

COMPREHENSIVE STUDY ON SELECTIVE LASER SINTERING 3D PRINTER POLYAMIDE 12 RECYCLE PARAMETER AND DIMENSION MEASUREMENT ACCURACY EFFECT ON MAINTENANCE APPLICATION

UNIVEANAS NAUFAL BIN ABD LATIFF. AKA

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE) WITH HONOURS

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Faculty of Mechanical and Manufacturing Engineering Technology



Anas Naufal Bin Abd Latiff

Bachelor of Mechanical Engineering Technology (Maintenance) with Honours

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ANAS NAUFAL BIN ABD LATIFF



Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "Comprehensive study on Selective Laser Sintering 3D printer POLYAMIDE 12 RECYCLE Parameter and Dimension Measurement Accuracy Effect on Maintenance Application" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name	Anas Naufal Bin Abd Latiff
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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 Mechanical Engineering Technology (Maintenance) with Honours.

Signature	fere.
Supervisor	Name Mohammad Rafi Bin Omar
Date	: 11/1/2023
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DEDICATION

This thesis is dedicated to my dearest father and late mother, supervisor, family's members, and friends who supported me throughout my study.



ABSTRACT

The fact that numerous 3D printed products have been developed, there are still issues with the printed product's physical properties and the accuracy of 3D printing produced product. This study examines comprehensive study on SLS 3D printer polyamide 12 recycle parameter and dimension measurement accuracy effect on maintenance application. A variable parameters of laser beam power and layer thickness recycled material were used for the Polyamide 12. The test specimens were prepared at different process parameters using the SLS 3D printer. The hardness, surface roughness, and surface morphology were tested. These samples were tested in accordance with ASTM D638-(IV) for tensile strength and roughness using a 10 mm x 10 mm coated sample prepared for scanning in an electron microscope. The SLS Farsoon 402P machine calibration block was used to measure and analyze how accurate the machine's X and Y axes were in terms of their measurements. This project will compare and validate 3D scanner data accuracy. By doing this, the researcher will get an exposure to reverse engineering software and fabricate experiment specimens using 3D printer machines. After run the experiment, the result to be expected are hardness test, roughness test, surface morphology, and dimension accuracy for each different parameter settings of SLS 3D printer machine on the specimens.

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ABSTRAK

Hakikat bahawa banyak produk bercetak 3d telah dibangunkan, masih terdapat masalah dengan sifat fizikal produk bercetak dan ketepatan produk percetakan 3D yang dihasilkan. Kajian ini mengkaji kajian komprehensif mengenai SLS 3D printer polimida 12 recycle parameter dan pengukuran dimensi kesan ketepatan pada aplikasi penyelenggaraan. Serbuk dikitar semula digunakan untuk komposisi Polimida 12. Spesimen ujian disediakan pada parameter proses yang berbeza menggunakan pencetak SLS 3D. Kekerasan, kekasaran permukaan, dan morfologi permukaan diuji. Sampel ini diuji mengikut ASTM D638 - (IV) untuk kekerasan dan kekasaran menggunakan sampel bersalut 10 mm x 10 mm yang disediakan untuk diimbas dalam mikroskop elektron. Blok kalibrasi mesin SLS Farsoon 402P digunakan untuk mengukur dan menganalisi ketepatan paksi X dan Y mesin dari aspek ketepatan dimensi. Projek ini memberi tumpuan kepada analisis SLS 3D parameter bahan pencetak bahan kitar semula. Projek ini akan membandingkan dan mengesahkan ketepatan data pengimbas 3D. Dengan melakukan ini, penyelidik akan mendapat pendedahan untuk membalikkan perisian kejuruteraan dan membuat blok eksperimen menggunakan mesin pencetak 3D. Setelah menjalankan eksperimen, hasil yang diharapkan adalah ujian kekerasan, ujian kekasaran, morfologi permukaan, dan ketepatan dimensi untuk setiap parameter mesin pencetak SLS 3D yang berbeza.

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LIST OF SYMBOLS AND ABBREVIATIONS

PR	-	Parameter
SLS	-	Selective laser sintering
PA-12	-	Polyamide-12
СР	-	Composition
SP	-	Sample
SEM	-	Scanning electron microscopy





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CHAPTER 1

INTRODUCTION

1.1 Introduction

A lot of industries nowadays acknowledged the 3D printing technologies as the top or the sixth manufacturing ranking. Established in the 1980s, 3D printing uses various materials like metals and plastics to make three-dimensional goods layer by layer based on a digital model, rather than using physical labor or mechanization. There has been a massive expansion in this field, with hundreds of thousands and numerous manufacturing equipments of 3D printed objects. The word 3d printing representing processes in technologies that offer a full capability for production parts and product in varying materials. Basically, the what all technologies of manufacturing have in common are the substrate of molding between layers in an additive process is quite different with the traditional methods of manufacturing regarding the subtractive ways or casting processes (Team, 2021).

Many of 3D printing technologies have been developed with each respective functional. According to ASTM standard F2792 for ASTM catalogue, it divided into seven groups. My type of 3D printing to be used is Selective Laser Sintering (SLS). This method uses laser to melt or sinter the powder to fuse the powder together. The powder bed fusion is the example of Selective Laser Sintering. Selective Laser Sintering is being used to make plastic, metal, and ceramic object. To build 3D product, a high laser beam power is being used to sinter the selected material such as polymer. Another thing is, electron beam melting augment an energy source to lit up the material. (Shahrubudin et al., 2019)

The Farsoon 402P series of Selective Laser Sintering not only for plain manufacturing geometry, but it also bring the state of art itself. It is a rapid prototyping and for additive manufacturing wielders. High in performance, multi-zone, imaging components, thermal stability advancements, removeable powder cylinders, bi-directional single powder feed system make the Farsoon an extrremely productive and efficient resolve for the high application demands. Farsoon technologies determined to a greater innovation by delivering a complete freedom to function with any open platform application. With perfect accessibility in machine parameters and settings, users can opt to any desired materials to meet the production or prototyping requirement. Polymers of 3D printing technologies are vastly used due to its

liquid form and melting point are low in cost, high mobility product processing, and low in weight.(Farsoon Technologies, 2017)

This study aims to optimize the highest accuracy parameter of PA-12 for specimen production using SLS 3D printer and to obtain high precision and accuracy of the produced specimen. In addition to it, to acquire the guideline for a superior parameter.

1.2 Problem Statement

By thoughtfully introducing material where it is needed, Additive Manufacturing (AM) processes enable the efficiency of bottom-up development of 3D objects. These approaches have improved in taste and texture, cost, complexity, resolution, and quality. Because Selective Laser Sintering produces parts with no supports, the design possibilities are practically limitless. Unlike traditional melt extrusion with strong shear mixing and shear fluidity, it does not compact during processing, making it a crucial 3D printing approach for the production of porous segregated structures. The disadvantage of the SLS 3D printer is that it takes a long time to print and the necessary dimensions may not be obtained because to shrinkage.

SLS parts have a grainy surface finish and a significant degree of interior porosity, so post processing may be required to obtain a smooth surface finish or watertightness. When compared to virgin polyamide-12, recycled polyamide-12 has a lesser strength.

More research is needed to understand the capacity of selective laser sintering 3D printers in order to produce geometry component accuracy. The content of a selective laser sintering 3D printer composition and parameter often necessitates a thorough examination because it affects the quality of the printed result.

Therefore, this study aims to optimize the highest accuracy parameter of PA-12 for specimen production using SLS 3D printer and to obtain high precision and accuracy of the produced specimen. In addition to it, to acquire the guideline for a superior parameter.

1.3 Research Objective

- a) To optimize the parameter of SLS 3D printing machine recycle materials of Polyamide 12.
- b) To obtain high precision and accuracy of the produced specimen.
- c) To acquire the guideline for a superior parameter of polyamide 12

1.4 Scope of Research

This study is limited to the following scope:

- a) Optimization of 3D printer parameter using Taguchi Method.
- b) Testing samples of polyamide 12 by using few of testing machines which are for hardness test, roughness test, and surface morphology.
- c) Validate the precision of 3D printed specimens by using calibration block and standard vernier caliper.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

By continuously adding materials to a geometrical representation, digital fabrication technology, also known as 3D printing or additive manufacturing, builds physical items from a geometrical representation. 3D printing is a new technology that is rapidly gaining traction. 3D printing is now widely used all around the world. In the fields of agricultural, healthcare, automotive, locomotive, and aviation, 3D printing technology is increasingly being used for mass customization and fabrication of any form of open source design. 3D printing uses layer-by-layer deposition of material to create an object directly from a computer-aided design (CAD) model. In figure 2.1 showed an overall elementary structure of 3D printing technology





Figure 2.1 Elementary structure of 3D printing technology MEL AKA

2.2 Types of 3D Printing

Different kinds of 3D printing technologies have been made, and they work in different ways. Figure 2.2 depicts a typical system structure for FDM 3D printing. In accordance with ASTM Standard F2792, ASTM categorised 3D printing technologies into seven distinct categories, including binding jetting, directed energy deposition, material powder bed fusion. extrusion. material jetting, sheet lamination, and vat photopolymerization. There are no disagreements regarding whether machine or technology is more effective because each 3D printer has its own specialised applications. The use of 3D printing technology is no longer limited to prototyping and is increasingly being applied to the production of a wide variety of items..(Shahrubudin et al., 2019)



Figure 2.2 Typical 3D printing system (FDM)

2.2.1 Binder Jetting

Binder jetting is a quick prototyping and 3D printing technique using the deposition of a liquid binder to combine powder particles. In order to form the layer, binder jetting technology shoots a chemical binder over the unfolded powder. From sand, binder jetting would be utilised to generate casting designs, raw sintered products, and comparable highvolume items. Binder jetting can print metals, sands, polymers, hybrids, and ceramics, among other substances. Binder jetting is capable of printing metals, sands, polymers, hybrids, and ceramics. Certain materials, such as sand, require no further processing. In addition, the binder jetting procedure is simple, economical, and quick since powder particles are linked together.

2.2.2 Directed Energy Deposition

Binder jetting is a quick prototyping and 3D printing technique using the deposition of a liquid binder to combine powder particles. In order to form the layer, binder jetting technology shoots a chemical binder over the unfolded powder. From sand, binder jetting would be utilised to generate casting designs, raw sintered products, and comparable highvolume items. Binder jetting can print metals, sands, polymers, hybrids, and ceramics, among other substances. Binder jetting is capable of printing metals, sands, polymers, hybrids, and ceramics. Certain materials, including such sand, require no further processing. In addition, the binder jetting procedure is simple, economical, and quick since powder particles are linked together.

2.2.3 Material Entrusion

3D printing technology based on material extrusion can be used to print multi-color and multi-material prints of plastics, living cells, or foods. This procedure is widely used among consumers, and the costs are quite low. Similarly, this process can generate fully functional product parts. The first example of a material extrusion system is fused deposition modelling (FDM). FDM was developed in the early 1990s, and the main material used is polymer. FDM works by extruding thermoplastic filaments such as ABS and PLA through a heated nozzle, allowing the material to melt and be applied layer by layer on a build platform.

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2.2.4 Powder Bed Fusion

Powder bed fusion is accomplished through selective laser sintering (SLS). To fuse or melt the material powder together, either a laser or an electron beam is used. Metals, polymers, ceramics, composites, and hybrids are some of the materials used in this process. The most basic example of powder-based 3D printing technology is selective laser sintering (SLS). SLS is a 3D printing technology that works quickly and accurately, and differs surface finish. Selective laser sintering can used to produce metal, plastic, and ceramic objects. SLS used a high-power laser to sinter polymer powders to fabricate a 3D product. In the meantime, SHS technology is another part of 3D Printing technology uses a head thermal print in the process to melt the thermoplastic powder to make 3D printed product. Lastly, electron beam melting augments an energy source to warm up the material.

2.2.4.1 Selective Laser Melting

The SLM method starts with a building platform covered in very thin layers of metallic powders that are later entirely melted by thermal energy generated by one or more laser beams. The cross-section area of the specified 3D part is created by melting and resolidifying metallic powders in each layer. A re-coater deposits and stages a new layer of powders after the building platform is lowered a short distance. Laser beams can be directed and focused using computer-generated patterns and carefully engineered scanner optics. As a result, the powder particles in the powder bed can be selectively melted, going to form 3D objects in the shape of the CAD design. (Munir et al., 2020)

2.2.4.2 Selective Laser Sintering

SLS (selective laser sintering) is a powder-based additive manufacturing method that uses laser light to melt and fuse powders before stacking them layer by layer to build a printed item based on 3D model data. Because powder quality has a significant influence on the effectiveness of SLS sintered products, powder design and preparedness are critical SLS technologies. (Xinpeng Gan, Guoxia Fei, Jinzhi Wang, Zhanhua Wang, Marino Lavorgna, Hesheng Xiaab, 2020)

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2.2.5 Material Jetting

Material jetting, according to ASTM standards, is a 3D printing operation in which build material is selectively hoarded drop by drop. A printhead dispenses droplets of a photosensitive material, which solidifies and builds a part layer by layer under ultraviolet (UV) light. Material jetting creates components with a swish surface finish and high dimensional accuracy at about the same time. Material jetting offers multi-material printing as well as a wide range of materials such as polymers, ceramics, composites, biologicals, and hybrids.

2.3 Comparison of 3D Printing Technologies

Table 1 below showed few types of 3D printer technology. Each 3D printer has its own uses or capability which used depend on user application target whereas. So, ones have to choose wisely which type will fulfil their project requirement to the best considering pros and cons of 3D printing machine. Table 2.1 below showed few types of 3D printer machine with its advantage, disadvantage, application, and common materials used.

Types of 3D printer	Advantage	Disadvantage	Application	Materials	Ref.
FDM	Fast. Low-cost consumer machines and materials	Low accuracy. Low details. Limited design compatibility	Low-cost rapid prototyping. Basic proof- of-concept models	Standard thermoplastics, such as ABS, PLA, and their various blends	
UNIVERSI	Great value. High accuracy. Smooth surface finish. Range of functional applications	Sensitive to long exposure to UV light KAL MAL	Functional prototyping Patterns, molds, and tooling Dental applications Jewelry prototyping and casting Modelmaking	Varieties of resin (thermosetting plastics). Standard, engineering (ABS-like, PP- like, flexible, heat-resistant), castable, dental, and medical (biocompatible).	(3D Printing Technology Comparison: FDM vs. SLA vs. SLS, 2022)
SLS	Strong functional parts. Design freedom. No need for support structures	Rough surface finish. Limited material options	Functional prototyping Short-run, bridge, or custom manufacturing	Engineering thermoplastics. Nylon 11, Nylon 12, and their composites.	

Table 2.1 The types of 3D printers

2.4 Testing

The two main tests conducted for this study were the surface roughness and surface morphology.

Following with the next testing which is surface roughness. The values can be obtained from the Mitutoyo SJ-410 device on the LCD display. The measurement of the points will be repeated for few times to develop precise data.

2.4.1 Hardness Test

The Rockwell Hardness test determines the hardness of a material by measuring the net increase in imprint depth as a force is applied. The R, L, M, E, and K scales are often used to represent hardness numbers, which have no units. Harder materials are indicated by higher numbers.

A standard specimen is placed on the Rockwell Hardness tester's surface. The gauge is reset to zero after a modest load is applied. A lever is tripped to apply the main load. The significant load is lifted after 15 seconds. After allowing 15 seconds for the specimen to recover, the hardness is read off the dial while the slight load is still applied.

2.4.2 Surface Morphology

The scanning electron microscope (SEM) is a tool for creating images of the otherwise invisible worlds of microspace 1um and nanospace 1nm. SEMs have the ability to magnify an object up to 300,000 times. An SEM image typically includes a scale bar. The scale bar is used to calculate the sizes of image features. SEM images have no colour (but may be artificially coloured), may appear three-dimensional (due to depth of field), and show only the sample's surface (due to minimal penetration of the electron beam into the sample).

To examine the morphology of the PA-12 material from different composition, a scanning electron microscopy (SEM) ZEISS EVO 18 to be equipped. The settings that need to be set such as magnification, electron high tension (EHT), and the material microstructure that has its own range to be set.(Rafi Omar et al., 2022)

2.4.3 Surface Roughness Test

The Mitutoyo Surftest SJ-410 surface roughness measuring instrument measures both skidded and skidless. The SJ-410 surface roughness measuring instrument includes 46 roughness parameters that meet the most recent ISO, DIN, ANSI, and JIS standards.

2.5 Materials

To generate uniformly high-quality products, 3D printing, like any other production process, needs high materials that match consistent criteria. To confirm this, suppliers, purchasers, and end-users of the material develop material control methods, requirements, and agreements. 3D printing technology is capable of producing fully functioning components in a variety of materials, comprising ceramic, metallic, and polymeric materials, as well as their mixtures in the form of hybrid, composite, or functionally evaluated materials.

2.5.1 Metals

The aerospace, medical, automotive, and manufacturing industries have shown a great deal of interest in metal 3D printing technology as a result of the advantages it offers. Metals have outstanding physical qualities and can be employed in a wide range of applications, from organ printing to aerospace components. These materials include cobalt-based alloys, aluminum-based alloys, nickel-based alloys, titanium alloys, and stainless steel, among others. In 3D-printed dental applications, a cobalt-based alloy is suitable for use. Using nickel-based alloys, 3D printing technology may also supply aeronautical components. Objects 3D-printed from nickel-based alloys may be utilised in hazardous situations.

2.5.2 Ceramics

Currently, 3D printing technology can produce 3D printed objects from ceramics and concrete without pores or cracks by optimising the settings and establishing the excellent mechanical qualities. Ceramic is durable, solid, and resistant to fire. Ceramics are frequently used in virtually any geometry or shape and are ideally suited for the construction and architecture of the future. Ceramics are advantageous in dentistry and aerospace applications. These materials are represented by alumina, bioactive glasses, and zirconia. 3D Printing technology has the ability to process alumina powder, for instance. Alumina is an excellent ceramic oxide with a wide range of applications. Aluminium oxide has a complicated solidification.

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2.5.3 Polymers

Polymer components with complicated shapes, stretching from prototypes to functioning constructions, are created using 3D printing technology. Using fused deposition modelling (FDM), it is possible to produce a 3D-printed item by depositing successive layers of extrusion thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP), or synthetic resin (PE). As 3D printing materials, thermoplastic filaments with greater melting temperatures, including such PMMA and PEEK, are now available. Liquid or low melting point 3D printing polymer materials are widely employed in the 3D printing industry due to their low cost, light weight, and production side..(Shahrubudin et al., 2019)

2.5.3.1 Mechanical Properties

When compared to traditional manufacturing methods, such as injection moulding, 3D printed polymer parts have different mechanical properties. They frequently exhibit reduced stiffness in comparison to fully dense parts produced by other manufacturing methods due to internal voids and pores. Inadequate layer adhesion, porosity, cracks, and other internal flaws all reduce ductility. Table 2.2 showed the SLS polymers from research (Gan et al., 2020).

Polymer			Thermodynamic temperature			Mec	hanical prop	erties	
		Average powder size (μm)	T _m (°C)	T _c (°C)	T _g (°C)	Tensile strength (MPa)	Strain at break (%)	Modulus (MPa)	Applications
Crystalline	PA12	53.8	181	148		39	76.31	295.43	Engineering parts
	PA11		189.8	166.3		42	18	1400	Engineering parts
	PA6	58.9	204	170		49	46.95	375	Engineering parts
	PEEK		372	334	164	88			Aerospace and automotive parts, medical implants
	PCL	168	77.4		-35	8.13		48.6	Tissue engineering scaffold
	PP	68	116.8	94.8		19.9	122	599	Corrosion resistant applications
	PE	231	106	92.4		5.98	42.9	170.67	Medical parts
Amorphous	PS	87.5			104	4.59	5.79	62.25	Casting mold
	PC	90			150	30			Casting mold
	TPU	185	150	78	101	14	500		Flexible sensors, shoes, acoustic energy absorbers

Table 2.2 Summary for several kinds of SLS polymers

2.5.3.2 Application

This powder bed fusion for SLS polymers commonly applicable in medicinal, electronic, aviation, automotive industry and lightweight structures. Others, SLS polymers used in biodegradable polymers. (Jandyal et al., 2022)

2.5.3.3 Melting Point

The pyramid graph Figure 3 below showed the melting point for thermoplastic polymers. The red is representing the SLS materials (Gan et al., 2020).

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2.6 Designing

The increasing design freedom is more facultative the transition of engineering design and analysis into a data-driven, algorithmically dominated practice. several analysis and products groups are developing tools design tools that modify physics-based generative improvement (thermo, fluid, and mechanical) of parts. Three tools from FormNext.

2.6.1 Autodesk Generative Design

Autodesk Generative design is a tool integrated with Autodesk's Fusion360 CAD system Figure 2.4. It provides the ability to produce and explore various resolves for vary manufacturing methods such injection molding, 2.5 to 5 axis CNC, or additive by defining keep-out zones, loads, and reference geometry. The tool offers us with a wide range of solutions that meet our goals. (Gmeiner, 2020)



Figure 2.4 Product of 3D printing objects by Autodesk

2.6.2 ParaMatters

ParaMatters is the only conceptual software product with a fully automated workflow based on proprietary modelling, high resolution finite element analysis, and computational geometry that does not require manual adjustment or reconstruction.

- <u>Mechanical generative design and topology optimization</u>. It is based on structural loads and geometric constraints.
- <u>Thermal generative design</u>. It is based on input temperature, heat flux, and volumetric heat and optimizes structures for thermal compliance.
- <u>Reverse engineering</u>. Enables the conversion of STLs from scans to be healed and converted to STEP files.

2.6.3 Farsoon Technologies Software Solution

All Farsoon systems come with a comprehensive software suite that allows the customer to get the most out of their additive manufacturing machine. BuildstarTM, a versatile build preparation programme, and MakestarTM, a robust open platform machine control software, are included in Farsoon's software package. The BuildstarTM and MakestarTM software packages include features that let users to manage their digital files from build preparation and parameter setting to machine control and in-build monitoring, all while maintaining a simple and straightforward user interface. Figure 2.5 showed MakeStar software of Farsoon technologies.



Figure 2.5 MakeStar software

2.6.3.1 BuildStar

BuildstarTM is a powerful build preparation software suite that lets you prepare build files for Farsoon additive manufacturing systems. BuildstarTM includes functionalities that make it possible to create build files from numerous digital models. Once imported, BuildstarTM provides a number of tools and modules to help Farsoon machines improve their additive processes.

2.6.3.2 MakeStar ERSITI TEKNIKAL MALAYSIA MELAKA

Farsoon's metal and plastic systems use the MakestarTMsoftware as a robust control and operating system. MakestarTM imports the build file generated by Farsoon's BuildstarTM software or a third-party create setup software and acts as an interface for the user to appoint Farsoon's systems to begin processing the build file. This software package is completely open source and includes a variety of functions and modules to aid in the construction process.

2.7 Effect

The effects of differential or changes of parameters play a good deal of influence on the mechanical properties of the 3D printed object. So, to obtain the desired mechanical properties, the parameters need to put into consideration.

2.7.1 Laser Power

According to the Leatherdale equation for tri-acrylatephotoresists, the laser intensity influences the two-photon absorption and polymerization process by a factor of two. As a result, the laser power influences the pace of initiation reaction in the current model, and the active centre formation rate varies greatly for different laser powers. To analyse the polymerization reaction kinetics, a coefficient termed initiation efficiency (α) was utilised from (Mueller et al., 2014)'s numerical model.

2.7.2 Layer Thickness

Polymer's mechanical properties are significantly impacted by the layer's thickness. With the exception of a layer thickness of 0.5 mm, tensile strength decreases by 46 percent, impact strength by 54.5 percent, and hardness by 40 percent as layer thickness increases. As a result, as the layer thickness rises, the material's mechanical properties deteriorate. In engineering, materials and technology are essential. All testing findings indicate that injection-molded samples have superior mechanical properties compared to 3D-printed samples. However, samples with a smaller layer thickness showed greater results and might be utilised as an alternative to injection moulding.. This according to research (Shubham et al., 2016)

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2.8 Research Gap

Table 2.3 below showed few of the researches those have been read. Each study had its own scope of research and some had its own variables of parameter to study effect upon respective material. All researches had been published within the latest five years.

Supplied and Sup									
Author	Parameter	Material	Virgin Material	Recycle Material	Physical Properties	Roughness	Surface Morphology	Dimension Accuracy	Hardness
(Rafi Omar et al., 2022)	 Laser power Layer Thickness 	Polyamide 12	/	/	/		/		
(Yang et al., 2020)	 Tensile strength Elongation Laser speed 	Polyamide 12	/	1	/		/		/
(Ayrilmis, 2018)	 Layer thickness Different layers Wettability 	Polylactic acid	کل م	<u></u>	تيڪ	ىسېتى	اونېوم		
(Chen et al., 2019)	 Laser power Scan speed Microstructure 	GH4169 Alloy	TEKN /	IKAL	MALAY	YSIA M	ELAKA /		/
	 Density Layer thickness 								

Table 2.3 Research gap previous researcher.

CHAPTER 3



METHODOLOGY

Figure 3.1 Flowchart of methodology

3.1 Literature Review

A literature review describes and analyses published data on the topic. Sometimes the information is limited to a specific time period. A literature review is more like a list of sources; it has an organized structure that includes both summary and synthesis. A summary is a reorganization or reshuffling of the significant information in the source, whereas a synthesis is a reorganization or of that material. It could offer a new perspective on old information or combine new and old perceptions. It could also chart the intellectual evolution of the field, including major controversies. Depending on the situation, the literature review may also analyze the sources and recommend the reader on the most pertinent or useful ones.

3.2 Sample Preparation

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The researcher will cut five of PA-12 specimens each with dimension of 10mm x 10mm with different composition for each specimen. The specimens then will run a few of tests.

3.2.1 Hardness Test

The tests are comprising hardness test Rockwell R Hardness with total force value of 107 N for PA-12 material according to standard ASTM D785 by this machine shown in figure 3.2. A standard specimen is placed on the surface of the Rockwell Hardness tester. A minor load is applied and the gauge is set to zero. The major load is applied by tripping a lever. After 15 seconds the major load is removed. The specimen is allowed to recover for 15 seconds and then the hardness is read off the dial with the minor load still applied. The standard specimen for ASTM D785 is shown in figure 3.3. (Astm & D, n.d.)



Figure 3.2 Mitutoyo Rockwell Hardness Testing Machine



3.2.2 Roughness Test

The roughness test with measured values of Ra, Rq, and Rz attained on the LCD's device using this machine figure 3.4 with 5 mm of probe travelling length, 2 mm of stylus tip radius, and 4 mN for detecting force. Figure 3.5 showed the specimen dimension for testing.



Figure 3.4 The Mitutoyo SJ-410



3.2.3

For the surface morphology test figure 3.6, the specimens will be coated first prior to the scanning process using electron microscope (SEM). This method is to allow manufacturer to examine the microstructure and coalescence. The material microstructure was examined by scanning in the 2 θ range of between 0 and 90 degrees with a magnification setting of 50 μ m – 100 μ m and an electron high tension (EHT) of 15 Kv. Figure 3.7 shows the microstructure of PA-12 powder. However, the ones that will be looked at are the 3D printed of specimens.



Figure 3.6 SEM ZEISS EVO 18 electron microscope



Figure 3.7 SEM images of the polyamide-12 powder.

3.3 Different SLS 3D printer Parameter Settings

The specimens will have been prepared using four different parameters settings. 1st parameter of PA-12 material which is containing 0.06mm layer thickness and 60Watt laser power of recycle material, 2nd parameter which is containing 0.06mm layer thickness and 80Watt laser power settings, 3rd parameter which is set to 0.12mm layer thickness and 60Watt laser power and lastly is 0.12mm layer thickness and 80Watt of laser power of recycled shown in Table 3.1. The researcher or manufacturer will determine the mechanical characteristic of the PA-12 in each specimen. After that, the PA-12 material will be compared between these 4 different parameters 3D printed specimens.

LAYSIA Laser Layer Parameter Thickness Power (PR) (mm) (Watt) 0.06 60 1 2 0.06 80 3 0.12 60 4 0.12 80 TEKNIKAL MALAYSIA MELAKA UNIVERSITI

Table 3.1 PA-12 Different parameters settings of SLS 3D printer

3.4 3D Print

In following the sequency shown in figure 3.8 3D printing processes, the completed samples will be scanned and 3D printed using SLS 3D Printer Farsoon 4092p figure 3.9.



Figure 3.9 SLS 3D Printer Farsoon 4092p

3.4.1 Pre-Process

A design product having a thin walls analysis feature can be used to examine parts with thin walls. This function simulates the printing process, allowing the designer to determine whether or not their design will print properly. If it is not, they can make the necessary adjustments before printing.

Designers can utilize their CAD software's filleting feature to smooth out rough edges before printing to ensure a good print.

3.4.2 3D Printing Process

Using a computer-aided design (CAD) programme, a designer creates a threedimensional model. The design is divided into two-dimensional (2D) layers. The SLS printer receives the split design. A levelling roller applies a thin coating of powdered material to the build platform of the printer. The material is heated and fused together using a CO2 laser that traces a cross-section on it. The build platform is lowered when each layer is completed to make room for the next layer of powder. After each layer is completed, any leftover material is recycled. The SLS process is repeated until the part is finished, layer by layer. (Team, 2021)

3.4.3 Post-Processing

Part recovery is the first stage in SLS post-processing. Parts that have been SLS printed are wrapped in a porous cocoon of partly sintered powder that must be torn open in order to remove the part. While this technique would be untidy at home, SLS is mostly employed in industrial settings, where specially constructed cleaning chambers with airtight enclosures and pressurized air inlets are used.

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SLS-printed items are reviewed and tested after they have been cleaned to ensure that they fulfil the original requirements. Because SLS parts are prone to shrinkage and warping, this procedure must guarantee that each part is suitable for its intended use.

3.4.4 Final Product

Last, to prepare them for real-world use, most SLS parts are coloured and/or coated. Dyes and coatings opt begin with plainly cosmetic to extremely practical, including coatings that are environmentally friendly.

3.5 3D Printing Accuracy

As this is the main objective of this research, to measure the 3D scanner accuracy. So, the 3D printed specimens with different percentage of composition are to be verified of which one has the highest accuracy after 3D printed hence the data will be collected to create a guideline for superior composition of PA-12 for 3D printing process to other users. The tool to be used is the standard vernier calipers shown in figure 3.10 and another tool to be used is calibration block as shown in figure 3.11. The dimension of 3D printed product as shown in figure 3.12.



Figure 3.10 Standard vernier calipers



3.6 Expected Result

Thereafter carry the experiment, such optimum or the best PA-12 composition will be obtained and the analyzation process will be completed to study the PA-12 material composition part of the characteristic. table 3.2 below shown the sorts of expected result.

Factorial Input Parameter		Expected Testing Result						
Parameter settings								
Laser Power	Layer Thickness	Hardness Test	Roughness Test	Surface Morphology	Dimension Accuracy			
60 80 60 80	0.06 0.06 0.12 0.12							

Table 3.2 Table of expected result sorting



CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results or analysis of the run experiments which were comprised of few tests on the specimen parameter 1, 2, and 3 settings on the SLS 3D Printer Farsoon 4092p. The first parameter is the layer thickness of 0.06mm and laser power of 60W. The second parameter with 0.06mm layer thickness and 80W. The third parameter is the layer thickness of 0.12mm and 60W laser power while the last parameter is 0.12mm and 80W of laser power. This chapter showed the factors of reason influencing the data obtained and it also presents the gap different between all parameters in terms of mechanical properties such as the hardness, roughness, surface morphology, and the accuracy of SLS 3D printed of PA-12 material specimen.

4.2 Result Analysis of Hardness Testing of PA-12

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Indenter of 6.35 ball dimension indicated diameter had been used to run the hardness test on the specimen PR1, PR2, PR3 and PR4. Each one PR represented 5 samples. The scale that has been used to test the specimen was 45X (scale symbol selected) which was matched or suitable with the used indenter. Data of the tested specimens are shown below in table 4.1 and also pattern graphs of the acquired result are shown in figure 4.2-4.3.



Figure 4.1 Hardness Samples





Figure 4.2 Hardness values of 5 samples for each different parameter settings

*PR1: 0.06 layer thickness, 60 laser power *PR2: 0.06 layer thickness, 80 laser power *PR3: 0.12 layer thickness, 60 laser power *PR4: 0.12 layer thickness, 80 laser power



Figure 4.3 Mean of parameters PR1, PR2, PR3 and PR4.

The data in figure 4.3 shows the mean values of each different parameter setting on the SLS 3D printer machine. The average value of first parameter (PR1) is 33.26, second parameter (PR2) is 12.58, third parameter (PR3) is 5.88 and the last parameter (PR4) is 22.02. From pattern of graph in figure 1, we can observe that highest line fell to PR1. In general, it is defined that the lowest layer thickness and the lowest laser power of parameter that had been set has the hardest or highest hardness of the specimen. Meanwhile, the lowest hardness value fell to PR3 and also as a turning point to rise up again its hardness value if the laser power increase beyond this value. As proved at PR4, it returned back up again to 22.02 of mean value of 5 specimens in PR4. From (Kumar et al., 2017), out of these three parameters (laser power, temperature, and part orientation), laser power and temperature have the most impact on the dimensional accuracy (i.e., the three measurements that need to be taken for an SLS prototype) and temperature has the most impact on the microhardness of an SLS prototype.

4.3 Result Analysis of Surface Roughness on PA-12

To find out the effect of changes or different variables of parameter set for the Selective Laser Sintering machine on the polyamide 12 specimen, one test has been carried out which was surface roughness or the flatness test. Static traction testing was performed on five different specimens, each with its own set of parameters. The speed employed for the testing was 0.5mm/s, and the distance between each point was approximately 4.8mm. Every specimen has been measured three times: once on the left, once in the center, and once on the right, as shown in figure 4.4. Table 4.2-4.5 contain the data value for surface roughness, Ra, that has already been obtained on each specimen.



Figure 4.4 Three Point Measurement of Surface Roughness.

The graph in figure 4.5 showed that sample 5 had the most promising surface roughness since its area of points located lower than the other 4 samples while sample 1 had the highest values of roughness. So, it meant sample 5 had the smoothest surface. The variance in roughness might be attributed to the presence of upwarp features on one of them. (Xu et al. 2019).

Specimen	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Right	11.46	9.99	9.53	10.8	10.21	10.4
Centre	10.95	10.72	11.84	9.57	9.95	10.61
Left	10.02	10.83	10	11.02	11.06	10.35

Table 4.2 Surface roughness Ra(µm) Layer thickness: 0.06mm, Laser power: 60W



Figure 4.5 Graph of Surface roughness Ra (μ m) Layer thickness: 0.06mm, Laser power: 60W

The pattern in graph figure 4.6 have shown that sample 4 had the most less smoothness due to its values located higher than others. Its two side values indicated beyond value 10 μ m and one of it even reached beyond 1 μ m. Meanwhile, sample 5 had the excellence smoothness for two of its values below than 9.38 μ m but only one value which was the centre roughness passed over 11 μ m. The laser exposure parameters might alter the surface roughness. How surface roughness is affected by one major characteristic is how far apart the laser scans are. (Czelusniak and Amorim 2021)

Specimen Sample 1 Sample 2 Sample 3 Sample 4 Sample 5 Average Right 10.87 9.83 10.05 9.83 9.08 9.93 Centre 9.61 10.03 10.21 11.36 11.7 10.58 Left 9.38 10.3 10.71 10.19 9.01 9.92





Figure 4.6 Graph Surface roughness Ra(µm) Layer thickness: 0.06mm, Laser power: 80W

The graph in figure 4.7 showed the Surface roughness data for five distinct samples with the layer thickness parameter set to 0.12mm and the laser power set to 60W. Precision-wise, sample 5 had the greatest smoothness with values of 9.74 μ m and 9.15 μ m below than 10 μ m while sample 2 had the highest values in majority those even passed over 11.5 μ m. It was found that the powders used in SLS 3D printing had mostly elliptical shapes and rough surfaces. Both of these things could be made better in terms of sphericity and surface quality. (Xu et al. 2019)

Specimen	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Right	10.16	13.59	10.25	10.06	9.15	10.64
Centre	12.75	11.83	14.15	14.18	13.07	13.2
Left	13.06	12.54	10.45	10.05	9.74	11.17

Table 4.4 Surface roughness Ra(µm) Layer thickness: 0.12mm, Laser power: 60W





Figure 4.8 below displays surface roughness data for five different samples with a layer thickness parameter of 0.12mm and a laser power of 80W. In precision aspect, sample 1 had the best smoothness due to its three values fell below 13µm while sample 5 had the less accuracy for its roughness values had the slightly higher than sample 4's (second highest). In spite of a possible smoothing effect as laser intensity rose, PA12 particles that hindered compression or tension were gradually eliminated. This may account for the apparent softening of the surface. On the other side, the polishing procedure may have relieved any residual stress, leading to the observed softening of the surface. (J. Guo et al. 2018)

Specimen	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Right	9.66	13.31	10.8	14.58	14.7	12.69
Centre	12.52	11.52	10.45	13.02	12.16	11.93
Left	10.21	10.59	11.47	12.49	13.45	11.64

Table 4.5 Surface roughness Ra(µm) Layer thickness: 0.12mm, Laser power: 80W



Figure 4.8 Graph Surface roughness Ra(µm) Layer thickness: 0.12mm, Laser power: 80W

A (b)

Figure 4.9 expresses the average value of each parameter of the surface roughness test. The highest uniformly smooth values fell upon PR2 which were below than 10.60 μ m. Meanwhile, PR4 had the lowest smoothness since its 3 areas tested had the roughness values beyond 11.50 μ m. According to (Mynderse et al., 2017), results showed that the manufacturing parameters affected the size of cracks and the roughness of the surface.



Figure 4.9 The average values of each parameter settings CPs

4.4 Result Analysis of Surface Morphology

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Images of scanning electron microscopy (SEM) are shown in figure 4.10 below. Some parameter settings are set for the experimental using the ZEISS EVO 18 machine on PA-12 specimens (PR1, PR2, PR3 and PR4) are shown in table 6 below.

	LINUX/EDG	Table 6: SI	EM parame	eters settings	NATEL ALZ	_
-	Magnification (µm)	Electron high tension EHT (Kv)	WD (mm)	Signal A	Contrast (%)	Brightness (%)
PR1	100		6.5		55.7	48.3
	20				55.7	48.3
PR2	100	15	5.5	SE1	60.5	47.9
	20				60.5	47.9
PR3	100		6.5		51.5	48.2
	20				48.1	45.2
PR4	100		8.0		57.8	47.3
	20				57.8	47.3



Figure 4.10 PA-12 SEM images for (a) PR4, (b) PR3, (c) PR2 and (d) PR1

Figure 4.10 shows how changing a few variables can affect the morphology of PA-12 powders' surfaces from scanning electron microscopy SEM machine. Each specimen has two images with different magnification of 100x and 200x. The parameters PR1, PR2, PR3, and PR4 showed considerable and subtle differences in particle forms, sizes, and distributions. At high laser power, the PR1 result showed that the powder's shape and size were bonded together. In term of porosity, PR1 has the smallest degree of porosity and less obvious that it almost hard to find a clear one. From the image, it also can provide researcher that it has more melted powder. On opposite, PR3 has the most apparent porosities indicated that it also has the most less melting powder sintered. Raise the PR2 and PR4 laser intensity to work with the low melting points of recycled powder (180-210°C)(Verbelen et al., 2016). Surface morphology studies of PR3 revealed a significantly higher degree of porosity than those of PR1, PR2, and PR4. Step size (forward step and side step), laser power, laser beam diameter, manufacturing speed, layer thickness, and manufacturing speed can all affect how porous and weak a part is. See figure 7. (Ilkgun, 2018).

To relate the relationship between surface morphology and hardness of different parameters for PA-12 material. Both testing result intertwined closely to each other. Since the highest hardness among PRs fell upon to PR1 from the hardness testing ran, here the most cooked or melt enough also fell on PR1 for morphology test. On the otherwise, the same thing applied on the lowest hardness and had highest degree of porosity which was PR3.



Figure 7: SLS processing parameters affecting porosity.

4.5 Dimension Accuracy

The primary tests conducted in this study include dimension accuracy measurement. A calibration block was prepared to obtain accurate results during the test. Dimensions were measured using a vernier calliper coordinate measuring tool. Table 4.6 shows the calibration block requiring 11 points for X-axis measurement and 11 points for Y-axis measurement with a nominal value for each measurement point.



Figure 4.11 3D printed calibration block product.



Table 4.6 The X and Y axes are calibrated to their nominal values.

In figure 4.12, the results showed that PR3's distribution was more accurate than PR1, PR2, and PR4. But the characteristics of precision stayed within the right range. The results showed that parameter 3 was the most accurate composition material for printing along the X-axis. It had a mean deviation error of only 0.42 percent. Also, the PR3 parameter got a score of 5/11 on an 11-point scale, which shows that it was less wrong than other parameters. PR1 had the highest mean deviation error, at 1.30%, but PR4 had the second-lowest mean deviation error, at 0.45%. In short, the warping rate of the material, the required recycled material composition, and the laser power needed for the chosen parameter were the main things that affected the accuracy of the dimensions.



Figure 4.12 The SLS calibration block graph of dimension accuracy for Deviation X axis.

The Y-axis printed direction in figure 4.13 demonstrates that a mean deviation error of only 0.32%, PR4's measurements are the most accurate in terms of dimension. Also, the X-axis printed direction of the PR4 was about 0.45% more accurate than the Y-axis printed direction of the PR1 and PR2. In the end, there wasn't much difference in error between the X- and Y-axis orientations. So, this mistake did not change the accuracy much, even though it was in a large printed part. In a previous study by (Zeng et al., 2019), the virgin polyamide 12 had an X-axis range accuracy of 1.23% to 1.5% and a Y-axis range accuracy of 1.14% to 3.35%. This study backed up what (Rasiya et al., 2021) had found in a previous study: that the shrinkage rate and deformation caused by shrinkage in virgin PA-12 make recycled material very accurate in terms of dimension accuracy.



Figure 4.13 The SLS calibration block graph of dimension accuracy for Deviation Y axis.



CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In general, it is said that the hardest or highest hardness of the specimen is at the lowest layer thickness and lowest laser power that had been set. The lowest hardness value fell to PR3, which also served as a turning point. If the laser power went above this value, the hardness value would go back up. As shown at PR4, it went back up to 22.02, which is the average of 5 samples. According to Kumar et al. (2017), out of these three parameters (laser power, temperature, and part orientation), laser power and temperature have the most effect on the dimensional accuracy (i.e., the three measurements that need to be taken for an SLS prototype) and temperature has the most effect on the microhardness of an SLS prototype.

In Figure 4.9, the average value of each surface roughness test parameter is shown. The values that fell on PR2 were the smoothest and most even. They were less than 10.60 μ m. On the other hand, PR4 had the least smoothness because 3 of the areas that were tested had roughness values higher than 11.50 μ m. The size of cracks and the roughness of the surface were affected by the manufacturing parameters, according to the results.

Figure 4.10 shows how scanning electron microscopy SEM machine factors affect PA-12 powder surface morphology. Each specimen comprises 100x and 200x photos. PR1, PR2, PR3, and PR4 had distinct particle structures, sizes, and distributions. At high laser power, PR1 revealed the powder's shape and size were bound. PR1 has the least porosity, making it hard to see. Researchers can see more melted powder from the image. PR3 has the most porosities and the least melting powder sintered. Increase PR2 and PR4 laser power for recycled powder's low melting point (180-210°C) (Verbelen et al., 2016). PR3 surface morphology showed a much higher porosity than PR1, PR2, and PR4. Step size (forward

and side step), laser power, laser beam diameter, manufacturing speed, layer thickness, and manufacturing speed impact how porous and weak a product is.

To relate surface morphology and hardness of PA-12 material characteristics. Both test results were intermingled. The hardest PR1, PR1, was likewise the most fried or melty for the morphology test. PR3 had the lowest hardness and largest porosity. PR3's distribution was more accurate than PR1, PR2, and PR4 (Figure 4.12). However, precision was within range. Parameter 3 yielded the best X-axis printing composition material. 0.42% was its mean deviation error. The PR3 parameter was less incorrect than others, scoring 5/11 on an 11-point scale. PR4 had the second-lowest mean deviation error, 0.45%, whereas PR1 had 1.30%. The dimensions' precision depended on the material's warping rate, recycled material composition, and laser power. Figure 4.13 shows that PR4's size measurements are most accurate with a mean deviation error of 0.32%. The PR4's X-axis printed direction was 0.45% more accurate than the PR1 and PR2's Y-axis. X- and Y-axis orientations had similar error rates. Despite being in a huge printed component, this mistake didn't affect accuracy. In a prior study (Zeng et al., 2019), virgin polyamide 12 possessed X-axis range accuracy of 1.23% to 1.5% and Y-axis range accuracy of 1.14% to 3.35%. This investigation confirmed (Rasiya et al., 2021) that virgin PA-12 shrinks and deforms, making recycled material very exact in size.

Testing	Parameter 1	Parameter 2	Parameter 3	Parameter 4
Hardness	33.26	12.58	5.88	22.02
	Right: 10.4µm	Right: 9.93µm	Right: 10.64µm	Right: 12.69µm
Roughness	Centre:10.61µm	Centre:10.58µm	Centre:13.20µm	Centre:11.93µm
	Left: 10.35µm	Left: 9.92µm	Left: 11.17µm	Left: 11.64µm
	Error	Error	Error	Error
Dimension	X-axis: 1.30 %	X-axis: 1.22 %	X-axis: 0.42 %	X-axis: 0.45 %
Accuracy	Y-axis: 1.69 %	Y-axis: 1.38 %	Y-axis: 0.47 %	Y-axis: 0.32 %
Surface Morphology	1st place	3rd place	4th place	2nd place

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5.2 **Recommendations**

For future improvements, accuracy of the 3D printing estimation results could be enhanced as follows:

- i. Choose the right or suitable laser power based on the PA-12 composition to acquire the right melting point.
- ii. Can use latest technology such Stereolithography SLA that has higher resolution in manufacturing.
- Lower the speed printing to get rid of echoes or ringing sounds around the edges of a feature on the final object, we may have to lower the quality of the image.
- iv. Pay close attention to setting up and maintaining the printer.

5.3 **Project Potential**

Another great idea to add into this project is the addition of product fabrication of Polyamide 12. Choose the more complex design of product. So, researcher could measure the accuracy of the complex design on the curvature parts of the product. By doing this, researcher could find a more method to measure the 3D printed product accuracy. Furthermore, the variables study could range wider than just studying about the effectiveness of parameter differentiation. For example, do study about the effect of speed, customized material parameter, and thermal parameter. All of these are a must-have method if you want to change how the prototype works.

REFERENCES

- Astm, D., & D, C. P. (n.d.). *Type 5A and 5B Specimen Tensile Properties ASTM D638 Note.*
- Farsoon Technologies. (2017). Selective Laser Sintering Systems FARSOON 402P SERIES Break free with Farsoon Technologies. *Manual Book Farsoon Sls 402P*.
- Gan, X., Fei, G., Wang, J., Wang, Z., Lavorgna, M., & Xia, H. (2020). Powder quality and electrical conductivity of selective laser sintered polymer composite components. In *Structure and Properties of Additive Manufactured Polymer Components*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-819535-2.00006-5
- Ilkgun, O. (2018). Effects of Production Parameters on Porosity and Hole. Master Thesis, 1–144.
- Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A., & Ul Haq, M. I. (2022). 3D printing A review of processes, materials and applications in industry 4.0. *Sustainable Operations and Computers*, *3*(October 2021), 33–42. https://doi.org/10.1016/j.susoc.2021.09.004
- Kumar, N., Kumar, H., & Singh, J. (2017). Experimental Investigation of process parameters for rapid prototyping technique (Selective Laser Sintering) to enhance the part quality of prototype by Taguchi method. 23, 352–360. https://doi.org/10.1016/j.protcy.2016.03.037
- Mueller, J. B., Fischer, J., Mayer, F., Kadic, M., & Wegener, M. (2014). Polymerization Kinetics in Three-Dimensional Direct Laser Writing. *Advanced Materials*, 26(38), 6566–6571. https://doi.org/10.1002/adma.201402366
- Rafi Omar, M., Ilman Hakimi Chua Abdullah, M., Rizal Alkahar, M., Abdullah, R., Fadzli Abdollah, M., Subramaniam, M., Seeni Ibramsa, R., & Teknologi Kejuruteraan Mekanikal dan Pembuatan, F. (2022). Effect of Polyamide-12 Material Compositions on Mechanical Properties and Surface Morphology of SLS 3D Printed Part. In *Journal of Mechanical Engineering* (Vol. 19, Issue 1).
- Rasiya, G., Shukla, A., Saran, K., Agarwal, P., Bajpai, L., Singh, C. P., Gupta, K., Davim, J. P., Wahab, M. S., Dalgarno, K. W., Cochrane, R. F., Beyerlein, S., Aboushama, M., Citarella, R., Giannella, V., Feng, L., Wang, Y., Wei, Q., Danezan, A., ... Peels, J. (2021). Triangulatica Software. *The Economist*, 47(July), 6896–6901. https://3dprint.com/188101/low-cost-selective-laser-sintering/%0Ahttps://www.tubitak.gov.tr/tr/kurumsal/politikalar/icerik-tubitak-oncelikli-ar-ge-ve-yenilik-konulari%0Ahttps://www.economist.com/special-report/2012/04/21/a-third-industrial-revolution%0Ahtt
- Shahrubudin, N., Lee, T. C., & Ramlan, R. (2019). An overview on 3D printing technology: Technological, materials, and applications. *Procedia Manufacturing*, 35, 1286–1296. https://doi.org/10.1016/j.promfg.2019.06.089
- Shubham, P., Sikidar, A., & Chand, T. (2016). The influence of layer thickness on mechanical properties of the 3D printed ABS polymer by fused deposition modeling. *Key Engineering Materials*, 706(August), 63–67. https://doi.org/10.4028/www.scientific.net/KEM.706.63
- Team, S. (2021). *The Process of SLS in Additive Manufacturing*. BS Spatial. https://blog.spatial.com/the-process-of-sls-in-additive-manufacturing
- Verbelen, L., Dadbakhsh, S., van den Eynde, M., Kruth, J. P., Goderis, B., & van Puyvelde, P. (2016). Characterization of polyamide powders for determination of

laser sintering processability. *European Polymer Journal*, 75, 163–174. https://doi.org/10.1016/j.eurpolymj.2015.12.014

Zeng, Z., Deng, X., Cui, J., Jiang, H., Yan, S., & Peng, B. (2019). Improvement on selective laser sintering and post-processing of polystyrene. *Polymers*, *11*(6). https://doi.org/10.3390/polym11060956



APPENDICES

	NOMINAL X-AXIS		PARAM	ETER 1			
Point	(mm)	1	2	3	Mean	SD	% Deviation
P1	12.7	13.23	13.42	13.56	13.40333	0.135236	5.53806
P2	38.1	38.26	38.11	38.47	38.28	0.147648	0.47244
Р3	63.5	64.22	64.55	64.71	64.49333	0.204015	1.56430
P4	88.9	89.37	89.4	89.63	89.46667	0.116142	0.63742
P5	114.3	114.79	114.91	114.99	114.8967	0.082192	0.52202
P6	139.7	140.1	140.45	140.33	140.2933	0.14522	0.42472
P7	114.3	114.91	114.8	114.74	114.8167	0.070396	0.45203
P8	88.9	89.26	89.25	89.67	89.39333	0.195675	0.55493
Р9	63.5	63.98	63.79	63.88	63.88333	0.077603	0.60367
P10	38.1	38.55	38.1	38.42	38.35667	0.189091	0.67367
P11	12.7	13.05	13	13.15	13.06667	0.062361	2.88714
	2		PARAM	ETER 2			
	EK	1	> 2	3			
P1	12.7	12.96	12.84	12.47	12.75667	0.20854	0.44619
P2	38.1	38.38	38.51	38.75	38.54667	0.153261	1.17235
Р3	63.5	63.87	63.85	63.25	63.65667	0.287673	0.24672
P4	88.9	89.08	89.45	89.73	89.42	0.266208	0.58493
Р5	114.3	114.85	114.59	114.32	114.5867	0.216384	0.25080
P6	139.7	140	140.75	140.98	140.5767	0.418436	0.62754
P7	114.3	114.95	114.32	114.75	114.6733	0.262848	0.32663
P8	88.9	89.57	89.16	89.61	89.44667	0.203361	0.61492
Р9	63.5	64	64.47	64.83	64.43333	0.339837	1.46982
P10	38.1	38.75	38.26	38.47	38.49333	0.200721	1.03237
P11	12.7	13.29	13.49	13.84	13.54	0.227303	6.61417
			PARAM	ETER 3			
		1	2	3			
P1	12.7	12.64	12.48	12.36	12.49333	0.114698	1.62730
P2	38.1	38.1	38.65	38.13	38.29333	0.252499	0.50744
Р3	63.5	63.4	63.75	63.3	63.48333	0.192931	0.02625
P4	88.9	88.78	88.45	88.14	88.45667	0.261321	0.49869
P5	114.3	114.19	114.18	114.86	114.41	0.318224	0.09624
P6	139.7	139.55	139.65	139.71	139.6367	0.065997	0.04534
P7	114.3	114.2	114.32	114.75	114.4233	0.236126	0.10790
P8	88.9	88.86	88.9	88.72	88.82667	0.077172	0.08249
P9	63.5	63.49	63.68	63.51	63.56	0.085245	0.09449
P10	38.1	38.09	38.18	38.67	38.31333	0.254864	0.55993
P11	12.7	12.61	12.76	12.36	12.57667	0.164992	0.97113

APPENDIX A The accuracy of PA-12 measurement for each parameter X axis.

PARAMETER 4									
		1	2	3					
P1	12.7	12.64	12.68	12.62	12.64667	0.024944	0.420		
P2	38.1	38.02	38.46	38.33	38.27	0.184572	0.446		
Р3	63.5	63.45	63.48	63.71	63.54667	0.116142	0.073		
P4	88.9	88.91	88.36	88.12	88.46333	0.33069	0.491		
P5	114.3	114.4	114.96	114.08	114.48	0.363685	0.157		
P6	139.7	139.67	139.25	139.06	139.3267	0.254864	0.267		
P7	114.3	114.26	114.79	114.25	114.4333	0.252234	0.117		
P8	88.9	88.92	88.36	88	88.42667	0.378535	0.532		
Р9	63.5	63.53	63.16	63.07	63.25333	0.199053	0.388		
P10	38.1	38.1	38.16	38.46	38.24	0.15748	0.367		
P11	12.7	12.72	12.63	12.09	12.48	0.278209	1.732		

		Mean	Mean	Mean	Mean				
	Nominal	PR1	PR2	PR3	PR4	SD	SD	SD	SD
Point	(mm)	(mm)	(mm)	(mm)	(mm)	PR1	PR2	PR3	PR4
1	12.7	13.4033	12.7567	12.4933	12.6467	0.1352	0.2085	0.1147	0.0249
2	38.1	38.2800	38.5467	38.2933	38.2700	0.1476	0.153 3	0.2525	0.1846
3	63.5	64.4933	63.6567	63.4833	63.5467	0.2040	0.2877	0.1929	0.1161
4	88.9	89.4667	89.4200	88.4567	88.4633	0.1161	0.2662	0.2613	0.3307
5	114.3	114.8967	114.5867	114.4100	114.4800	0.0822	0.2164	0.3182	0.3637
6	139.7	140.2933	140.5767	139.6367	139.3267	0.1452	0.4184	0.0660	0.2549
7	114.3	114.8167	114.6733	114.4233	114.4333	0.0704	0.2628	0.2361	0.2522
8	88.9	89.3933	89.4467	88.8267	88.4267	0.1957	0.2034	0.0772	0.3785
9	63.5	63.8833	64.4333	63.5600	63.2533	0.0776	0.3398	0.0852	0.1991
10	38.1	38.3567	38.4933	38.3133	38.2400	0.1891	0.2007	0.2549	0.1575
11	12.7	13.0667	13.5400	12.5767	12.4800	0.0624	0.2273	0.1650	0.2782
		10 10	0			0.1296	0.2531	0.1840	0.2309

LININ	/ERSITI TE	KNIKAL MA	ALAYSIA M	FLAKA
100 B B B B	% Deviation	% Deviation	% Deviation	% Deviation
Nominal	PR1	PR2	PR3	PR4
0.0000	5.53806	0.44619	1.62730	0.41995
0.0000	0.47244	1.17235	0.50744	0.44619
0.0000	1.56430	0.24672	0.02625	0.07349
0.0000	0.63742	0.58493	0.49869	0.49119
0.0000	0.52202	0.25080	0.09624	0.15748
0.0000	0.42472	0.62754	0.04534	0.26724
0.0000	0.45203	0.32663	0.10790	0.11665
0.0000	0.55493	0.61492	0.08249	0.53243
0.0000	0.60367	1.46982	0.09449	0.38845
0.0000	0.67367	1.03237	0.55993	0.36745
0.0000	2.88714	6.61417	0.97113	1.73228
	1.30276	1.21695	0.41974	0.45389

Y-AXIS % Point (mm) 1 2 3 Mean SD Deviation P1 12.7 13.14 13.65 13.86 13.5500 0.3023 6.69291 P2 38.1 38.67 38.09 38.94 38.5667 0.3546 1.22484 P3 63.5 63.83 63.14 63.23 63.4000 0.3063 0.15748 P4 88.9 89.24 89.65 89.14 89.3433 0.2207 0.49868 P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667	N		NOMINAL		PARAME	ETER 1			
Point (mm) 1 2 3 Mean SD Deviatio P1 12.7 13.14 13.65 13.86 13.5500 0.3023 6.69291 P2 38.1 38.67 38.09 38.94 38.5667 0.3546 1.22484 P3 63.5 63.83 63.14 63.23 63.4000 0.3063 0.15748 P4 88.9 89.24 89.65 89.14 89.3433 0.2207 0.49868 P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 <	Y		Y-AXIS						%
P1 12.7 13.14 13.65 13.86 13.5500 0.3023 6.69291 P2 38.1 38.67 38.09 38.94 38.5667 0.3546 1.22484 P3 63.5 63.83 63.14 63.23 63.4000 0.3063 0.15748 P4 88.9 89.24 89.65 89.14 89.3433 0.2207 0.49868 P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767	ıt (ı	Point	(mm)	1	2	3	Mean	SD	Deviation
P2 38.1 38.67 38.09 38.94 38.5667 0.3546 1.22484 P3 63.5 63.83 63.14 63.23 63.4000 0.3063 0.15748 P4 88.9 89.24 89.65 89.14 89.3433 0.2207 0.49868 P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.14 13.98 13.04 13.4767 0.3866 6.11548 P2 38.1 38.67 38.51 38.44 38.567 <		P1	12.7	13.14	13.65	13.86	13.5500	0.3023	6.6929134
P3 63.5 63.83 63.14 63.23 63.4000 0.3063 0.15748 P4 88.9 89.24 89.65 89.14 89.3433 0.2207 0.49868 P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 <		P2	38.1	38.67	38.09	38.94	38.5667	0.3546	1.2248469
P4 88.9 89.24 89.65 89.14 89.3433 0.2207 0.49868 P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167		P3	63.5	63.83	63.14	63.23	63.4000	0.3063	0.1574803
P5 114.3 114.65 114.75 114.8 114.7333 0.0624 0.37911 P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 PARAMETER 2 1 2 3 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495		P4	88.9	89.24	89.65	89.14	89.3433	0.2207	0.4986877
P6 139.7 140.03 140.74 140.09 140.2867 0.3215 0.41994 P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733		P5	114.3	114.65	114.75	114.8	114.7333	0.0624	0.3791193
P7 114.3 114.95 114.22 114.74 114.6367 0.3068 0.29454 P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.233 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 <t< td=""><td></td><td>P6</td><td>139.7</td><td>140.03</td><td>140.74</td><td>140.09</td><td>140.2867</td><td>0.3215</td><td>0.4199475</td></t<>		P6	139.7	140.03	140.74	140.09	140.2867	0.3215	0.4199475
P8 88.9 89.63 89.26 89.61 89.5000 0.1699 0.67491 P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.1438 0.33882 <		P7	114.3	114.95	114.22	114.74	114.6367	0.3068	0.2945465
P9 63.5 64.26 64.08 64.16 64.1667 0.0736 1.04986 P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.2924 0.37911		P8	88.9	89.63	89.26	89.61	89.5000	0.1699	0.6749156
P10 38.1 38.78 38.15 38.55 38.4933 0.2603 1.0323 P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.2924 0.37911 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911		P9	63.5	64.26	64.08	64.16	64.1667	0.0736	1.0498688
P11 12.7 13.41 13.98 13.04 13.4767 0.3866 6.11548 PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.2924 0.37911 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911		P10	38.1	38.78	38.15	38.55	38.4933	0.2603	1.032371
PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.2924 0.37911		P11	12.7	13.41	13.98	13.04	13.4767	0.3866	6.1154856
PARAMETER 2 1 2 3 P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.2924 0.37911 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911									
P1 12.7 13.14 13.12 13.25 13.1700 0.0572 3.70078 P2 38.1 38.67 38.51 38.44 38.5400 0.0963 1.15485 P3 63.5 63.83 63.9 63.84 63.8567 0.0309 0.56167 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.1438 0.33882 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911			MALAI	YS/4 .1	PARAIVIE 2	21ER 2 3			
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P3 03.3 03.83 03.3 03.34 03.8307 0.0309 0.30107 P4 88.9 89.24 89.34 89.12 89.2333 0.0899 0.37495 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.1438 0.33882 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911	Ш	D2	62 5	62.82	62.0	62.84	62 8567	0.0303	0.5616708
P4 88.5 85.24 85.34 85.12 85.2333 0.0855 0.3745 P5 114.3 114.65 114.72 114.04 114.4700 0.3054 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.1438 0.33882 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911	-		P 03.5	03.83	03.9	03.04	03.8507	0.0303	0.2740521
P5 114.3 114.05 114.72 114.04 114.4700 0.3034 0.14873 P6 139.7 140.03 140.12 140.37 140.1733 0.1438 0.33882 P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911	1	Г4 DE	00.9	114 65	114 72	114.04	03.2333	0.0055	0.3749331
P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911			114.5	14.05	14.72	14.04	14.4700	0.5054	0.146/514
P7 114.3 114.95 114.93 114.32 114.7333 0.2924 0.37911			139.7	1140.05	140.12	140.57	140.1733	0.1450	0.3300213
	5	F7	114.5	114.95	114.95	114.52	114.7555	0.2924	0.5791195
			62.5	64.26	64.05	69.15	64.3907	0.2055	1 1068504
P9 03.5 04.20 04.05 04.47 04.2000 0.1715 1.19085		P9	03.5	04.20	04.05	04.47	04.2000	0.1715	1.1908504
P10 38.1 38.78 38.58 38.12 38.4933 0.2763 1.0323	U	P10	UNIVERS	38.78	38.58	38.12	38.4933	0.2763	1.032371
PII 12.7 13.41 13.25 13.64 13.4333 0.1601 5.77427		P11	12.7	13.41	13.25	13.64	13.4333	0.1601	5.//42/82
PARAMETER 3					ΡΔΡΔΜ	TER 3			
1 2 3				1	2	3			
P1 12.7 12.7 12.36 12.48 12.5133 0.1408 1.4698		P1	12.7	12.7	12.36	12.48	12.5133	0.1408	1.4698163
P2 38.1 38.12 38.14 38.04 38.1000 0.0432 1.865		2	38.1	38.12	38.14	38.04	38.1000	0.0432	1.865E-14
P3 63.5 63.5 63.54 63.11 63.3833 0.1940 0.183		2	63.5	63.5	63.54	63.11	63.3833	0.1940	0.183727
P4 88.9 88.92 88.46 88.14 88.5067 0.3201 0.4424		24	88.9	88.92	88.46	88.14	88.5067	0.3201	0.4424447
P5 114.3 119.43 114.09 114.75 116.0900 2.3771 1.5660		25	114.3	119.43	114.09	114.75	116.0900	2.3771	1.5660542
P6 139.7 139.72 139.28 139.74 139.5800 0.2123 0.0858		°6	139.7	139.72	139.28	139.74	139.5800	0.2123	0.0858984
P7 114.3 114.4 114.07 114.26 114.2433 0.1352 0.0495		7	114.3	114.4	114.07	114.26	114.2433	0.1352	0.0495771
P8 88.9 88.97 88.28 88.75 88.6667 0.2878 0.2624		8	88.9	88.97	88.28	88.75	88.6667	0.2878	0.2624672
P9 63.5 63.46 63.65 63.84 63.6500 0.1551 0.2362		9	63.5	63.46	63.65	63.84	63.6500	0.1551	0.2362205
P10 38.1 38.1 38.58 38.49 38.3900 0.2083 0.7611		210	38.1	38.1	38.58	38.49	38,3900	0.2083	0.7611549
P11 12.7 12.71 12.95 12.49 12.7167 0.1879 0.1312		 P11	12.7	12.71	12.95	12.49	12,7167	0.1879	0.1312336

APPENDIX B The accuracy of PA-12 measurement for each parameter Y axis.

	PARAMETER 4										
		1	2	3							
P1	12.7	12.75	12.65	12.87	12.7567	0.0899	0.4461942				
P2	38.1	38.09	38.42	38.46	38.3233	0.1658	0.5861767				
Р3	63.5	63.5	63.45	63.38	63.4433	0.0492	0.0892388				
P4	88.9	88.9	88.64	88.36	88.6333	0.2205	0.2999625				
P5	114.3	114.37	114.36	114.75	114.4933	0.1815	0.1691455				
P6	139.7	139.73	139.87	139.88	139.8267	0.0685	0.0906705				
P7	114.3	114.33	114.75	114.86	114.6467	0.2284	0.3032954				
P8	88.9	88.98	88.78	88.36	88.7067	0.2584	0.2174728				
P9	63.5	63.55	63.68	63.7	63.6433	0.0665	0.2257218				
P10	38.1	38.12	38.08	38.4	38.2000	0.1424	0.2624672				
P11	12.7	12.68	12.63	12.48	12.5967	0.0850	0.8136483				

		Mean	Mean	Mean	Mean				
	Nominal	PR1	PR2	PR3	PR4				
Point	(mm)	(mm)	(mm)	(mm)	(mm)	SD PR1	SD PR2	SD PR3	SD PR4
1	12.7	13.5500	13.1700	12.5133	12.7567	0.302324	0.057155	0.140791	0.089938
2	38.1	<mark>38</mark> .5667	38.5400	38.1000	38.3233	0.35462	0.096264	0.043205	0.165798
3	63.5	<mark>63</mark> .4000	63.8567	63.3833	63.4433	0.306268	0.030912	0.193964	0.049216
4	88.9	89.3433	89.2333	88.5067	88.6333	0.220656	0.089938	0.320139	0.220504
5	114.3	114.7333	114.4700	116.0900	114.4933	0.062361	0.305396	2.377057	0.181537
6	139.7	140.2867	140.1733	139.5800	139.8267	0.32149	0.143836	0.212289	0.068475
7	114.3	114.6367	114.7333	114.2433	114.6467	0.306848	0.292385	0.135236	0.228376
8	88.9	89.5000	89.3967	88.6667	88.7067	0.169902	0.20548	0.287789	0.258371
9	63.5	64.1667	64.2600	63.6500	63.6433	0.073636	0.171464	0.155134	0.0665
10	38.1	38.4933	38.4933	38.3900	38.2000	0.260299	0.276325	0.208327	0.142361
11	12.7	13.4767	13.4333	12.7167	12.5967	0.386638	0.160069	0.187853	0.084984

	% Deviation	% Deviation	% Deviation	% Deviation	
Nominal	PR1	PR2	PR3	PR4	
0.000	6.6929	3.7008	1.4698	0.4462	
0.000	1.2248	1.1549	0.0000	0.5862	
0.000	0.1575	0.5617	0.1837	0.0892	
0.000	0.4987	0.3750	0.4424	0.3000	
0.000	0.3791	0.1487	1.5661	0.1691	
0.000	0.4199	0.3388	0.0859	0.0907	
0.000	0.2945	0.3791	0.0496	0.3033	
0.000	0.6749	0.5587	0.2625	0.2175	
0.000	1.0499	1.1969	0.2362	0.2257	
0.000	1.0324	1.0324	0.7612	0.2625	
0.000	6.1155	5.7743	0.1312	0.8136	
	1.6855	1.3837	0.4717	0.3185	