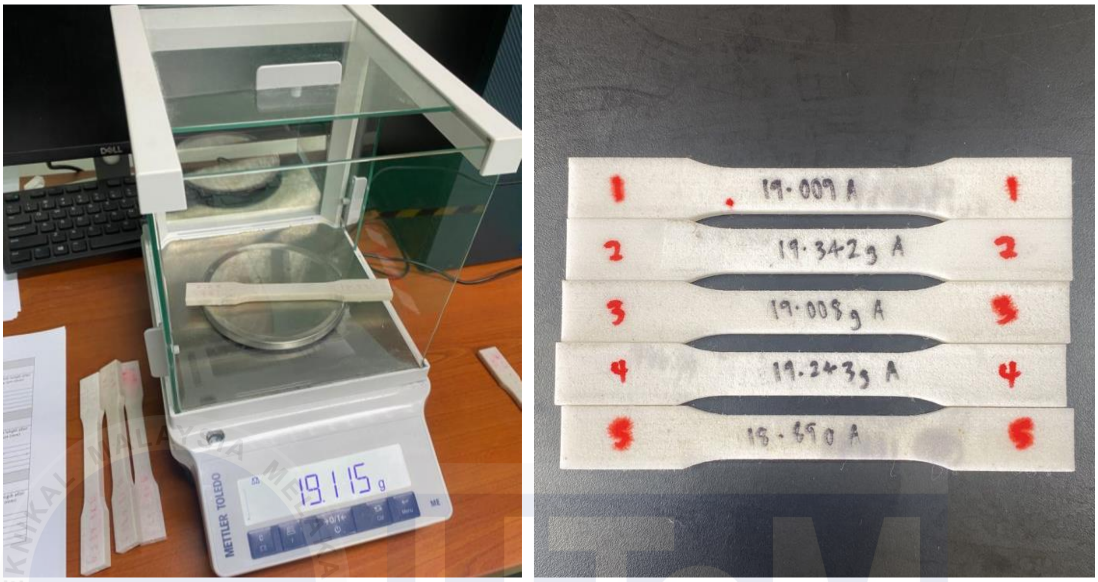


Figure 21: SLS Process for Farsoon FS402P (Rafi Omar et al., 2022)

Test Setup

Two significant tests were conducted for this study in order to confirm the mechanical properties and fracture behavior of the virgin and severely aged powder PA-12. The universal testing machine was used to perform tests on material elongation and tensile strength. “This data was helpful in qualitatively characterizing a stiffer CP material in accordance with the ASTM D638 standard” (Rafi Omar et al., 2022).

3.7.1 Weight Measurement

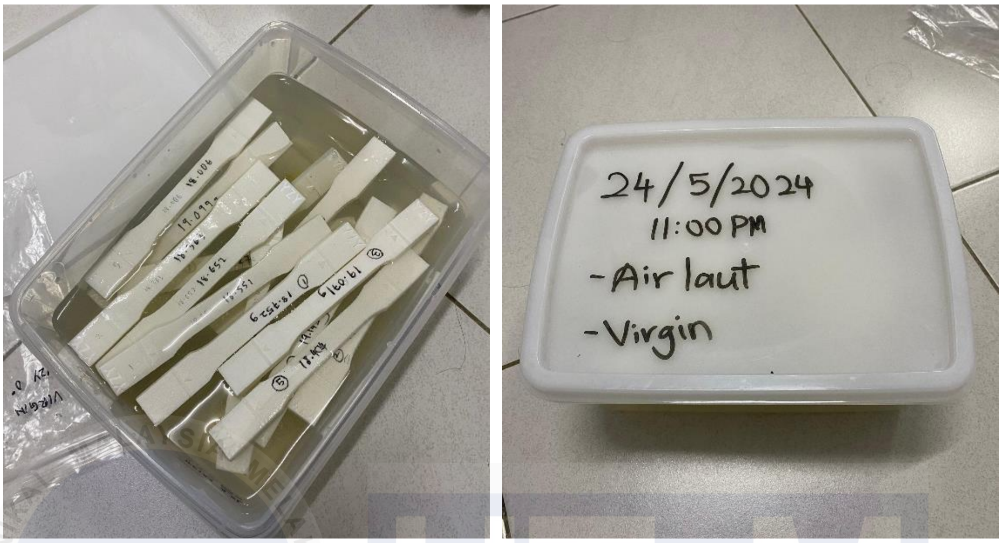


(a) (b)

Figure 22: (a) and (b) Sample Weighing Process and Labelling

Figure 26 (a) illustrates the procedure of measuring weight was carried out at two critical stages to monitor changes in the material. To get the baseline values for the samples' weight, the first measurement was carried out right after the 3D sintering procedure. To find any changes brought on by extended exposure to the environment, a second dimension and weight measurement was performed after the immersion process is finished after 1000 hours. The weighing procedure was done by using the scientific weighing scale and then the samples were labelled each of them as Figure 26 (b) to ensure the parts will not be wrongly switched when doing the tensile test process. The material's performance in practical applications is directly impacted by this stage, which is important in assessing the material's water absorption, dimensional stability, and overall integrity upon immersion.

3.7.2 Seawater Immersion Process (1000 hours)



(a) **(b)**

Figure 23: (a) and (b) Immersion Process of Sintered Sample

The sintered Polyamide 12 (PA12) samples are then submerged in seawater for prolonged periods of time as part of the soaking test procedure. This process aims to simulates actual aquatic circumstances and evaluates the samples' long-term performance. The immersion period of 42 days is allowing the study to evaluate the material's resistance to seawater exposure. The purpose of this test was also to determine important elements including dimensional stability, water absorption, and any potential deterioration over time.

3.7.3 Tensile Testing

(a) (b)

Figure 24: Tensile Test Process

Figure 28 shows the tensile test procedure was implemented by using Universal Testing Machine (UTM). This process was conducted after the final dimension and weight measurements, following the completion of the soaking test. With 5 samples for each parameter, a total of 45 samples were tested according to ASTM D638 Type III standards, which specifies the procedure for evaluating the mechanical properties of plastics. The purpose of this test is to evaluate important mechanical properties, such as tensile strength, elongation at break, and Young's modulus, to analyze how long-term seawater immersion has damaged the material's structural integrity. The data collected from tensile testing is then analyzed as in Appendix C-F to evaluate the material's long-term behavior. Figure 25 shows few samples of (a) virgin sintered PA 12 powder and (b) used powder after the tensile testing process.

(a)

(b)

Figure 25: Samples After Tensile Test

3.8 Limitation of Proposed Methodology

It is important to acknowledge the primary limitations of this study was the inability to conduct a detailed analysis of the fracture surfaces using a Scanning Electron Microscope (SEM). The analysis of fracture behavior under SEM supposed to be important for understanding the failure mechanisms, such as brittle or ductile fracture modes, and for correlating these mechanisms with the mechanical properties of the samples. Unfortunately, due to the unavailability and malfunction of the SEM equipment in the laboratory, this objective could not be achieved. As a result, critical insights into the microstructural features of the fractured samples, including the nature of the bonding between layers and the existance of voids or defects, remain undiscovered.

Without SEM imaging, the study's results were based primarily on macroscopic mechanical testing data such as tensile strength, Young's modulus, and elongation at break. Although these tests offer important insights into the samples' general mechanical performance, they don't provide specific details regarding microscopic failure processes. As a result, the lack of fracture surface analysis restricts the study's thoroughness, especially when it comes to spotting any microstructural defects or irregularities that can affect the mechanical behavior of PA12 components.

3.9 Summary

In summary, selective laser sintering (SLS) was used to fabricate polyamide 12 (PA12) samples using different process parameters, specifically varying laser power (65 W and 75 W) and layer thickness (0.09 mm and 0.15 mm) with the sintering orientation at YZY 0 degree. 9 groups of samples with 5 samples each group were built to evaluate the influence of laser power and the layer thickness on the mechanical properties of PA 12 material after being immersed in seawater after 1000 hours. Mechanical testing, including tensile strength, Young's modulus, and elongation at break, was conducted by using universal tensile testing machine to assess the stiffness, strength, and ductility of the fabricated samples. The material water stability also was studied by analysing the weight changes and water absorbtion of samples before and after the immersion test. The impact of powder reuse on material performance was examined using virgin and aged PA 12 powders. The methodology also aimed to analyze the fracture surfaces using Scanning Electron Microscopy (SEM) to better understand the failure mechanisms, although this analysis could not be completed due to equipment failure.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter explains the findings of an experimental study executed to evaluate the long-term performance of sintered Polyamide 12 (PA 12) samples after immersion in seawater. The main purpose of this study is to assess the properties of virgin and extremely aging powder PA-12 depending on the desired parameters, laser power (65 W, 70 W, 75 W) and layer thickness (0.09 mm, 0.12 mm, 0.15 mm). These samples were printed in the YZY 0-degree orientation using Selective Laser Sintering (SLS) and exposed to a severe marine underwater environment by immersing them in seawater for 1000 hours of soaking test.

The results are analyzed based on three main objectives. First, the weight stability and water absorption of PA-12 samples are examined before and after seawater immersion to understand how the material's physical characteristics change under extreme conditions. Second, the mechanical properties including tensile strength, young's modulus and elongation are evaluated to find out the impact of seawater exposure on the material's structural integrity. Next, the fracture behavior of the samples will be investigated, focusing on failure modes and the influence of different laser power settings and layer thicknesses on crack propagation.

4.2 Seawater Impact to Weight Stability of PA 12

In this part, the study examined the impact of prolonged seawater immersion after 1000 hours on the weight stability of PA 12 parts produced through Selective Laser Sintering (SLS). The results highlight variations in weight changes due to different process parameters, including laser power and layer thickness. The weight differences are expressed as percentages, comparing the weight before and after immersion, with the average differences for each sample type calculated.

According to data obtained from Table 4 below, the highest weight change was observed in the sample produced with 75W laser power and 0.09mm layer thickness, which showed an average difference of 2.36%. This significant increase suggests that thinner layers sintered with higher energy are more prone to water absorption, likely due to increased porosity or microvoids within the material. The material absorbs moisture and shows a greater weight gain as a result of these gaps, which let more seawater in.

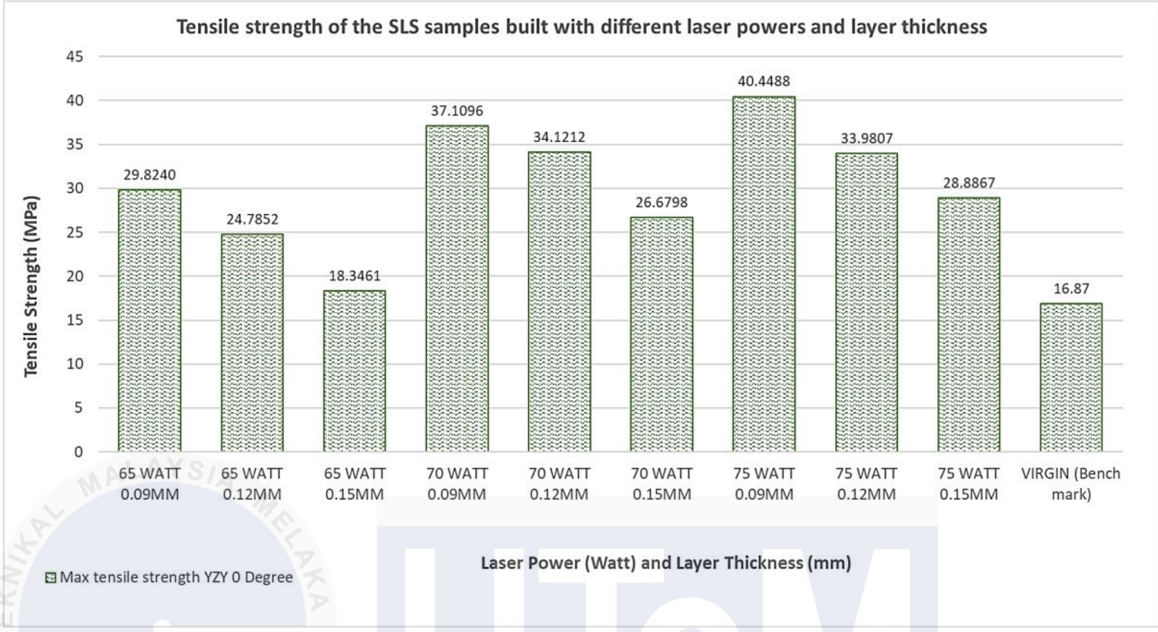
In contrast, the lowest weight change was recorded in the aged samples of 70-Watt laser power at a layer thickness of 0.12 mm. This sample showed an average weight difference of 1.59%, which is the lowest among all aged powder samples in the dataset. The sample's lower weight change may be assigned to the ideal sintering conditions, which generally produced a more uniform microstructure with less porosity, lowering the rate of water absorption. Besides, virgin sample produced with 65W laser power and 0.15mm layer thickness also showing a good resistance to water absorbtion with an average difference of 1.63%. The more compact structure and lower porosity of the virgin sample, which result in less moisture absorption during immersion, may be the cause of its minor weight change.

Overall, samples with thinner layers tend to show higher weight changes, possibly due to increased surface area and porosity. On the other hand, samples with thicker layers made with less laser power show stronger resistance to moisture absorption, sustaining more weight stability over time. Samples manufactured with higher laser power exhibited greater weight changes since higher laser power generates more energy during the sintering process, which lead to excessive material heating and localized degradation or over-melting. This also align with findings from (Rosley et al., 2024) that over-melting results in irregular bonding between the powder particles, causing the formation of microvoids or defects in the material's internal structure. While samples produced with lower laser power are exposed to lower energy levels, resulting in more uniform sintering without excessive heating. As a consequence, the pieces become denser and have fewer gaps and fractures, which reduces the possibility that they would absorb seawater. As a result, upon immersion, these components show improved weight stability.

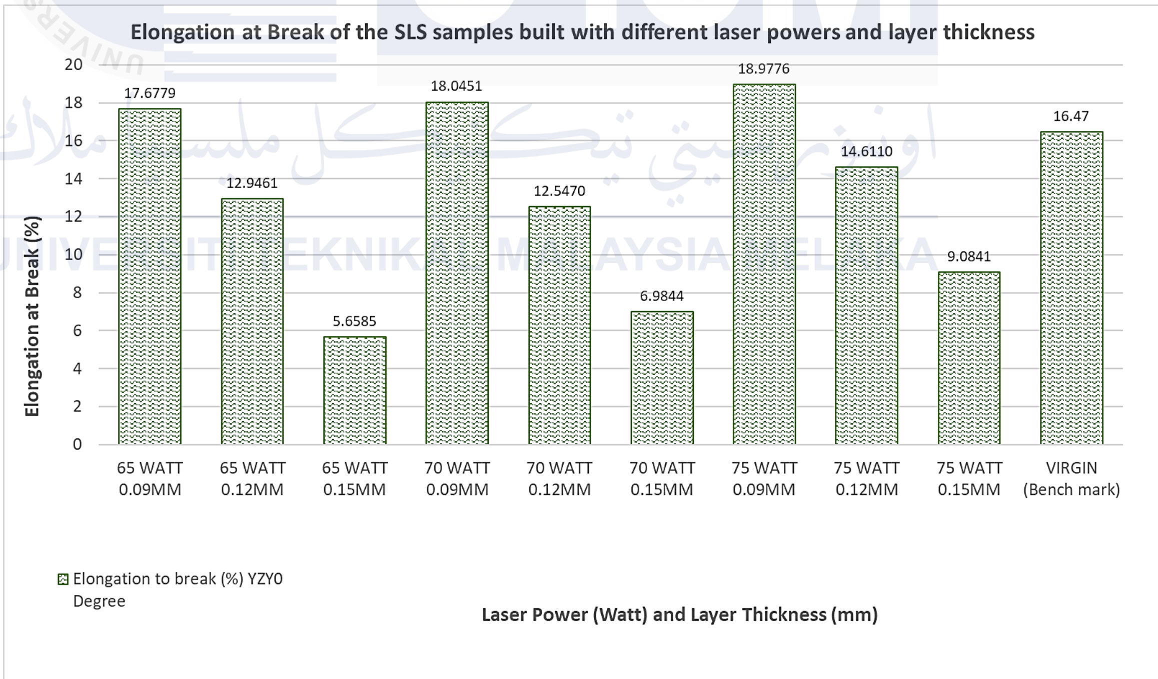
Table 4: Weight Changes After Seawater Immersion

Parts Name	No	Weight before immersed (g)	Weight after immersed (g)	Difference (%)	Average difference (%)
65 WATT 0.15MM (VIRGIN)	1	18.752	19.009	1.37	1.63
	2	18.598	18.89	1.57	
	3	19.071	19.243	0.90	
	4	19.143	19.342	1.04	
	5	18.404	19.008	3.28	
75 WATT 0.15MM	1	17.032	17.25	1.28	1.92
	2	17.165	17.597	2.52	
	3	17.185	17.724	3.14	
	4	17.004	17.245	1.42	
	5	16.778	16.99	1.26	
75 WATT 0.12MM	1	17.272	17.6	1.90	1.98
	2	17.321	17.677	2.06	
	3	17.311	17.623	1.80	
	4	17.578	17.943	2.08	
	5	17.218	17.571	2.05	
75 WATT 0.09MM	1	18.528	19.041	2.77	2.36
	2	18.568	18.9	1.79	
	3	18.675	19.14	2.49	
	4	18.745	19.206	2.46	
	5	18.682	19.115	2.32	
70 WATT 0.15MM	1	16.136	16.36	1.39	1.75
	2	16.775	17.113	2.01	
	3	16.738	16.971	1.39	
	4	16.743	16.982	1.43	
	5	16.747	17.173	2.54	
70 WATT 0.12MM	1	17.129	17.481	2.05	1.59
	2	17.478	17.821	1.96	
	3	17.335	17.556	1.27	
	4	17.554	17.805	1.43	
	5	17.698	17.917	1.24	
70 WATT 0.09MM	1	18.698	19.07	1.99	1.88
	2	18.63	18.968	1.81	
	3	18.685	19.015	1.77	
	4	18.732	19.118	2.06	
	5	18.609	18.937	1.76	
65 WATT 0.15MM	1	16.069	16.395	2.03	2.09
	2	16.115	16.513	2.47	
	3	15.63	16	2.37	
	4	16.737	17.031	1.76	
	5	15.932	16.222	1.82	
65 WATT 0.12MM	1	17.442	17.693	1.44	2.16
	2	17.811	18.16	1.96	
	3	17.571	18.045	2.70	
	4	17.676	18.241	3.20	
	5	17.581	17.845	1.50	
65 WATT 0.09MM	1	18.751	19.102	1.87	1.93
	2	18.573	18.944	2.00	
	3	18.564	18.946	2.06	
	4	18.4	18.724	1.76	
	5	18.716	19.081	1.95	

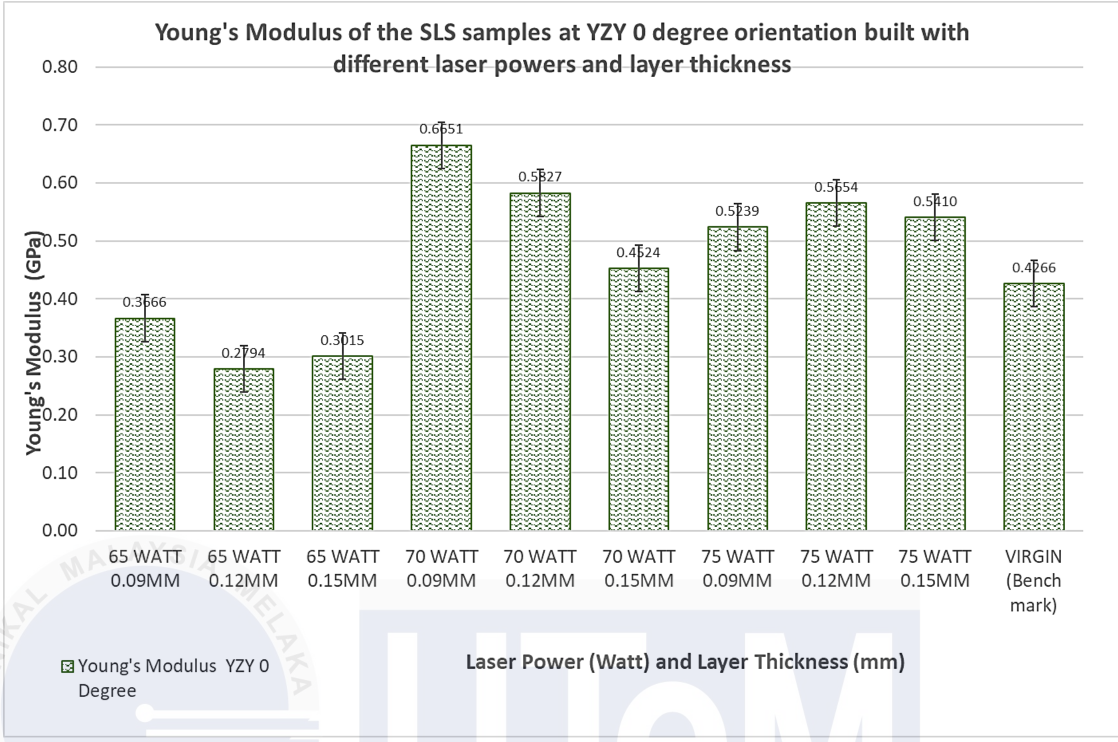
4.3 Effect of Laser Power and Layer Thickness to the Mechanical Properties of Seawater Immersed PA 12



(a)



(b)



(c)

Figure 26: Effect of Laser Power and Layer Thickness to (a) Tensile Strength, (b) Elongation at Break and (c) Young's Modulus of Immersed PA12 in Seawater

The mechanical properties of PA12 samples, such as Young's modulus, elongation at break, and tensile strength, are strongly impacted by layer thickness and laser power used in sintering process.

Among the samples tested as shown in Figure 30 (a), the highest tensile strength of 40.4488 MPa was recorded for the sample produced with 75-watt laser power and 0.09 mm layer thickness, while the lowest tensile strength of 18.83461 MPa was observed in the sample at 65-watt laser power and 0.15 mm of layer thickness. This result indicates that optimized process parameters, particularly higher laser power and thinner layers, enhanced the density and mechanical bonding of the sintered parts, leading to improved tensile properties. This is also consistent with study from (El Magri et al., 2022) which discovered that the tensile strength increases as the laser power increases.

On the other hand, Figure 30 (b) illustrates the elongation at break of PA 12 samples after being immersed in seawater for 1000 hours. The aging sample with 75-watt laser power and 0.09 mm layer thickness exhibited the highest value of 18.9776% elongation, whereas the lowest elongation of 5.6585% was noted for the sample with 65-watt laser power and 0.15 mm layer thickness. This also enlightened that higher laser power promotes better fusion between powder particles, thereby enhancing ductility. On the other hand, thicker layers, when combined with lower laser power, result in insufficient fusion and greater porosity, reducing the material's ability to stretch before breaking. Findings from (Malashin et al., 2024) also discovered the thinner the layer, the higher value of elongation of the specimen.

Figure 30 (c) displayed Young's Modulus data obtained which describes the material stiffness and how easily it can stretch or deform under tension or compression. The highest value of 0.6651 GPa was achieved by the sample processed with 70-watt laser power and 0.09 mm layer thickness, reflecting its outstanding stiffness and load-bearing capacity. In contrast, the sample created with a 65-watt laser power and a 0.12 mm layer thickness had the lowest modulus, 0.2794 GPa. This trend highlights the critical role of laser energy density in determining the ultimate stiffness of SLS-fabricated parts, where insufficient energy results in poorly bonded and less rigid structures.

Overall, increasing laser power while decreasing layer thickness improves the mechanical performance of PA12 components by improving interlayer bonding and reducing porosity.

4.4 Effect of Extemely Aging Powder Used to the Tensile Properties of Seawater Immersed PA 12

The data obtained in Figure 30: (a) shows a significant difference in mechanical properties between virgin and aged samples. The aged samples generally produced higher tensile strength compared to the virgin sample. The virgin sample recorded the lowest tensile strength (16.87 MPa) and Young's modulus (0.4266 GPa), indicating weaker structural integrity. The used powder samples revealed higher tensile strength compared to the virgin powder samples across all orientations and processing parameters due to the thermal history effect where reused powder has undergo repeated thermal exposure during the SLS process, which lead to partial melting of fine particles on the surface as dicovered by (Gazzerro et al., 2023). The repeated heating and cooling cycles of reused powder may cause higher crystallinity in PA 12, which could contribute to increased tensile strength since the crystalline regions provide more resistance to deformation.

In contrast, the graphs for Young's modulus and elongation at break between both virgin and aged sample achieved relatively identical results with slight changes depending on sample processing conditions. For instance, as Figure 30 (b) interpreted the virgin sample produced at 65-watt and 0.15 mm achieved 16.47% of elongation at break while the highest elongation obtained was 18.4956% by aged powder at 75-watt and 0.09 mm. Not only that, data for Young's modulus also remain close between virgin and used sample. The virgin sample exhibit 0.4266 GPa while the highest was 0.6651 GPa from used powder at 70-watt and 0.09 mm condition. As studied by (Gomes et al., 2022), when processed under optimized laser power and layer thickness conditions, both virgin and aged powders, can achieve similar densification.

4.5 Impact of Sintering Orientation (XYY 0°, YZY 0°, YZY 90°) on the Tensile Properties of Seawater Immersed PA 12

The tensile properties of PA12 produced using Selective Laser Sintering (SLS) were evaluated for three build orientations: XYY 0°, YZY 0°, and YZY 90°. Important tensile characteristics, such as elongation at break, Young's modulus, and tensile strength, were investigated at different laser power levels and layer thicknesses. The analysis highlights the significant influence of orientation on mechanical performance.

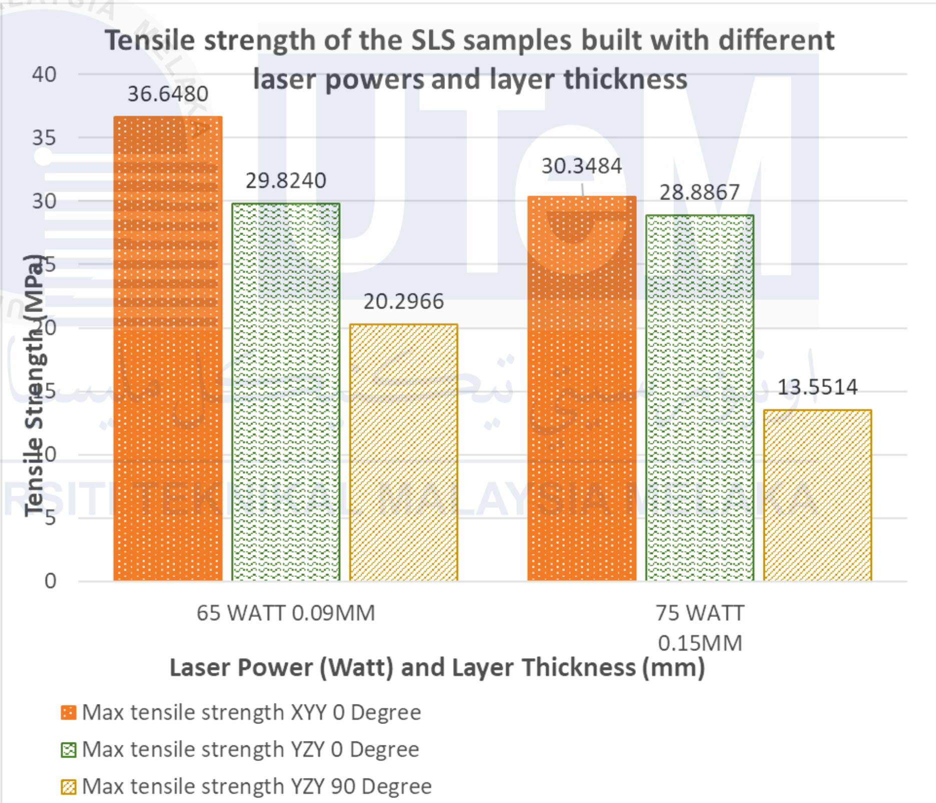


Figure 27: Effect of Build Orientation to Tensile Strength of PA12

When the samples are produced with 65 W laser power and 0.09 mm layer thickness, the tensile strength data as in Figure 31 indicates that parts built in the XYY 0° orientation achieve the highest strength (36.6480 MPa). This is followed by YZY 0° (29.8240 MPa) and YZY 90° (20.2966 MPa), demonstrating a reduction in tensile strength when the orientation changes from horizontal (XYY) to vertical (YZY). Under 75 W laser power and 0.15 mm layer thickness, data observed also showing the same trend where the tensile strength for XYY 0° was 30.3484 MPa and YZY 0° (28.8867 MPa), while a more significant drop is observed in YZY 90° (13.5514 MPa). The reduction in tensile strength for YZY 90° can be attributed to the weaker inter-layer bonding in vertically oriented layers, which is more exposed to failure under tensile loads.

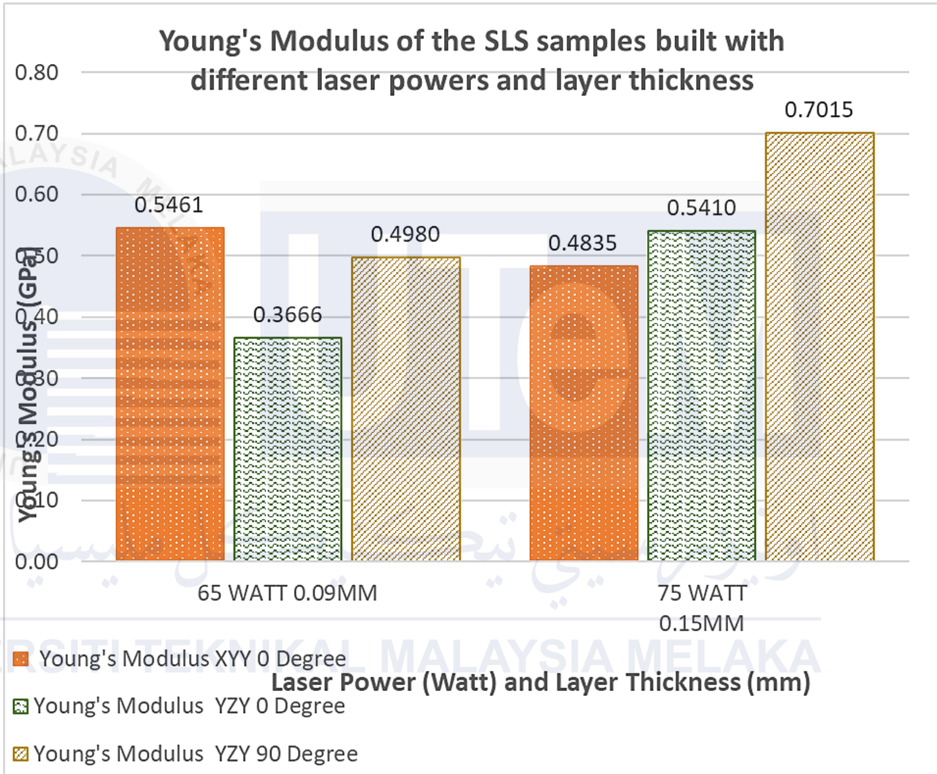


Figure 28: Effect of Build Orientation to Young's Modulus of PA12

Young's modulus, which quantifies the stiffness of a material, shows a clear dependence on the orientation and processing parameters as in Figure 32**.** When produced at 65-watt and 0.09 mm, The XYY 0° orientation achieves the highest Young's modulus at 0.5461 GPa, followed by YZY 90° **(**0.4980 GPa) and YZY 0° **(**0.3666 GPa) the lowest young's modulus. When the laser power and layer thickness are increased to 75 W and 0.15 mm, there is a notable increase in stiffness across all orientations. In this case, YZY 90° exhibits the highest Young's modulus (0.7015 GPa), outperforming YZY 0° (0.5410 GPa) and the lowest XYY 0° (0.4835 GPa).

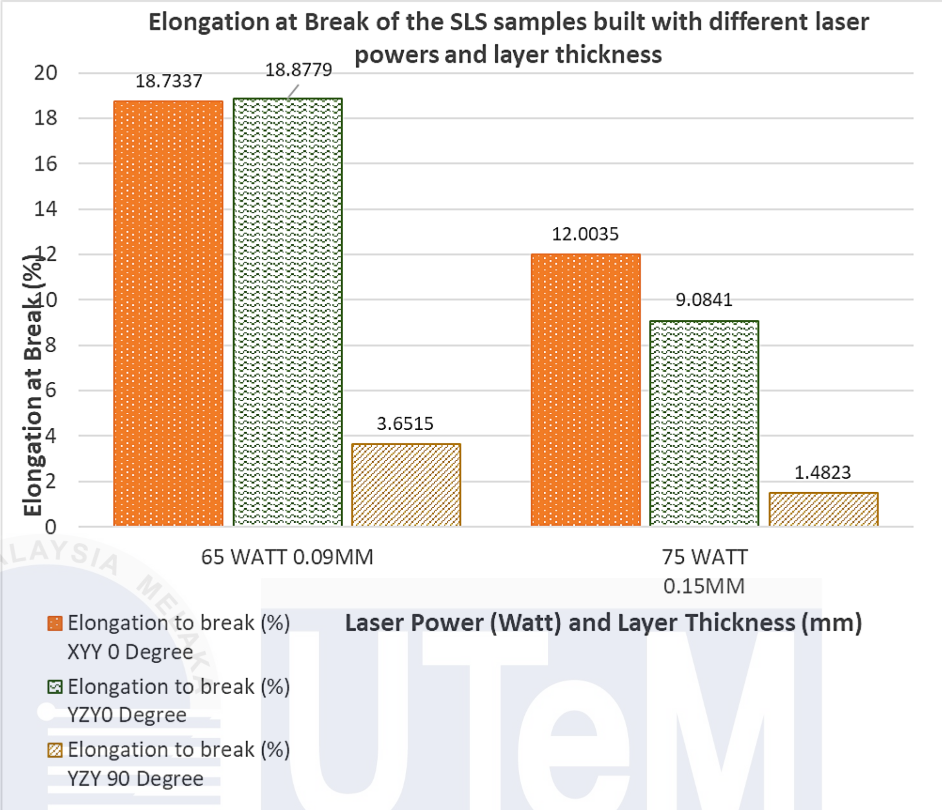


Figure 29: Effect of Build Orientation to Elongation at Break of PA12

Ductility, measured by elongation at break, also increases progressively with sets of parameters as shown in Figure 33. For 65 W and 0.09 mm layer thickness, both XYY 0° and YZY 0° orientation were found to have high elongation values of 18.7337% and 18.8779% respectively thus has good ductility. Nevertheless, the YZY 90° orientation has the lowest elongation at break of 3.6515% that is associated with the brittle behavior of vertically oriented samples. As the laser power and layer thickness increases to 75 W and 0.15 mm, the elongation at break is reduced for all specimen orientation; XYY 0° is 12.0035%, YZY 0° is 9.0841% and YZY 90° is 1.4823%. The analysis also revealed a consistent pattern similar to figure 27.

The observed differences in tensile properties can be linked to the anisotropic nature of SLS-built parts, where mechanical properties are direction-dependent due to the layer-wise construction method. The XYY 0° orientation, being parallel to the build platform, benefits from better in-plane bonding and minimal inter-layer weak points, resulting in better tensile strength and ductility, as explored by (Hofland et al., 2017). Molecules tend to align parallel to the stress axis during sintering at XYY and YZY 0° orientations, maximizing layer direction. On the other hand, the YZY 90° orientation, which is perpendicular to the build platform, exhibits the lowest mechanical performance due to the higher prevalence of inter-layer weaknesses. As supported by research from (Goodridge et al., 2012), it highlights those parts built in the x-axis orientation had the highest tensile while parts built in the y-axis had the highest flexural results.

4.6 Summary

The results of this study revealed that seawater immersion has relatively minor impacts on the weight stability of PA 12 samples. Sintered parts made with thinner layers and higher laser power exhibit more water absorption, which lowers the weight stability but opposite with the mechanical properties. The mechanical characteristics of PA 12 submerged in saltwater showed that severely aged powder samples had a greater tensile strength than new powder, but that the two types of powders' Young's modulus and elongation at break were identical. Furthermore, the tensile characteristics were affected by the various sintering orientations; XYY 0° and YZY 90° demonstrated greater stiffness and strength than YZY 0°. However, the inability to do the fracture behavior investigation using Scanning Electron Microscopy (SEM) due to equipment failure restricts the ability to learn more about the microstructural impacts of seawater.

CHAPTER 5

CONCLUSION

5.1 Introduction

This research delivers a comprehensive analysis of how prolonged seawater immersion affects the mechanical characteristics, dimensional stability, and water absorption of PA12 samples made utilizing various laser powers, layer thicknesses, and sintering orientations using the Selective Laser Sintering (SLS) technique. The study showed that the weight stability of PA12 is slightly affected by saltwater immersion, especially in samples made with thinner layers and greater laser power, which showed higher rates of water absorption. When oriented at YZY 0°, the sample produced with 70W laser power and 0.12mm layer thickness has the greatest specifications in terms of water resistance, as it exhibited the lowest weight change. This finding highlights the necessity of optimizing process parameters for applications involving extended exposure to aquatic environments by showing an obvious correlation between them and the water stability of sintered PA12 components.

Besides, the findings of the tensile test showed that the greatest mechanical properties were achieved by setting the laser power to 75-watt and layer thickness of 0.09 mm which exhibited 40.4488 Mpa of tensile strength, 18.9776% elongation at break and 0.5339 GPa of Young's modulus. These results indicate it has excellent load-bearing capacity, significant resistance to deformation, and good ductility, making it both strong and capable of absorbing energy before fracture.

Besides, aged PA12 powder had a greater tensile strength when compared to virgin powder, indicating that components with similar or even better mechanical qualities may be produced by reusing powder under carefully monitored SLS parameters. However, it is interesting to observe that both virgin and aged powder had comparable Young's modulus and elongation at break values, suggesting that aging powder has less of an impact on stiffness and ductility. Additionally, the impact of sintering orientation was prominent, as XYY 0° displays the best orientation for tensile strength and elongation at break while YZY 90° orientations produced greatest stiffness in Young’s modulus. This emphasizes how essential orientation is to obtain the best possible mechanical performance.

Unfortunately, equipment failure obstructed a planned Scanning Electron Microscopy (SEM) investigation of fracture behavior, which limited the study's capacity regarding the third objective to provide microstructural insights of the tensile tested PA 12 samples after been immersed in seawater for 1000 hours.

This research is going to provide specific insights particularly relevant to the development of the HydroQS water quality monitoring device housing, as it directly addresses the need for a robust and dependable material capable of withstanding the harsh conditions of seawater exposure. The findings suggested that with the proper process parameters, PA 12 produced by SLS technique may be an appropriate choice for such purposes, delivering both mechanical robustness and water resistance. By considering the factor of water absorbtion rate and mechanical properties of PA 12 after 1000 hours seawater immersion, utilizing the aged PA 12 powder with 75-watt of laser power and 0.09 mm layer thickness would be the perfect material selection and parameter setting during the sintering process at YZY 0° to ensure the HydroQS housing's long-term durability and performance in a harsh water condition.

5.2 Recommendation

In order to acquire a better understanding of how seawater immersion impacts the structural integrity of PA 12 samples, it is recommended to implement the SEM procedure. This could provide useful microstructural information, enabling a more thorough assessment of mechanisms of failure and fracture propagation in PA 12 under extreme condition.

Moeover, since water absorption was found to be higher in samples with thinner layers and higher laser power, future studies could explore the use of surface treatments or coatings to enhance water resistance. This could help improve the dimensional stability and overall durability of PA12 parts in underwater applications, making them more suitable for long-term deployment in harsh environments.

REFERENCE

[1] A. Awad, F. Fina, A. Goyanes, S. Gaisford, and A. W. Basit, “3D printing: Principles and pharmaceutical applications of selective laser sintering,” International Journal of Pharmaceutics, vol. 586, Aug. 2020, doi: 10.1016/j.ijpharm.2020.119594.

[2] A. el Magri, S. E. Bencaid, H. R. Vanaei, and S. Vaudreuil, “Effects of Laser Power and Hatch Orientation on Final Properties of PA12 Parts Produced by Selective Laser Sintering,” Polymers, vol. 14, no. 17, Sep. 2022, doi: 10.3390/polym14173674.

[3] H. J. O’Connor, A. N. Dickson, and D. P. Dowling, “Evaluation of the mechanical performance of polymer parts fabricated using a production scale multi jet fusion printing process,” Additive Manufacturing, vol. 22, pp. 381–387, Aug. 2018, doi: 10.1016/j.addma.2018.05.035.

[4] M. K. Razaviye, R. A. Tafti, and M. Khajehmohammadi, “An investigation on mechanical properties of PA12 parts produced by a SLS 3D printer: An experimental approach,” CIRP Journal of Manufacturing Science and Technology, vol. 38, pp. 760–768, Aug. 2022, doi: 10.1016/j.cirpj.2022.06.016.

[5] F. Yang, N. Zobeiry, R. Mamidala, and X. Chen, “A review of aging, degradation, and reusability of PA12 powders in selective laser sintering additive manufacturing,” Materials Today Communications, vol. 34. Elsevier Ltd, Mar. 01, 2023. doi: 10.1016/j.mtcomm.2022.105279.

[6] P. du Maire, M. Deckert, M. Johlitz, and A. Öchsner, “Characterisation of the mechanical properties of polyamide 12 powder when using titanium dioxide as antimicrobial additive,” Materialwissenschaft und Werkstofftechnik, vol. 54, no. 4, pp. 385–390, Apr. 2023, doi: 10.1002/mawe.202200329.

[7] M. Petousis, N. Vidakis, N. Mountakis, V. Papadakis, and L. Tzounis, “Three-Dimensional Printed Polyamide 12 (PA12) and Polylactic Acid (PLA) Alumina (Al2O3) Nanocomposites with Significantly Enhanced Tensile, Flexural, and Impact Properties,” Nanomaterials, vol. 12, no. 23, Dec. 2022, doi: 10.3390/nano12234292.

[8] I. Malashin, D. Martysyuk, V. Tynchenko, V. Nelyub, A. Borodulin, and A. Galinovsky, “Mechanical Testing of Selective-Laser-Sintered Polyamide PA2200 Details: Analysis of Tensile Properties via Finite Element Method and Machine Learning Approaches,” Polymers, vol. 16, no. 6, Mar. 2024, doi: 10.3390/polym16060737.

[9] F. Lupone, E. Padovano, F. Casamento, and C. Badini, “Process phenomena and material properties in selective laser sintering of polymers: A review,” Materials, vol. 15, no. 1. MDPI, Jan. 01, 2022. doi: 10.3390/ma15010183.

[10] N. Vidakis et al., “Sustainable additive manufacturing: Mechanical response of polyamide 12 over multiple recycling processes,” Materials, vol. 14, no. 2, pp. 1–15, Jan. 2021, doi: 10.3390/ma14020466.

[11] M. Picard, A. K. Mohanty, and M. Misra, “Recent advances in additive manufacturing of engineering thermoplastics: Challenges and opportunities,” RSC Advances, vol. 10, no. 59. Royal Society of Chemistry, pp. 36058–36089, Oct. 01, 2020. doi: 10.1039/d0ra04857g.

[12] S. Lv, Y. Li, S. Zhao, and Z. Shao, “Biodegradation of Typical Plastics: From Microbial Diversity to Metabolic Mechanisms,” International Journal of Molecular Sciences, vol. 25, no. 1. Multidisciplinary Digital Publishing Institute (MDPI), Jan. 01, 2024. doi: 10.3390/ijms25010593.

[13] R. Puglisi et al., “Photo- and Water-Degradation Phenomena of ZnO Bio-Blend Based on Poly (lactic acid) and Polyamide 11,” Polymers, vol. 15, no. 6, Mar. 2023, doi: 10.3390/polym15061434.

[14] X. Zhang and Z. Deng, “Effects of Seawater Environment on the Degradation of GFRP Composites by Molecular Dynamics Method,” Polymers, vol. 14, no. 14, Jul. 2022, doi: 10.3390/polym14142804.

[15] M. M. Brette, A. H. Holm, A. D. Drozdov, and J. de C. Christiansen, “Pure Hydrolysis of Polyamides: A Comparative Study,” Chemistry (Switzerland), vol. 6, no. 1. Multidisciplinary Digital Publishing Institute (MDPI), pp. 13–50, Feb. 01, 2024. doi: 10.3390/chemistry6010002.

[16] C. Amstutz, B. Weisse, S. Valet, A. Haeberlin, J. Burger, and A. Zurbuchen, “Temperature-dependent tensile properties of polyamide 12 for the use in percutaneous transluminal coronary angioplasty balloon catheters,” BioMedical Engineering Online, vol. 20, no. 1, Dec. 2021, doi: 10.1186/s12938-021-00947-8.

[17] K. Wudy, D. Drummer, F. Kühnlein, and M. Drexler, “Influence of degradation behavior of polyamide 12 powders in laser sintering process on produced parts,” in AIP Conference Proceedings, American Institute of Physics Inc., 2014, pp. 691–695. doi: 10.1063/1.4873873.

[18] L. Zheng, M. Wang, Y. Li, Y. Xiong, and C. Wu, "Recycling and Degradation of Polyamides," Molecules, vol. 29, no. 8, p. 1742, Apr. 2024, doi: 10.3390/molecules29081742.

[19] K. Wudy and D. Drummer, "AGING BEHAVIOR OF POLYAMIDE 12: INTERRELATION BETWEEN BULK CHARACTERISTICS AND PART PROPERTIES."

[20] B. Sanders, E. Cant, H. Amel, and M. Jenkins, "The Effect of Physical Aging and Degradation on the Re-Use of Polyamide 12 in Powder Bed Fusion," Polymers, vol. 14, no. 13, Jul. 2022, doi: 10.3390/polym14132682.

[21] D. S. Nakonieczny et al., "Cenospheres-Reinforced PA-12 Composite: Preparation, Physicochemical Properties, and Soaking Tests," Polymers, vol. 14, no. 12, Jun. 2022, doi: 10.3390/polym14122332.

[22] M. Bahrami, J. Abenojar, and M. A. Martínez, "Comparative characterization of hot-pressed polyamide 11 and 12: Mechanical, thermal and durability properties," Polymers, vol. 13, no. 20, Oct. 2021, doi: 10.3390/polym13203553.

[23] J. Bai, J. Song, and J. Wei, "Tribological and mechanical properties of MoS2 enhanced polyamide 12 for selective laser sintering," Journal of Materials Processing Technology, vol. 264, pp. 382–388, Feb. 2019, doi: 10.1016/j.jmatprotec.2018.09.026.

[24] M. Kadkhodaei, M. Pawlikowski, R. Drobnicki, and J. Domański, "Modeling of hyperelasticity in polyamide 12 produced by selective laser sintering," Continuum Mechanics and Thermodynamics, vol. 35, no. 4, pp. 1735–1744, Jul. 2023, doi: 10.1007/s00161-023-01199-8.

[25] R. D. Goodridge, C. J. Tuck, and R. J. M. Hague, "Laser sintering of polyamides and other polymers," Progress in Materials Science, vol. 57, no. 2. pp. 229–267, Feb. 2012. doi: 10.1016/j.pmatsci.2011.04.001.

[26] M. Y. Kondo et al., "Recent advances in the use of Polyamide-based materials for the automotive industry," Polimeros, vol. 32, no. 2, 2022, doi: 10.1590/0104-1428.20220042.

[27] M. Rafi Omar et al., "Effect of Polyamide-12 Material Compositions on Mechanical Properties and Surface Morphology of SLS 3D Printed Part," 2022.

[28] "TITLE: FABRICATION OF HOUSING FOR HYDRO QUALITY SURVEY SYSTEM (HydroQS) OF SUNGAI MELAKA USING RECYCLED AGING POLYAMIDE PA-12 POWDER."

[29] M. I. F. Rosley, N. R. Mat Nuri, M. Z. Mohammad Nasir, M. R. Omar, and M. F. Mamat, "The mechanical properties of aged PA-12 FS3300PA powder: influence of layer thickness, sintering orientations, and laser power," *Engineering Research Express*, vol. 6, no. 4, Dec. 2024, doi: 10.1088/2631-8695/ad923d.

[31] A. Gazzerro, W. Polini, L. Sorrentino, and G. Giuliano, “Aging of PA12 Powder in Powder Bed Fusion,” *Applied Sciences (Switzerland)*, vol. 13, no. 9, May 2023, doi: 10.3390/app13095599.

[32] P. C. Gomes, O. G. Piñeiro, A. C. Alves, and O. S. Carneiro, “On the Reuse of SLS Polyamide 12 Powder,” *Materials*, vol. 15, no. 16, Aug. 2022, doi: 10.3390/ma15165486.

[33] E. C. Hofland, I. Baran, and D. A. Wismeijer, “Correlation of Process Parameters with Mechanical Properties of Laser Sintered PA12 Parts,” *Advances in Materials Science and Engineering*, vol. 2017, 2017, doi: 10.1155/2017/4953173.

APPENDIX

Laser Power		65 watt						70 watt						75 watt						70 watt (virgin)	
No	Dimension	0.09	% diff	0.12	% diff	0.15	% diff	0.09	% diff	0.12	% diff	0.15	% diff	0.09	% diff	0.12	% diff	0.15	% diff	0.12	% diff
1	12.7		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
2	38.1		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
3	63.5		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
4	88.9		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
5	114.3		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
6	139.7		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
7	114.3		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
8	88.9		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
9	63.5		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
10	38.1		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
11	12.7		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00		-100.00
12	12.7		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
13	38.1		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
14	63.5		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
15	88.9		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
16	63.5		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
17	38.1		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
18	12.7		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
		Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22	Average	-22.22
			100.33		100.33		100.33		100.33		100.33		100.33		100.33		100.33		100.33		100.33

Appendix A: Specimen Calibration Data

Appendix B: Gantt Chart

No.	Task	Implementation	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
1	PSM 2 online briefing	Plan													
		Actual													
2	Meeting with supervisor	Plan													
		Actual													
3	Tensile test 65watt virgin	Plan													
		Actual													
4	Tensile test 75watt aging	Plan													
		Actual													
5	Tensile test 70watt aging	Plan													
		Actual													
6	Tensile test 65watt aging	Plan													
		Actual													
7	Brief PSM 2 (Dr Azazi)	Plan													
		Actual													
8	Dimensional stability analysis	Plan													
		Actual													
9	Brief PSM 2 (Dr syed)	Plan													
		Actual													
10	Brief PSM 2 (Dr mahanum)	Plan													
		Actual													
11	Tensile data analysis	Plan													
		Actual													
12	Report Preparation	Plan													
		Actual													

Plan (P)	
Actual (A)	

Appendix C: Tensile Testing Result for Virgin Sample

	Ref. point	DTM 638-3 Tensile Test		
Sample position condition	Sample No.	Max tensile strength YZY0 Degree	Elongation to break (%) YZY0 Degree	Young's Modulus (Mpa) YZY0 Degree
YZ/Y 0 DEGREE (Bench mark)	1	10.27941	14.9331	0.347274
	2	22.52239	16.2309	0.611518
	3	18.29096	16.0921	0.503182
	4	18.22444	18.8819	0.360058
	5	15.03698	16.2286	0.310764
	Average	16.87	16.47	0.43

Appendix D: Tensile Testing Result for Aged Sample at 75-watt Laser Power

	Ref. point	DTM 638-3 Tensile Test		
Sample position condition	Sample No	Max tensile strength YZY0 Degree	Elongation to break (%) YZY0 Degree	Young's Modulus (Mpa) YZY0 Degree
75 WATT 0.15MM	1	26.95866	5.8406	0.558497
	2	29.05145	10.4447	0.52273
	3	29.88146	8.3001	0.555009
	4	29.33395	11.5365	0.53543
	5	29.20814	9.2985	0.533338
	Average	28.8867	9.0841	0.5410
75 WATT 0.12MM	1	33.08347	15.2629	0.515991
	2	34.37988	14.4019	0.598252
	3	34.7359	14.7112	0.58536
	4	34.57983	14.0201	0.585774
	5	33.12435	14.6588	0.54169
	Average	33.9807	14.6110	0.5654
75 WATT 0.09MM	1	39.80836	19.2897	0.513065
	2	40.83044	19.0387	0.535605
	3	40.60961	19.2099	0.516593
	4	40.52063	18.7679	0.523569
	5	40.47496	18.5816	0.530494
	Average	40.4488	18.9776	0.5239

Appendix E: Tensile Testing Result for Aged Sample at 70-watt Laser Power

	Ref. point	DTM 638-3 Tensile Test		
Sample position condition	wg dimensio	Max tensile strength YZY0 Degree	Elongation to break (%) YZY0 Degree	Young's Modulus (Mpa) YZY0 Degree
70 WATT 0.15MM	1	23.2713	5.2744	0.391724
	2	27.88144	8.0348	0.464703
	3	28.14468	8.0118	0.473795
	4	27.19873	6.6577	0.464857
	5	26.90268	6.9433	0.467091
	Average	26.6798	6.9844	0.4524
70 WATT 0.12MM	1	32.32687	10.8406	0.546491
	2	34.71133	12.3885	0.601528
	3	34.61493	13.0827	0.565579
	4	34.13211	13.0158	0.58483
	5	34.82098	13.4074	0.614903
	Average	34.1212	12.5470	0.5827
70 WATT 0.09MM	1	36.41578	18.5852	0.679878
	2	37.58234	18.1023	0.661059
	3	37.29618	17.9809	0.640581
	4	37.00626	18.7387	0.659728
	5	37.24748	16.8184	0.684411
	Average	37.1096	18.0451	0.6651

Appendix F: Tensile Testing Result for Aged Sample at 65-watt Laser Power

	Ref. point	DTM 638-3 Tensile Test		
Sample position condition	wg dimensio	Max tensile strength YZY0 Degree	Elongation to break (%) YZY0 Degree	Young's Modulus (Mpa) YZY0 Degree
65 WATT 0.15MM	1	12.96445	3.8187	0.477078
	2	19.96572	6.7911	0.267492
	3	17.49362	4.274	0.255838
	4	20.99029	5.4488	0.302946
	5	20.31664	7.96	0.204006
	Average	18.3461	5.6585	0.3015
65 WATT 0.12MM	1	24.16034	12.1699	0.252033
	2	29.15554	14.6812	0.402358
	3	23.80451	12.7151	0.254705
	4	23.01934	12.0953	0.25075
	5	23.78637	13.069	0.236984
	Average	24.7852	12.9461	0.2794
65 WATT 0.09MM	1	27.66916	17.4874	0.29724
	2	34.57561	18.5136	0.528119
	3	28.27561	17.2593	0.313103
	4	29.39094	18.3875	0.364345
	5	29.20844	16.7418	0.330054
	Average	29.8240	17.6779	0.3666