PARAMETER OPTIMIZATION IN 3D PRINTER RECYCLE MACHINE

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A report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled ―Parameter Optimization in 3d Printer Recycle Machine” is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....

Supervisor's Name : ....

Date : ....

DEDICATION

To my beloved mother and father, and those who always support me.

ABSTRACT

3D printing technology has evolves rapidly to becoming one of the most postulate method in manufacturing process. Commonly, standard manufacturing process which is subtractive that produces a lot of waste opposite to 3D printing technology is way friendly to the environment. Application of additive manufacturing method in 3D printing leads to less or no wasted materials. For this promising technology, it still developing especially when there are lots of open source medium for people to access and discover the 3D printing technology. There is always a problem in every human-made creation. As for 3D printing, consumption of plastic materials has significantly increased due to high demand in market. In order to minimize the negative impact of plastic waste to the environment, a machine of recycle 3D printing has been made and a study on parameter optimization on 3D printer recycle machine have been done. By using Minitab software, analysis has been made on the factor of parameter of recycle 3D printing. From that analysis, Taguchi method suggests some of experiment to do and give an optimal value for each parameter that need to optimize in extruding operation. After the optimal value obtained, percentage of error diameter of new filament has been calculated. Analysis of extruded filament was done for every 30cm with minimum of three repetitions. In comparison of the new extruding filament and original filament show that some minor difference of the mechanical properties by using tensile test method. Percentage of error for diameter of filament indicates 1.77mm diameter with 1.14% as the lowest error while diameter of 1.82mm with 4.00% as the highest error. This show that optimization on 3D printer recycle machine has done by get the percentage of error below than 5% and it gives hope for future improvement in this project of recycling waste of ABS polymer.

ABSTRAK

Teknologi percetakan 3D telah berkembang pesat untuk menjadi salah satu kaedah yang paling pasif dalam proses pembuatan. Biasanya, proses pembuatan yang biasa menghasilkan banyak sisa berbeza dengan teknologi percetakan 3D adalah mesra alam sekitar. Penggunaan kaedah pembuatan bahan tambahan dalam percetakan 3D membawa kepada kurangnya atau tiada bahan terbuang. Untuk teknologi yang canggih ini, ia masih berkembang terutamanya apabila terdapat banyak medium sumber terbuka bagi orang untuk mengakses dan menerokai teknologi percetakan 3D. Selalunya akan ada masalah dalam setiap ciptaan buatan manusia. Bagi pencetakan 3D, penggunaan bahan plastik meningkat dengan ketara berikutan permintaan yang tinggi dalam pasaran. Untuk meminimumkan kesan negatif sisa plastik ke alam sekitar, mesin pencetakan kitar semula 3D telah dibuat dan kajian terhadap pengoptimuman parameter pada mesin daur ulang pencetak 3D telah dilakukan. Dengan menggunakan perisian Minitab, analisis telah dibuat berdasarkan faktor parameter pencetakan kitar semula 3D. Dari analisis itu, kaedah Taguchi mencadangkan beberapa percubaan untuk dilakukan dan memberikan nilai optimum untuk setiap parameter yang perlu dioptimalkan dalam operasi penyemperitan. Selepas mendapatkan nilai optimum, peratusan diameter ralat filamen baru akan dikira. Analisis filamen tersemperit dilakukan untuk setiap 30cm dengan minimum tiga ulangan. Sebagai perbandingan filamen tersemperit yang baru dan filamen asli menunjukkan bahawa beberapa perbezaan sifat mekanik dengan menggunakan kaedah ujian tegangan. Peratusan ralat untuk diameter filamen menunjukkan diameter 1.77mm dengan 1.14% sebagai kesilapan terendah manakala diameter 1.82mm dengan 4.00% sebagai ralat tertinggi. Ini menunjukkan bahawa pengoptimuman pada mesin kitar semula pencetak 3D telah dilakukan dengan mendapatkan peratusan kesilapan di bawah 5% dan memberikan harapan untuk peningkatan di masa depan untuk projek kitar semula bahan buangan polimer ABS.

ACKNOWLEDGEMENTS

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RP	-	Rapid prototyping
PLA	-	Polylactic acid
ABS	-	Acrylonitrile butadiene styrene
€	-	Modulus young's
^{o}C	-	Temperature
%	-	Percentage
S/N	-	Single to noise
Ŋ	-	Single to noise ratio
Y	-	Variance
mm	-	Millimeter
w	-	Power
m/s	-	Velocity

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CHAPTER 1

INTRODUCTION

1.1 Background

In today's era, technology evolves rapidly from day to day. Rapid prototyping (RP) or mostly known as 3D printing is a good example of growth manufacturing technology which just not increase production rate but also saves time consumption and overall cost including cutting down labor cost. There are a lot of advantages in 3D printing such as low material using. That is because Rapid prototyping technologies are able to produce complex physical model in a layer by layer. Before we can successfully manufacture a batch of zero defect product, there is always some reject of final products due to human error or technical error. Due to this, there will be a bunch of 3D printed material waste.

Plastic filament is available in a variety of types of material, colours, diameters and lengths. Two types of materials commonly used as filament for 3D printing which are known as Polylactic Acid (PLA) and Acrylonitrile-Butadiene-Styrene (ABS). Both of the materials are plastic based and easy to melt once it is exposed to heat. 3D filament is the basic consumable resource that most types of 3D printers use for printing. As a traditional printer needs ink cartridges in order to print, 3D printers need plastic filament. Most of the filament produced today is from virgin, unused petroleum based plastic which generates not only increasing amounts of global waste but contributes to carbon emissions, resulting in significant environmental damage. That is why it is necessary to recycle the rejected products to prevent waste and to achieve cost effective production in 3D printing technology.

In market there are many type of 3d printer recycle machine even we can make it our own. There some important parameters in 3d printer recycle machine such as material, pressure and temperature. Usually, the aim for this project is mainly to optimize the parameter of 3D printer recycle machine which could significantly make a new filament. Those can be achieved by recycling failed prints of 3D project by shredding and extruding process into new filament.

1.2 Problem Statement

In this project, existing low cost 3D printing machine which is called Mendel 3D printer is used as reference model. This machine is built by using open source technology. The filament is quietly expensive because the materials are mixture of petroleum-based and plant-based source and this are not biodegradable material. That is why technology on recycle device for filament is elevating. So there goes production of several 3D printer recycle machines by different companies. But, none of them are integrated recycle machine which can be attached to the 3D printer. Due to that, a project for integrated 3D printer recycle machine had been developed as shown in Figure 1.1.

Figure 1.1 : Integrated 3D printer recycle machine

However, the current machine was too small and the size of filament been extruded does not achieve the standard and consistent filament size. The other limitation is the machine is too heavy to be attached to the 3D printer. Therefore, this latest project is about to design a new and improved 3D printer recycle machine to overcome those problems. Make a parameter optimization based on 3D printer recycle machine.

1.3 Objective

The objectives of this project are as follows:

1. To optimize the parameter in 3D printer recycle machine by measuring a new recycle filament.
2. To analyze the parameter in 3D printer recycle machine by using Taguchi method application in Minitab software.
3. To make a comparison of mechanical properties with two different filament by using tensile test method.

1.4 Scope of Project

The scopes of this project are:

1. Minitab software will be used in analyze parameter in 3D printer recycle by using Taguchi method.
2. The new recycle machine will implement the similar working principle of the previous one.
3. Optimization based on previous one 3D printer recycle machine.

CHAPTER 2

LITERATURE REVIEW

2.1 3D Printing

3D printing is a common method being used in rapid prototyping technology. It is basically used to manufacture plastic parts used for concept visualization or even final parts. (Bak, 2003) state that during future dramatic increase within the application of 3-d printing generation. In addition, manufacturers in various industries already implement the use of 3D printing due to its efficiency and faster rate of production. These mean that 3D printing is on rising demand for production line.

To ensure faster progress on the improvement of 3D printing technology, open source platform such as RepRap is the one with low cost of investment needed compared to others. RepRap are the most commonly used 3-D printers (Moilanen & Vadén, 2012). There are various model of open source for low cost 3D printer such as Prusa i3 and delta. To considerably abbreviate the ideal opportunity for creating patterns, molds, and models, some manufacturing ventures have begun to utilize fast prototyping strategies for complex patterns making and factor prototyping (Yan & Gu, 1996).

As the benefits of 3D printing have lured many developers and manufacturers to use it, this situation results the high volume of filament usage for printing. That is why this state has leads inventor to develop waste recycle system for low cost 3D printing so that the waste can be put into used without having to spend so much money to buy new set of filaments.

2.2 Recycle System Integration

As the demand on the low cost 3D printing seems to reach the extravagant level due to its ability to just not only work efficiently but also cheap and reliable, has cause the high request on the building materials. Devices which can recycle material and help slow the depletion of natural resources and make engineering and manufacturing a more ecological-friendly practice are very beneficial in the industry (Rensberger & Hinora, 2016). That is why a recycle system for plastic waste is required.

In addition to the system, extrusion principal is needed to extrude the filament produced by the recycle system. They made use of the similar principle to injection moulding that used screw, which in their cases was to force the material into the barrel with heating element and then plastic was melted before being compressed and driven through a die (Rensberger & Hinora, 2016). To be clear, those initial projects are not integrated with low cost 3D printing. They made the recycle machine that extrude new filament separately. Besides, the plastic shredder and filament extruder are disassociated from one another for the recycle system. This will cause more time being consumed due to the need to handle separate machines one after another. Thus, this method does not comply with the requirement for integrated recycle machine with low cost 3D printing.

To meet the objective of having an integrated recycle machine on a low cost 3D printing, (Ramli *et al.* 2015) came out with a concept system. The concept was about low cost 3D printers that are integrated with a plastic waste recycle machine which can produce filament with only one cycle of process. In addition, the cost of feedstock for 3D printing were reduced along with the energy used because of the proposed system did not use filament, but fed directly from the shredded plastic waste as the source of the recycle machine.

2.3 Parameter Optimization

In order to optimize manufacturing process, there are several important criteria need to be an attention. Different strategies have been utilized to improve this procedure, for example, genetic algorithm, geometric programming, geometric plus linear programming, disperse seek strategy, and reaction surface system. For 3d printer recycle machine, the important parameter need to optimize is their pressure, temperature and the material using. (Udroiu & Nedelcu, 2011) say that some extruding parameters must be optimized, such as pressure, temperature control and material consumption.

2.3.1 Taguchi Method

Genichi Taguchi, Japanese engineer proposed the Taguchi method is an advancement approach that contains exploratory outline and factual examination to enhance the item quality by coordinating quality control at the planning stages (Shrestha & Manogharan, 2017). This strategy accomplishes by making the item or process execution coldhearted to varieties in components, for example, materials, manufacturing hardware, workmanship and working conditions. The fundamental objective is to present the impact or advantage of the procedure as a component of certain plan factors with a general target to amplify or limit the estimation of the capacity inside the manufacturing procedure. Figure 2.1 show example table of Taguchi method included the parameters.

Figure 2.1: Example of Taguchi method table (Shrestha & Manogharan, 2017)

Table I. Printing parameters with their ranges and values at three levels

Parameter design	Printing parameters	Range	Level 1	Level 2
A	Saturation	35–100%	35	70
B	Layer Thickness	80–120 μm	80	100
C	Roll Speed	6–14 mm/s	6	10
D	Feed-to-Powder Ratio	1–3	1	2

2.4 Injection Moulding

Injection moulding is a manufacturing technique for making parts from thermoplastic and thermosetting materials. Injection moulding can be referred as a process to solidify molten material inside a mould. This process is basically using screw mechanism that pushes the material through the cylinder with heating element into the mould. Various materials can be used with injection moulding depending on the required product to produce and this manufacturing method is suitable and reliable. Various issues identifying with cost, exactness, and quality of 3-D items should be overcome before this innovation can accomplish across the board appropriation. (Sherman, 2009) stated that in terms of cost, materials suitable for 3-D printing can run 10 to 100 times more than typical injection molding thermoplastics.

2.4.1 Process Elements

The fundamental process for injection moulding is part formation in the mould cavity from injected molten polymer that is compressed and forced into a die after being compressed inside the heated barrel (Berman, 2012).

There are four significant units involve in the injection moulding process which are hopper, injection unit, control unit and the clamp unit. Hopper is mainly to shred material into little pieces or bits before being melted in the injection unit. In the injection unit, there are heating and melting elements followed by pumping and material injection into the mould cavity. Then the control unit has the task to monitor and control the injection unit. Finally the clamp unit that has ejecting plate is used for clamping the mould and ejecting solidifies material inside it. Another source states that 3-D printing is competitive with plastic injection molding of runs around 1,000 items (‗Print Me,‘‘ 2011).

Figure 2.1 illustrates the units involved including the important units for single stage screw machine in injection moulding process.

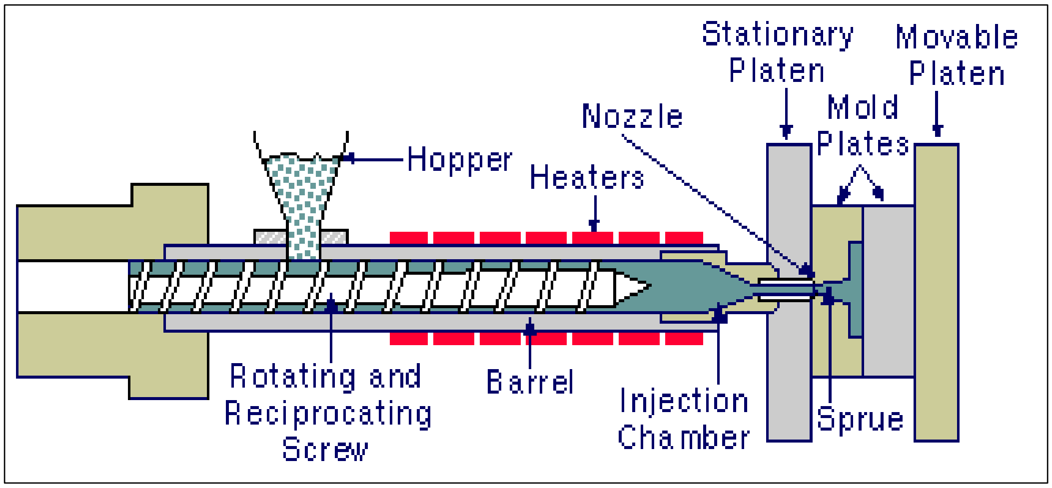

Figure 2.2: Single Stage Screw Machine (*dc.engr.scu*)

2.5 Filament

As we know 3D printing is additive manufacturing that build a product layer by layer by using plastic as their raw material that call filament. There are two types of filament that are commonly being used in 3D printing which are Polylatic Acid (PLA) and Acrylonitrile butadiene styrene (ABS). There are lots of materials that had been explored for 3D printing because of its characteristic which is thermoplastic. Two recent open-source equipment innovative improvements, 3-D printers and RecycleBots, offer another way to deal with polymer reusing enveloping the potential for disseminated handling to high-value included items. (Kreiger *et al.,* 2014) stated that this can reverses the historical trend towards centralized recycling facilities. Commercial 3-D printers, which allow for accurate fabrication of merchandise or scale fashions, are a beneficial production and design tool.

Manufacture of feedstock with RecycleBots from post-purchaser plastic likewise can possibly reduce the natural effect of 3-D printing, and may give a motivating force to conveyed, in-house reusing of plastic (Pearce *et al.* 2010).

2.5.1 Characteristic of PLA and ABS

Both PLA and ABS do have similarity especially in the way they are used in 3D printing. But there are also differences between them, advantage and disadvantages also the fields of application for those two materials. Table 2.1 summarize the characteristics of PLA and ABS.

Table 2.1: Characteristics of PLA and ABS

CHARACTERISTICS	**PLA**	ABS
Melting temperature (°C)	160-190	210-240
Printing temperature (°C)	190-220	230-250
Printbed temperature (°C)	50-70	80-120
Printbed	Not necessary	Compulsory
Cooling system	better in printing	Not required
Biodegradable	Yes	No
Mechanical properties (Durability, malleability, flexibility)	Good	Excellent
Post-processing	good	Excellent
Field of application	Household items, toys, gadgets	Interlocking parts, pin-joints

Figure 2.3 shows the physical comparison on the surface of finish parts that were printed with the identical original 3D CAD dimension. On the left side was printed using black PLA while on the right side was printed with black ABS.

Figure 2.3: Surface finish comparison of printed parts using PLA (left) and ABS (right) *(cubex3dprinting.blogspot.my)*

2.6 Polymer

Reasonable, sturdy and lightweight are the featured qualities for this plastics that are synthetically made with various rehashing units. Polymer has a lot of commitment since it is dependably been picked as the material utilized as a part of assembling businesses. That is the reason generation of polymers have increment essentially to meet the requests of different producers. Regarding to the finding from (Wendel *et al.*, 2008), due to increased globalization and the resulting price fight among competitors, products must achieve shorter payback periods. Moreover, higher requests are made for opportunity of item plan and expanding geometric part multifaceted nature.

There are few types of polymers being produced which are thermosets, elastomers and thermoplastics. The focus of further description and explanation will be onto thermoplastics. This is because it is related to this project by which means the characteristic of the filament being used for 3D printing and also for recycling are basically made of thermoplastic family.

2.6.1 Thermoplastics

Thermoplastics can experiences a few sort of procedures by warming which are softening, liquefying, molding, framing and welding. Not to overlook, it can be chilled off to make it strong. In any case, need to recollect, before preparing the thermoplastics, it should be dried legitimately with the goal that it don't discharge gasses or water vapor. A few cycle of rehashed warming and cooling procedures would not influence the properties of thermoplastics. Because of that, thermoplastics can be reused and reprocessed. Indeed, even the squanders are halfway reusable as crude issue as a result of the physical softening and liquefying are reversible.

Current FDM technologies available commercially possess some limitations on the use of a variety of the materials that can be easily processed using this technology. (Mohan *et al.,* 2017) said that with this limitation, only thermoplastic polymers and some materials of low melting point are found to be most suitable materials for this technology. As the thermoplastics is spent as fiber, the primary focal points and disservices of this sort of polymer are obligatory to be recognized. Table 2.2 shows the advantages and disadvantages of thermoplastics.

Table 2.2: Advantages and disadvantages of thermoplastics

ADVANTAGES	DISADVANTAGES
Welding and thermoforming are allowed by heating	Increasing temperature causes modulus holding to decrease
No chemical reaction of crosslinking allows very fast process cycle.	Trail and moderation manner are not as good as thermosets when temperature increases.
Easy process monitoring due to only physical transformation	In fire, fusibility prefer dripping and destroys final residual physical solidarity.

2.7 Polymer Recycling

Changing procedure for misuse of plastics into useful items is alluded to plastic reusing. The state of reused plastics, as far as structure properties may not be as indistinguishable figuratively speaking before being reused. Because of the presence of non-biodegradable plastics, it uncommonly has increment the need to reuse the plastic waste to forestall harm to the earth. The reuse procedure is impossible haphazardly, yet should be particularly following the class or code for plastics that are alluded to in reusing polymer.

(Hunt *et al.* 2015) expressed these patterns demonstrate that more people will produce their own particular polymer items; however, there is a hazard that a much bigger fraction of polymer waste won't be reused because it has not been coded.

2.7.1 Code Identification of Plastics

There are seven gatherings of plastics in polymer, with each having particular properties. These properties are utilized as a rule in bundling applications. A number or a letter is sketched out for each gathering as a code as indicated by the Plastic Identification Code (PIC). These codes go about as the aides for uniform ID arrangement of different class of polymers. Table 2.3 demonstrates the PIC with its properties, material and their application.

Table 2.3: Plastic Identification Code (PIC) with properties, material and their applications. Form (http://oss.aliyuncs.com)

Code	Material	Applications
1 PETE OR 1 PET	Polyethylene Terephthalate	Clear soft drink and beverage bottles, food packaging
2 HDPE OR 2 PE-HD	High Density Polyethylene	Bottles(especially for food products, detergent and cosmetics), industrial wrapping and film, sheets, plastic bags
3 V OR 3 PVC	Polyvinyl Chloride	Bottles packaging film, credit cards, water containers, water pipes.
4 LDPE OR 4 PE-LD	Low Density Polyethylene	Cling film, plastic bags, flexible containers and food wrap
5 PP	Polypropylene	Packaging such as yoghurt and margarine pots, sweet and snack wrappers, medical packaging, milk and beer crates, shampoo bottles
6 PS	Polystyrene	Disposable hot or cold drink cups and plates, fast food clamshells, dairy product containers
7 OTHER OR 7 O	All other resins and multi-materials not otherwise defined	Other resins, complex composites and laminates

2.7.2 Filament Recycling

Filaments are made of PLA and ABS. They are ordered in bunch 7 as different tars and multi materials. To reuse these materials, it has to take after every particular property because of blend of plastics. The go for reusing the fiber is chiefly to support the generation of fiber to meet the requests of 3D printer clients. Other than that, it is obviously to diminish the measure of plastic squanders because of disappointment in printing items and keeping it as a financially savvy creation process.

(Kreiger *et al.* 2014) stated that the processes involve in transforming plastic wastes of 3D printing into usable filament are shredding and extruding. MakerBot and Filamaker had as of now start the mission to reuse the plastic squanders. From that point, different open source designers took after their means in improving the reuse innovation and agree to the objective to lessen the effects to the earth. One of the created frameworks is Lyman Filament Extruder that can be found at thingiverse.com, while some others are appeared at instructables.com. The working expense of the RepRap can be additionally decreased by lessening the cost of the feedstock. Manufacture of feedstock from waste plastic would bring down expenses and lessen the ecological effect of rapid prototyping (Baechler *et al.* 2013).

2.8 Tensile Test

Tensile testing, also known as tension testing is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are specifically measured by means of a ductile test are extreme elasticity, breaking quality, most extreme extension and lessening in zone. From these estimations the accompanying properties can likewise be resolved: Young's modulus, Poisson's proportion, yield quality, and strain-solidifying attributes (Tanikella *et al.*, 2017).

Uniaxial elastic testing is the most regularly utilized for acquiring the mechanical qualities of isotropic materials. A few materials utilize biaxial tractable testing. The examples of filament are tried for elasticity strength during tensile test. The outcomes are displayed and conclusions are drawn about the mechanical properties of different melded filament manufacture materials. The examination exhibits that the elasticity strength of a 3D printed specimen depends to a great extent on the mass of the specimen, for all materials (Mohan *et al.,* 2017). Figure 2.4 show the test specimen nomenclature.

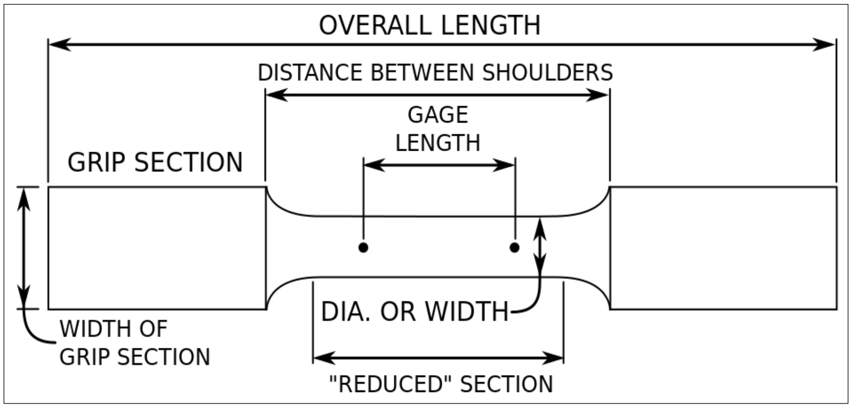

Figure 2.4: Nomenclature of a tensile test specimen. From (www.azom.com)

2.8.1 Tensile Specimen

A tractable example is an institutionalized specimen cross-area. It has two shoulders and a gage area in the middle. The shoulders are substantial so they can be promptly held, while the gage segment has a littler cross-segment with the goal that the deformation and failure can happen here. The shoulders of the test specimen can be manufactured in various ways to mate to various grips in the testing machine (see the figure 2.5). While decision must be made for the settings and task of each testing and in addition the nature of polymer filament utilized, practically solid parts can be made with open-source 3D printers inside the limits of their mechanical properties (Tymrak *et al.* 2014).

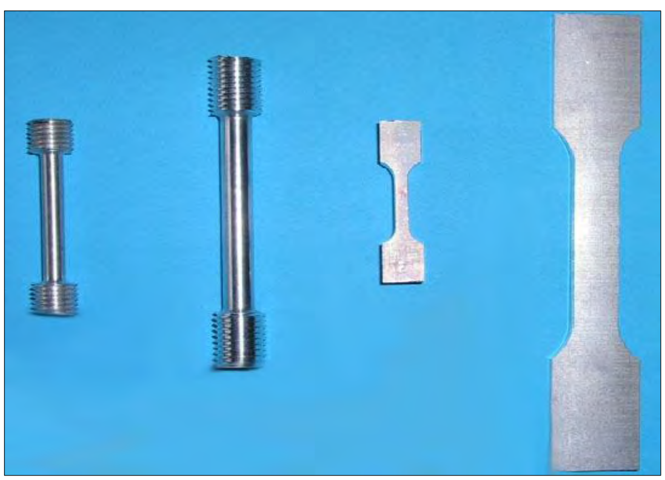

Figure 2.5: Example tensile specimen from (https://en.wikipedia.org)

2.9 Minitab Software

Minitab is a command and menu driven programming bundle for factual investigation depends on insights and hard information to give process change. Using a progression of apparatuses, techniques, and information positions, prepared experts can decide issues inside a procedure, how every issue can be redressed, actualize the fundamental changes, and after that screen the situation. The software Minitab for Window can used for multiple regression analysis of the experimental data obtained (Gao & Gu, 2007). The example of analysis model using MINITAB Software is shown in Figure 2.6.

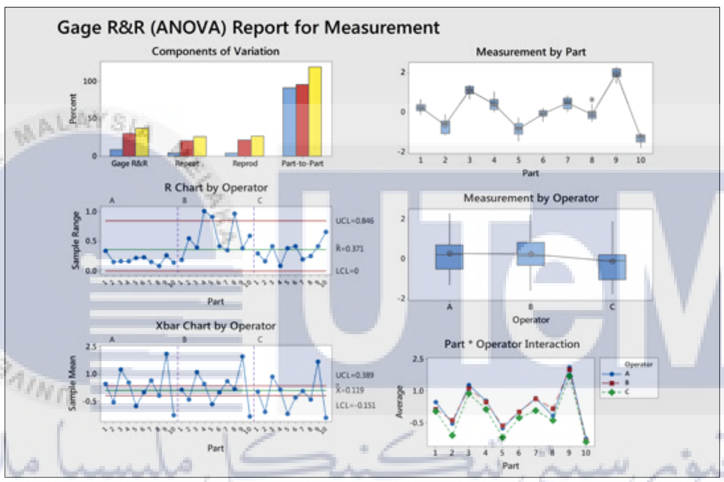

Figure 2.6: Example of analysis model by using Minitab software.
(http://www.inprolink.com)

2.10 Plastic Decomposition Technique

Decaying or breaking down materials is referred to decomposition process. This process plays a crucial part in recycling plastic waste from failed prints of 3D printing. This is because most of the waste might be in big chunky form or at least in a solid hard state. That is why breaking down the plastic waste into smaller form or even better as fine flakes is necessary. By doing so, it will help in better recycling process afterward without having to worry about the possibility for the machine to face a problem. (Cruz *et al.* 2012) state that the procedures for modeling the life cycle of recycled plastics can be decomposed in four phases material, process, evaluation and recycling for multiple processing (see figure 2.7).

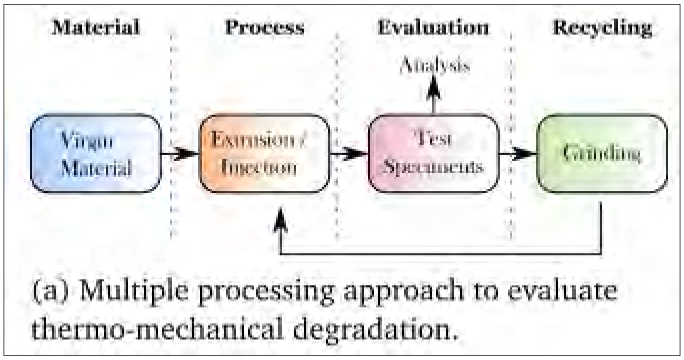

Figure 2.7: Multiple processing approach to evaluate thermo-mechanical degradation. From a review in Macromolecular Materials and Engineering (2008)

2.10.1 Plastic Shredder

Plastic shredder is commonly built with a set of rolling shafts, each with a series of blades or gear-like shredders. It is built with almost no space in between the gears to ensure that every plastic waste is break down as fine as it could be. Plastic shredder normally has two open spaces which are one for waste inlet and the other one is for shredded waste or flakes. Figure 2.8 shows the example of mini plastic shredder that is in process of shredding a plastic material.

Figure 2.8: Example of plastic shredder. From (https://i.pinimg.com)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, it will explain the workflow and also the methods that are being used to of the optimization on 3D printer recycle machine. This chapter will focus on what kind of method being used to obtain the necessary data for the topological optimization process. This project is initiated by doing study and research of the related fields and projects including the previous 3D printer recycle machine.

The reason for the study is to get the idea and true understanding how this project can be done in the correct and efficient way so that a better recycle machine can be produced. At this stage, the knowledge gained from the syllabus on mechanical engineering can be applied. As can be observe in the flow chart provided in figure 3.1 and figure 3.2, the flow is the step required to have the maximum result to optimize the parameter in 3D printer recycle machine.

3.2 Flow Chart

3.2.1 PSM I

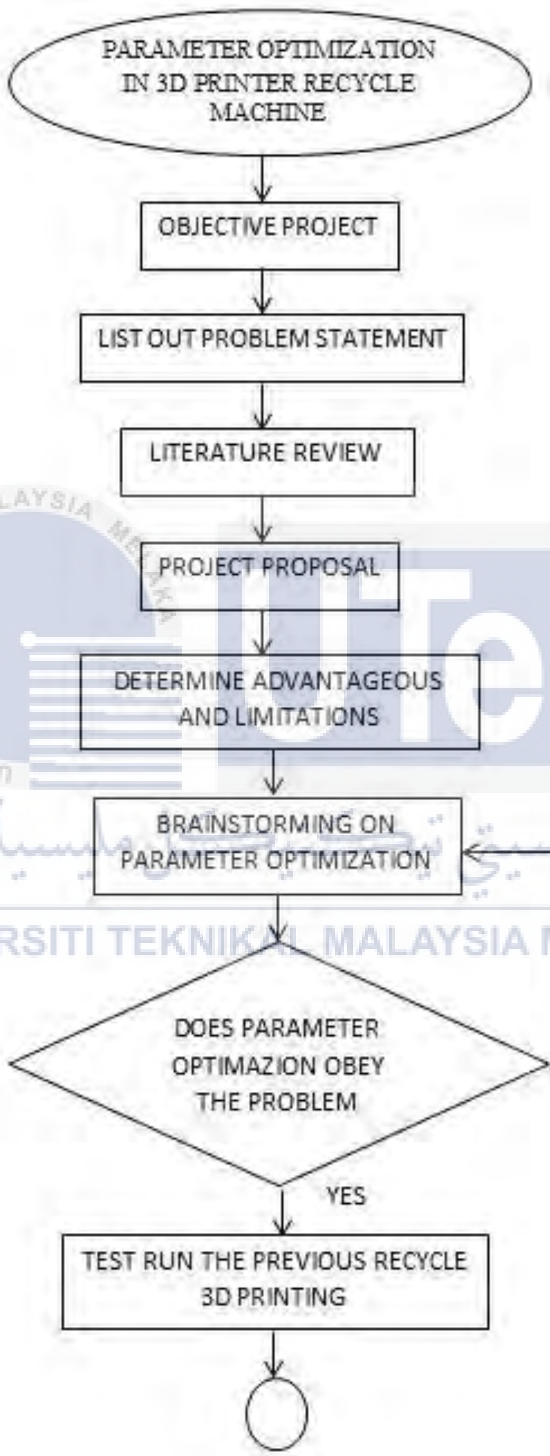

Figure 3.1: Methodology flow chart for PSM I

3.2.2 PSM II

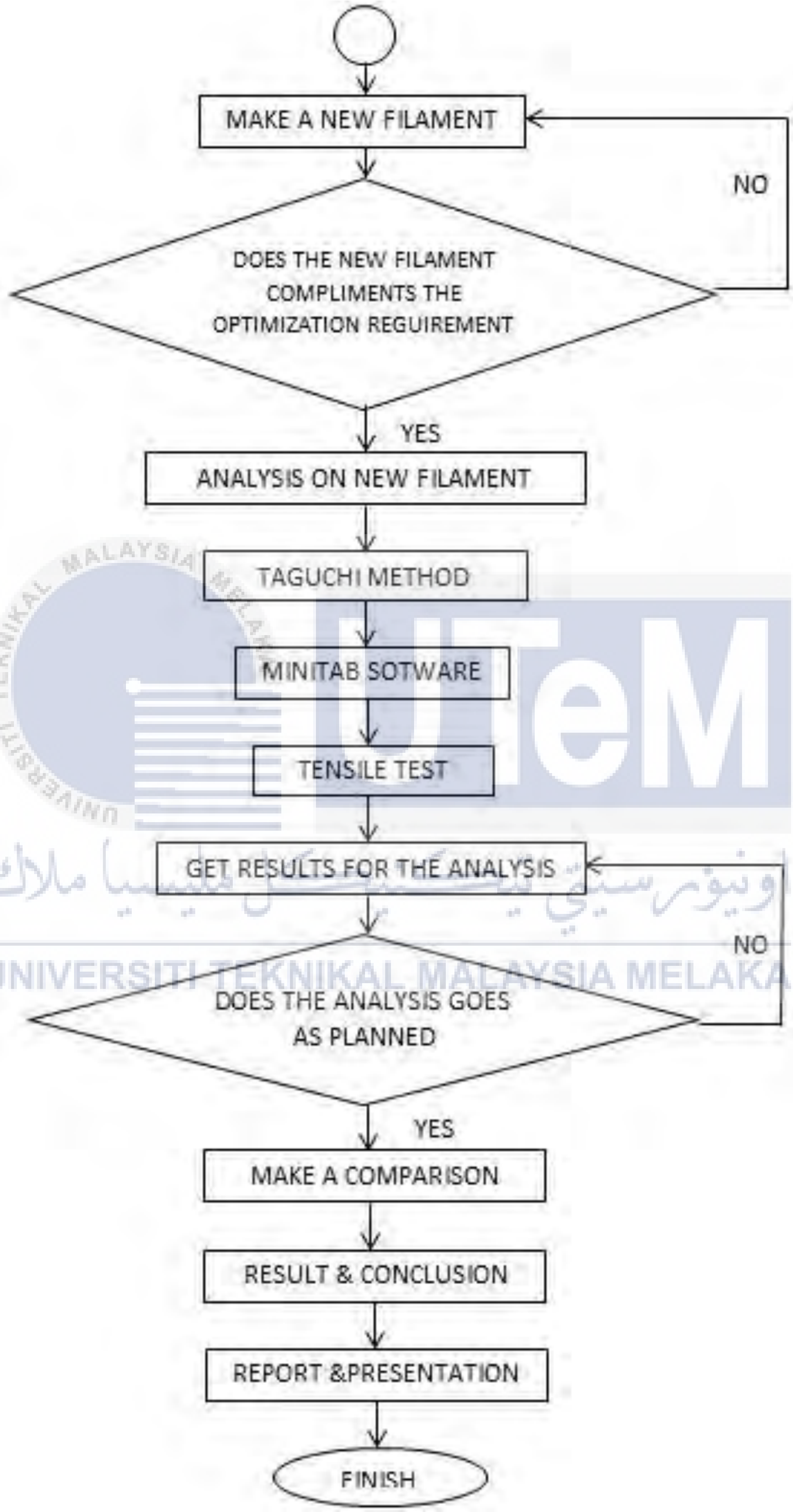

Figure 3.2: Methodology flow chart for PSM II

3.3 Methodology Description

In this project to analysis and order to meet the objective of the project, the design will consist of several parts of subsection. In the subsequent sections, each subsystem will be discussed in term of collection of theories, concepts, ideas, criteria, calculation and selection of the project specifications. To achieve these, the following methods will be followed closely. Below show the most viable research method.

3.3.1 Project Proposal

The first step in this project is preparing proposal project that will introduce on the project. The content of this proposal include project title, introduction, objective, scope, problem statement, and methodology. By this proposal, advantageous and limitations of this project can be identify.

3.3.2 Project Planning

Project planning is the planning in terms of timeline of every week on how the project will be done throughout. Project planning are separated with 2 section which is project planning for PSM I and PSM 2. The appendix will show the project planning in actual and planned for this whole project.

3.3.3 Literature Review

The initial stage of the project is based solely on research whereby data and information are obtained through various ways, such as internet, book, journal, research paper, convention and more. This conduct our literature review by others regarding of parameter optimization of 3D printer recycle machine.

The literature review in previous section was carried out by dividing into 10 subtopics. The first subtopic is discussed and explained about Rapid Prototyping or 3D printing. The function, types, material used is obtained by other research journal. The second subtopics are about recycle system integration, idea for recycle waste material. This idea or concept can recycle waste filament to reduce the cost of feedstock for 3D printing.

The third subtopic is about parameter optimization on 3D printer recycle machine. The explanation on what is optimization and type of method that used in this project is discussed. Optimization is on previous recycle 3D printing machine (Filastruder). On the next subtopic is discussed about injection moulding. This process is injecting a molten material inside a mould. Filastruder is a recycle 3D machine that used a single stage screw principle to extrude a new filament.

Next, only the fifth subtopics are discussed about material that used in 3D printing is filament. Polylatic Acid (PLA) and Acrylonitrile butadiene styrene (ABS) is a commonly type of filament used in industry. Many characteristic that list between (PLA) and (ABS), for this project (ABS) filament is using for comparison to new recycle filament. The sixth and seventh subtopic are discussed about polymer and recycle process. The sixth subtopic is discussed about advantages and disadvantages of thermoplastic. There are many code identification for plastic in different material to easy to split them used for recycle process.

Subtopic eighth and ninth is focused on how to get a data and result for this project. An analysis is making for new recycle filament by using Minitab software and tensile test to compare the mechanical properties between original filaments. Lastly, decomposition process is about decaying waste material such as failed prints of 3D printer. This important because most of the waste might be in big chunky form or at least in a solid hard state that can affect to Filastruder to extrude a new filament.

3.3.4 Analysis

The first thing to be done on recycle 3D printer is the analysis. The data will go through analysis for a new filament that extruded by Filastuder. An analysis is making by used Taguchi method in Minitab software. Minitab was used to define a statistical analysis and hard data to provide a process improvement. This software also can determine problems within a process, how each problem can be rectified, implement the necessary changes, and then monitor the situation. Figure 3.3 show example data that gained form Minitab software.

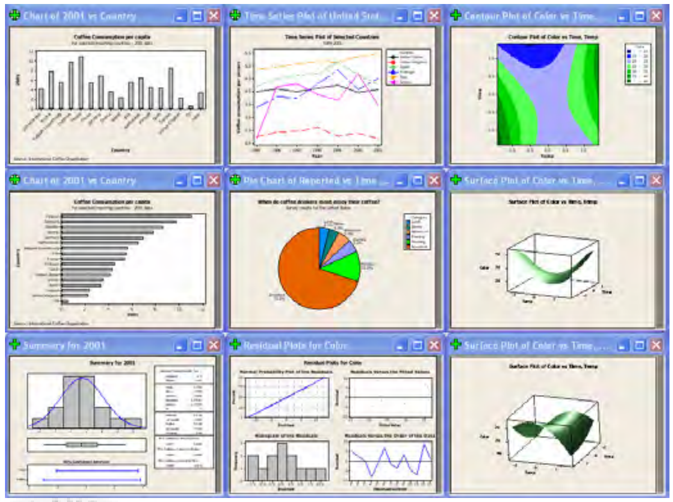

Figure 3.3: Example data obtained from Minitab software.
From (http://kavanaugh.ca)

First thing to do is list important parameters of recycle 3D printing to extrude a new filament. From these parameters, Taguchi method will use to design a suitable orthogonal array experiment for extrude a new filament. There are three parameters listed in this research with is a power, speed and temperature with three level experiment. L9 orthogonal array design is used to conduct this experiment. The information needed to get from this experiment is an average diameter of every nine experiment results. Measurement for each filament‘s diameter is done by using vernier caliper for every 50mm. After that, this data will be entered into the Taguchi method to obtain the result the optimal process parameter values. Result that can obtain from Taguchi method is analysis of the signal-to-noise and analysis of variance. This analysis is to investigate which of the process parameters significantly affect the performance characteristics.

To obtain optimal machining performance, the lower-the-better performance characteristic for diameter of filament should be taken for obtaining optimal machining performance. Taguchi method also can give the predicted regression equation to determine the optimal diameter for extruding filament. After the suggested parameters value is get, these value parameters will use to extrude a new filament more than 3m to printing process.

Another analysis is obtained from tensile test for new filament and original filament. From these estimations the going with properties can be resolved is strain-hardening traits, yield quality, Poisson's extent, and Young's modulus. The data have collected to compare the performance of new recycle filament. Figure 3.4 show the shape of ductile specimen at various stage of testing.

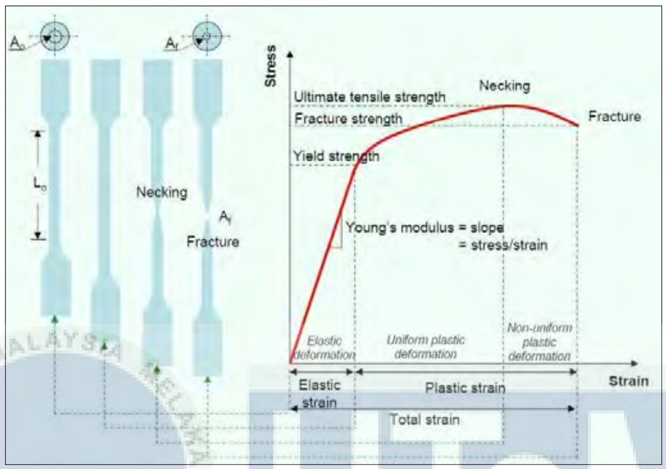

Figure 3.4: Tensile test analysis data. From (http://practicalmaintenance.net)

Some formula is using in in order to collect data from tensile test such as determined stress, strain and young modulus.

$$\text{Stress} = \frac{\text{force}}{\text{area}} \qquad \text{Equation(3.1)}$$

$$\text{strain} = \frac{\text{length of strecth}}{\text{original length}} \qquad \text{Equation(3.2)}$$

$$\text{young modulus (€)} = \frac{\text{stress}}{\text{strain}} \qquad \text{Equation(3.3)}$$

The aim of this analysis is to produce theoretical data. Based on the theoretical data, only the parameter optimization can be performed. Analysis data also needed to compare the data of new recycle filament and data of general filament that commonly used. In order to get a new recycle filament with occupied a specification of great filament. The filament is used thermoplastic material and other waste polymer material. It will be different from original filament. However, this is just to compare mechanical properties with between two filaments.

3.3.5 Extruding Process

In this research, error printed product (ABS) will use to be recycle filament to compare with original filament (ABS). First, the raw material should be chopped in small form to put in Filastruder for easier melting process. Filastruder machine is set up by follow all the parameters such as power, speed and temperature from Taguchi optimal extruding parameters suggestion. New filament that extrude from Filastruder need more than 3m use for print the test specimen. After that, make the measurement of average diameter of new filament every 300mm by using vernier calliper. From this data, the percentage of error will be obtain to know the accuracy dimensional of new extrude filament compare to dimensional original filament. The formula used was:

$$Percentage\ of\ error\ (\%) = \frac{Diameterexperimental - Diametertheoritical}{Diametertheoritical} \text{ X } 100$$

Equation(3.4)

3.3.6 Printing Process

After get the new filament from extruding process, that filament will use for next step is printing process. Fused Deposition Modelling (FDM) is used to print the specimen test by using these two materials (ABS) filament and new recycle filament. Product will print with same polar print, infill density, layer thickness, dimension and printing setting. Kossel is an open source of Fused Deposition Modelling machine made by previous student is used to print the product. The product to print is a dog bone or specimen test for tensile test to obtain a mechanical properties such as stress, strain and young' modulus.

3.3.7 Report Writing

When every aspect of this thesis is finish, all the data that gather were satisfactory and the comparison between theoretical and experiment data are at acceptable range then the objectives are achieved, documentation is proceed. Report writing function is to document everything that was done from the start to the end of the whole project. All data concerning the analysis and physical experiment will be tabulated and discuss thoroughly.

3.4 Summary

In this chapter, the methods to complete the project are discussed throughout. In order to meet the objectives of this project, many subsystems need to be considered. Hence, steps to accomplish and many of subsequent section which to deal will be described from start to end of the project. This method can be divided into two main sections which is PSM I and PSM II. Part one process is about project outline, project proposal, project planning, literature study and analysis of the product. After part one is complete, only part two which is for PSM 2 is conducted. Part two is to investigate parameter optimization to the recycle machine and the result is obtained from the filament produced. The analysis data obtained are then tabulated and compared to get the result. The last part is about report writing of the thesis with all the information gathered.

CHAPTER 4

RESULT AND DISCCUSION

4.1 Introduction

In this chapter, the new recycle filament extrude form Filastruder are being analyzed. This process includes the steps from shredding material until the printing specimen test before it being analyzed. Fused Deposition Modelling (FDM) is used to printing a product by using new recycle filament (ABS) and original filament (ABS). Data will gain from experiment test and software analysis to compare these two materials.

4.2 Experimental Setup

Extruding is the first most common method for making a filament of 3D printing machine. In a reusing operation, its necessary task to pick extruding parameters for achieving high extruding performance. Usually, the required extruding parameters area unit determined supported expertise or by use of a reference book. Extruding parameters area unit mirrored on diameter of filament, surface texture and dimensional deviations of the filament. A dimensional deviation, that is employed to work out and to gauge the standard of a filament, is one in all the main quality attributes of associate extruding filament.

To select the extruding parameters properly, many mathematical models supported regression or neural network techniques are created to determine the connection between the extruding performance and extruding parameters. Then, associate degree objective operate with constraints is developed to resolve the best extruding parameters victimization optimization techniques. Therefore, significant data and skill square measure needed for this approach. During this study, another approach supported the Taguchi methodology is employed to see the required extruding parameters additional potency.

The first objective of this studies is to illustrate a use of the Taguchi parameter layout so that it will become aware of the optimum dimensional deviations overall performance with a specific aggregate of extruding parameters in a recycling operation. A top level view of the parameter design based totally at the Taguchi approach is given first. Then, the parameter layout with the multiple overall performance characteristics is delivered. The experimental detail of using the parameter design to determine and analyze the most desirable parameters in extruding operations is described next.

4.2.1 Taguchi Method

The objective of the parameter design is to optimize the settings of the technique parameter values for improving performance characteristics and to perceive the product parameter values beneath the foremost technique parameter values. In addition, its miles anticipated that the best technique parameter values obtained from the parameter design are insensitive to the version of environmental situations and other noise factors. Consequently, the parameter design is the key step within the Taguchi technique to attaining excessive exceptional without increasing value.

Normally, classical parameter layout is complex and no longer right to use. Mainly, a large wide variety of experiments need to be completed while the variety of the procedure parameters increases. To remedy this mission, the Taguchi technique makes use of a special layout of orthogonal arrays to have a look at the whole parameter space with a small quantity of experiments handiest. Figure 4.1 show the Taguchi design from Minitab software. The deviation between the experimental value and the desired value is calculated by a loss of function. Taguchi recommends to degree the overall performance characteristic deviating from the desired value by using the loss function.

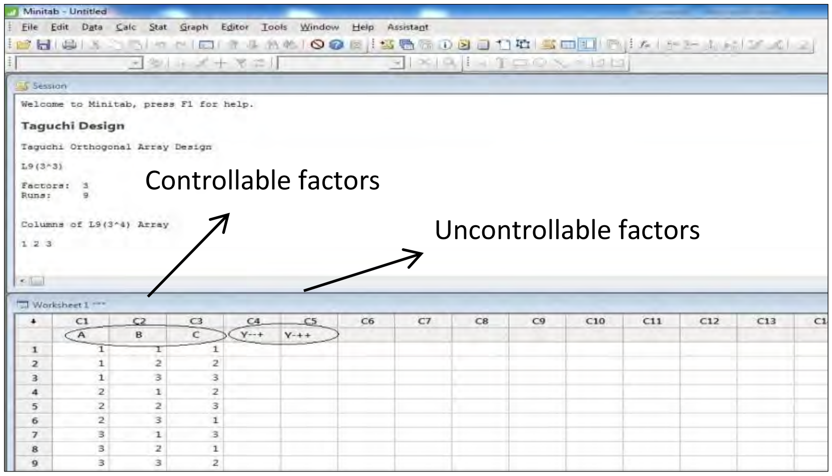

Figure 4.1: Taguchi orthogonal array design.

Signal-to-noise (S/N) ratio ŋ is similarly transformed from the value of the loss function. There are 3 classes of the performance function inside the analysis of the S/N ratio, that is, the lower-the-better, the higher-the-better, and the nominal- the-better. The S/N evaluation is computed primarily based from the S/N ratio for each level of system parameters. Regardless of the category of the performance characteristic, the bigger S/N ratio corresponds to the better overall performance characteristic. Therefore, the most effective degree of the manner parameters is the level with the biggest S/N ratio ŋ.

However, to see which process parameters are statistically significant a statistical analysis of variance (ANOVA) is performed. The optimal combination of the process parameters can be predicted by using S/N and ANOVA analyses. Then, a confirmation experiment is conducted to affirm the top-quality process parameters received from the parameter design. Figure 4.2 below shows the performance characteristic in the analysis of the S/N ratio.

$$\text{Nominal is the best: } S/N_T = 10 \log \left(\frac{\bar{y}}{s_y^2} \right) \quad (1)$$

$$\text{Larger-is-the better(maximize): } S/N_L = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right) \quad (2)$$

$$\text{Smaller-is-the better(minimize): } S/N_S = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right) \quad (3)$$

Figure 4.2: Performance characteristic in the analysis of the S/N ratio.
From (M. Nalbant *et al*. 2006)

In which $\bar{y}$, is the average of observed facts, s^2y is the variance of y, n is the range of observations and y is the found records. Observe that those S/N ratios are expressed on a decibel scale. We might use S/NT if the objective is to lessen variability around a specific target, S/NL if the system is optimized whilst the reaction is as big as possible, and S/NS if the device is optimized whilst the reaction is as small as viable. Issue stages that maximize the precise S/N ratio are top of the line. The goal of this research was to produce minimum diameter (mm) of filament in an extruding operation. Smaller diameter values represent better or improved dimensional deviations. Therefore, in this study a smaller-the-better quality characteristic was implemented.

4.2.2 Extruding Parameters and their Levels

Filastruder is a recycle filament machine that use single stage screw method to extrude new filament. Three extruding parameters, power (watt), speed (m/s), and temperature (^{o}C) must be determined in an extruding operation. A common method of evaluating machining performance in an extruding operation is based on the diameter of filament. Basically, diameter of filament is strongly correlated with extruding parameters such as temperature, speed, and power of that machine used. Diameter of filament is not strongly correlated with extruding pressure therefore extruding pressure is not used in this paper.

Right selection of the extruding parameters can gain higher dimensional of latest filament. Therefore, optimization of the extruding parameters primarily based at the parameter design of the Taguchi method is adopted in this paper to improve dimensional in an extrude operation. Based on background study, the melting temperature point for ABS material is 190-260 ^{o}C.

The initial extruding parameters were as follows: a power of 67.5 watt, a speed of 0.003 m/s, and a temperature of 225 ^{o}C. The feasible range for the extruding parameters was recommended by a background study, power in the range 54.0 – 81.0 watt, speed in the range 0.001 – 0.005 m/s, and temperature in the range 215 – 235 ^{o}C. Therefore, three levels of the cutting parameters were selected as shown in Table 4.1. The diameter of new filament must nearest to diameter original filament is 1.75mm.

Table 4.1: Extruding parameters and their levels

symbol	Extruding parameter	Level 1	Level 2	Level 3
C1	Power (watt)	54.0	67.5	81.0
C2	Speed (m/s)	0.001	0.003	0.005
C3	Temperature (^{o}C)	215	225	235

4.3 Determination of Optimal Extrusion Parameters

In this phase, the usage of an orthogonal array to reduce the variety of extrusion experiments for determining the foremost extruding parameters is pronounced. Effects of the extruding experiments are studied by using the usage of the S/N and ANOVA analyses. Based totally on the results of the S/N and ANOVA analyses, best extruding parameters for diameter of filament are received and verified.

4.3.1 Orthogonal Array Experiment

The degrees of freedom are described as the quantity of comparisons between process parameters that need to be made to decide which stage is higher and particularly how an awful lot higher it's miles. To choose the suitable orthogonal array for experiments, the whole degrees of freedom need to be computed. As an example, a three-degree system parameter counts for two degrees of freedom. The degrees of freedom related to interaction between procedure parameters are given through the product of the stages of freedom for the two manner parameters. Essentially, the tiers of freedom for the orthogonal array must be extra than or at the least equal to the ones for the system parameters.

On this observe, an L9 orthogonal array turned into used. This array has twenty six ranges of freedom and it may cope with three-level manner parameters. Each extruding parameter is assigned to a column and twenty seven extruding parameter combinations are available. Therefore, most effective twenty seven experiments are required to observe the complete parameter area using the L9 orthogonal array. Table 4.2 shows the experimental layout for the three extruding parameters using the L9 orthogonal array. Table 4.3 shows the experimental results and S/N ratio of diameter of filament.

Table 4.2: Experimental layout using an L9 orthogonal array

Experiment number	Extruding parameter level			
	C1	C2	C3	C4
	Power (w)	Speed (m/s)	Temperature (^{o}C)	Diameter (mm)
1	1	1	1	
2	1	2	2	
3	1	3	3	
4	2	1	2	
5	2	2	3	
6	2	3	1	
7	3	1	3	
8	3	2	1	
9	3	3	2	

Table 4.3: Experimental results for diameter of filament and S/N ratio

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6
	Power (w)	Speed (m/s)	Temperature (c)	diameter (mm)	SNRA1	MEAN1
1	54.0	0.001	215	2.187	-6.79698	2.187
2	54.0	0.003	225	2.007	-6.05095	2.007
3	54.0	0.005	235	1.800	-5.10545	1.800
4	67.5	0.001	225	2.067	-6.30681	2.067
5	67.5	0.003	235	1.927	-5.69763	1.927
6	67.5	0.005	215	2.087	-6.39045	2.087
7	81.0	0.001	235	2.247	-7.03206	2.247
8	81.0	0.003	215	2.153	-6.66088	2.153
9	81.0	0.005	225	2.027	-6.13707	2.027

4.3.2 Analysis of the signal-to-noise (S/N) ratio

As stated earlier, there are three classes of performance characteristics, the lower-the-better, the higher-the-better, and the nominal-the-better. To gain most reliable machining performance, the lower-the-better overall performance characteristic for diameter of filament must be taken for acquiring best machining performance. Table 4.3 shows the experimental effects for diameter of filament and the corresponding S/N ratio using Eq. (3). For the reason that experimental design is orthogonal, it's miles then possible to split out the impact of every extruding parameter at exclusive degrees.

For example, the imply S/N ratio for the power at degrees 1, 2 and 3 can be calculated by using averaging the S/N ratios for the experiments 1–3, 4–6, and 7–9, respectively. The mean S/N ratio for each level of the opposite reducing parameters may be computed within the comparable way. The imply S/N ratio for each level of the parameters is summarized and known as the suggest S/N response table for diameter of filament (Table 4.4). Similarly, the entire imply S/N ratio for the 9 experiments is likewise calculated and indexed in Table 4.4.

Table 4.4: Response table mean S/N ratio for diameter factor and significant interaction

symbol	Extruding parameter	Mean S/N ratio		
		Level 1	Level 2	Level 3
C1	Power	-5.984	-6.132	-6.610
C2	Speed	-6.712	-6.136	-5.878
C3	Temperature	-6.616	-6.165	-5.945
Total mean S/N ratio = -6.242				

Figure 4.3 shows the mean S/N ratio graph for diameter of filament. The S/N ratio corresponds to the smaller variance of the output characteristics around the desired value.

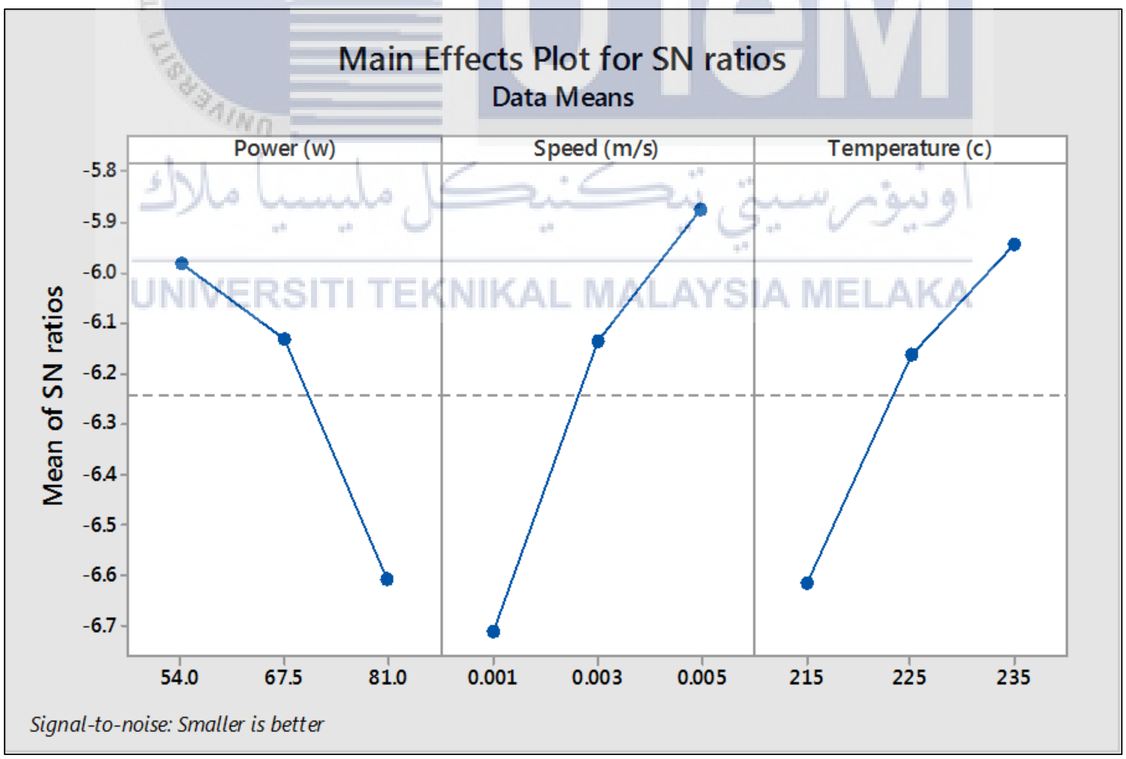

Figure 4.3: The mean single-to-noise graph for diameter of filament.

4.3.3 Analysis of Variance

The reason of the ANOVA is to analyze which of the manner parameters notably affect the performance characteristics. This is performed by isolating the entire variability of the S/N ratios, which is measured via the sum of the squared deviations from the whole imply of the S/N ratio, into contributions by way of every of the technique parameters and the error. Table 4.5 indicates the effects of ANOVA for diameter of filament. It may be found that the speed is the sizable extruding parameters for affecting the diameter of filament. The alternate of the power and temperature inside the range given by table 4.1 has a mere impact on diameter of filament. Consequently, based totally at the S/N and ANOVA analyses, the foremost extruding parameters for diameter of filament are the temperature at level 3, the power at level 1 and the speed at level 3 as show in Appendix A.

Table 4.5: Results of the analysis of variance for diameter of filament.

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Contribution %
Power (w)	1	0.03125	0.031248	5.86	20.90
Speed (m/s)	1	0.05743	0.057428	10.76	38.40
Temperature (^{o}C)	1	0.03420	0.034202	6.41	22.87
error	5	0.02667	0.005335		17.83
total	8	0.14955			100

From analysis of ANOVA, the regression equation to determine the optimal diameter for extruding filament is given below:

Diameter = 3.540 + 0.00535 power (watt) - 48.9 speed (m/s) - 0.00755 temperature (c)

Equation(4.1)

Diameter of filament can be advanced simultaneously through this approach in preference to using engineering judgment. The confirmation experiments have been carried out to verify the most beneficial extruding parameters. The percentage contributions of power, speed and temperature are 20.90, 38.40 and 22.87 respectively. In extruding, use of low power (54.0 watt), high speed (0.005 m/s) and high temperature (235 ^{o}C) are recommended to obtain better dimensional for the specific test range.

4.4 Filament Extrusion

4.4.1 Extruding Process

To complete this process, acrylonitrile butadiene styrene (ABS) such as error printed product is used to be a raw material. The material should be chopped in small form to put in Filastruder for easier melting process. The recycle machine is put on several test runs in order to observe and analyze its condition during the operation. First thing first, the socket is switched on. Then, only the switch for temperature controller is on in order to let the heater band to heat the connector and the end part of barrel evenly. Temperature was set at 235℃.

A small fan is placed near the extrusion system in order to help in reducing the heat transferred from heater band to the upper part of the barrel. Acrylonitrile butadiene styrene (ABS) that are pre-crashed into granules form are prepared. The connector that is projected directly with heat from the heater band can sustain high temperature. The nozzle and the barrel do not have problem to withstand high temperature. For precaution action, a cooling fan is placed near the barrel to prevent the heat to reach the clamp of the barrel and causing it to melt. Figure 4.4 show the Filasturder machine is set to the temperature for that polymer and raw material to use.

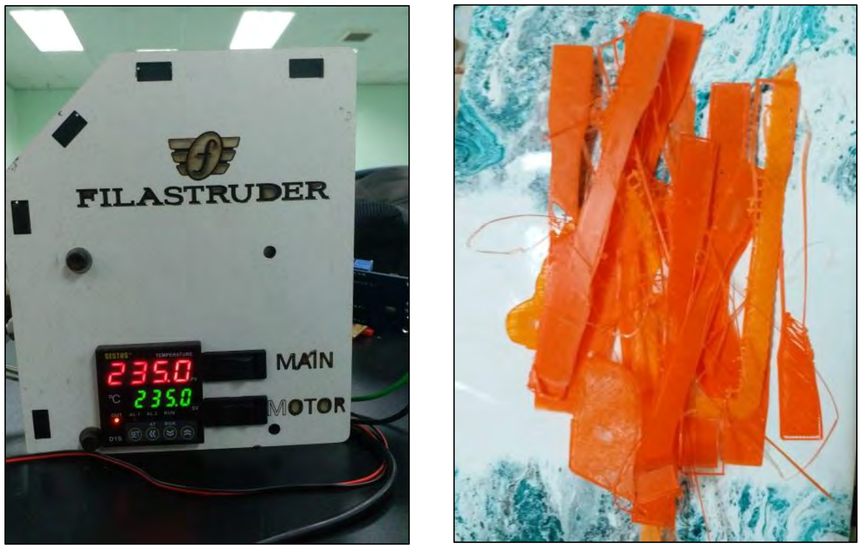

Figure 4.4: Temperature setting for Filastruder and error printed product used for recycle.

The 12V and DC-geared motor rotate the drill bit smoothly without causing friction with the inner side of the barrel. That is possible with the help of the coupler. Then, small amount of the waste granules are poured into the hopper in order to observe and determine the performance of the extrusion system. The motor is turned off for a while in order to let the waste polymer to melt properly before being extruded. Furthermore, this method is to reduce the power required to force extrusion of the non-ready state of waste polymer into a new strand of filament. Besides that, it can help prevent the torque of the motor to cause failure to the motor housing which is 3D printed. Figure 4.5 shows the extruded filament.

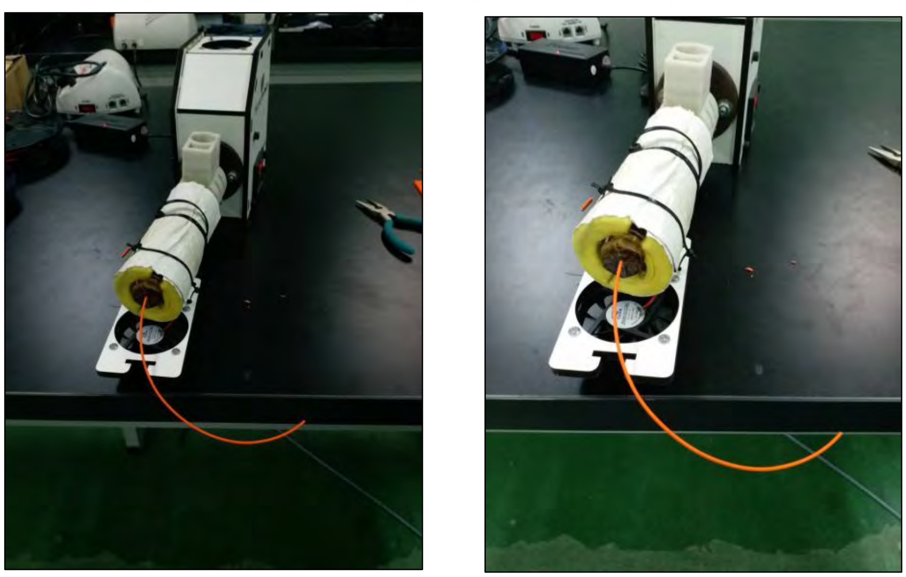

Figure 4.5: Filament extrude out from nozzle.

4.4.2 Extruding Data

In order to optimize the parameter of recycle machine, analyzed must for the size of extruded filament with respect to the standard measurement, diameter of the filament was measured after every 300 mm. New filament will be extruding more than 3m need for print process for printed a test specimen product. Percentage of error is used to calculate the percent value of difference between the experimental and theoretical dimension of the extruded filament with the common filament. The formula used was:

$$Percentage\ of\ error\ (\%) = \frac{Diameter_{experimental} - Diameter_{theoritical}}{Diameter_{theoritical}} \text{ X } 100$$

Equation(3.4)

For each temperature, the readings were taken three times to get the average measurement. Table 4.6 shows the results of percentage error for each set of temperature.

Table 4.6: Results of percentage error for diameter of filament.

Diameter of filament for 300mm	Percentage of error %
1.78	1.71
1.79	2.29
1.81	3.43
1.82	4.00
1.80	2.86
1.80	2.86
1.78	1.71
1.77	1.14
1.78	1.71
1.77	1.14

Measurement for each filament‘s diameter is done by using vernier calliper. All the parameters such as power, speed and temperature is set by follow the Taguchi optimal extruding parameters suggestion. Due to the opening of nozzle was 1.80 mm, the results did not come out as expected. The standard diameter of filament is 1.75 mm, which the extruded filament did not satisfy. From the result of the percentage error, it indicates that all the diameter values are below 5% of error. The lowest error is 1.77mm diameter with 1.14% while the highest error is 1.82mm diameter that equals to 4.00%.

4.5 Printing Process

In this process Fused Deposition Modelling (FDM) is used to print the specimen test by using these two materials (ABS) filament and new recycle filament. Product will print with same polar print, infill density, layer thickness and dimension. Kossel is an open source of Fused Deposition Modelling machine made by previous student is used to print the product. The product to print is a dog bone or specimen test for tensile test to obtain a mechanical properties such as stress, strain and young‘ modulus. Figure 4.6 show an open source machine used for print the specimen test.

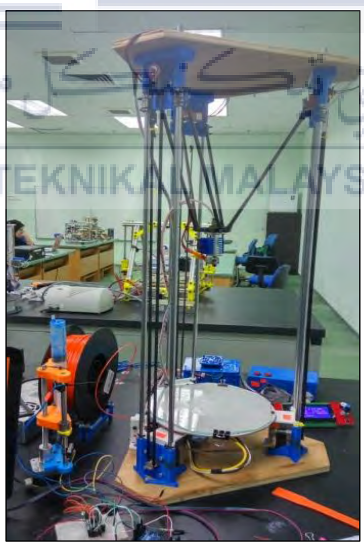

Figure 4.6: Fused Deposition Modelling (FDM) that used to print the product.

Some 3D printing software is easier to learn than others. Repetier-Host is one of the familiar software uses in 3D printing. The design specimen tests is slice a STL file using

Repetier software and then make configure slicing settings such print setting, filament setting, and printer setting. Figure 4.7 show specimen test in STL format.

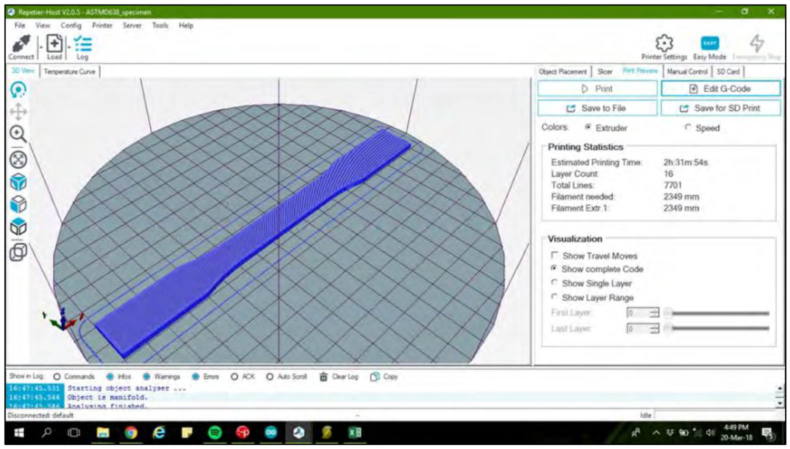

Figure 4.7: Tensile test specimen in STL format.

For the first, original filament is used to print the specimen test and follow by the new extruded filament. After all setting is done; Kossel start print the product with first layer thickness is 0.25mm and follows by next layer 0.2mm. Repetier software can tell how long those filaments need to print the product and the time consumer for that process. Figure 4.8 show the printed process of tensile specimen test.

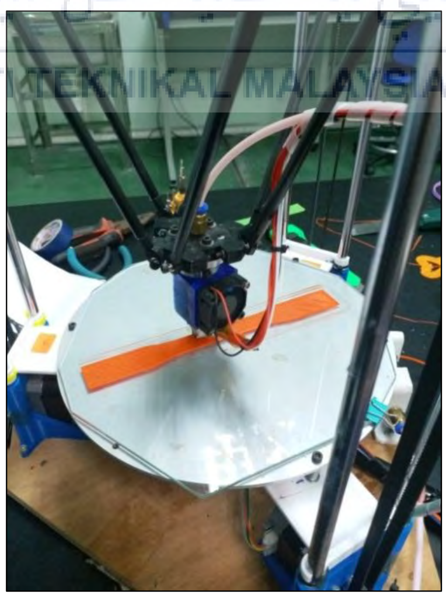

Figure 4.8: Printed process of tensile specimen test.

In order to compare the mechanical properties of two different material of filament, the specimen test must be printed in same print characteristic. Tables 4.7 show the print characteristic of (ABS) filament and new extruding filament.

Table 4.7: Characteristic print of two different filaments.

Dimension	Standardized
Polar print	Rectilinear
Layer height	0.2 mm
Infill density	20 %
Angle	45 ^{o}
Temperature nozzle	220 ^{o}c
Temperature bed	90 ^{o}c

4.6 Tensile Test and Analysis Data

In order to compare the mechanical properties of this two filament, the standardized of specimen test is print by using two different filament which is original filament and new extruded filament. Instron Material Testing machine is using to conduct this experiment to get the value of the mechanical properties show in Figure 4.9. Before test is run, some specification must be set such as thickness and length of specimen and speed of pulling force.

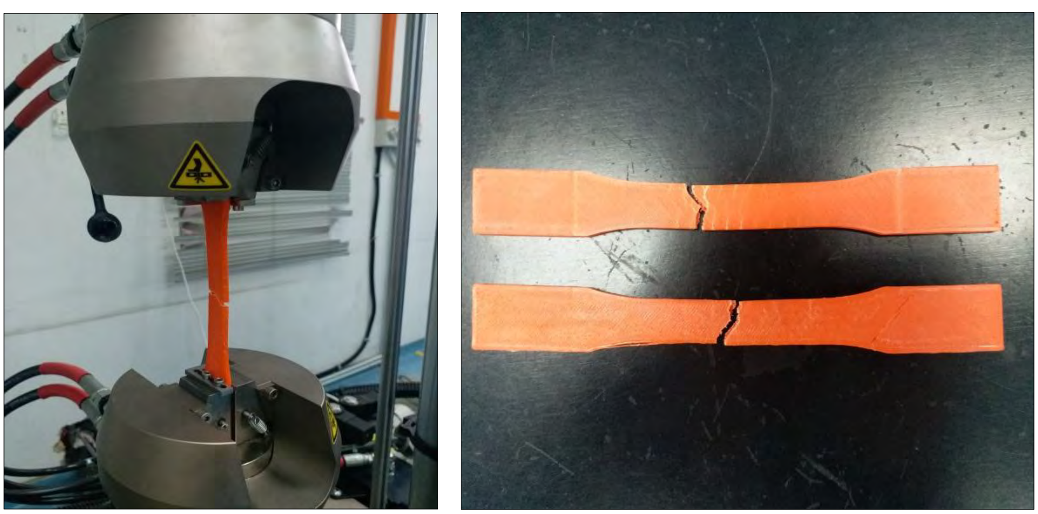

Figure 4.9: Tensile specimen during operation.

The data is collected and summarize in graph tensile stress versus tensile strain. Figure 4.10 shows the plot graph of original filament. The necking point of original filament specimen appears after 3% of extension and slightly decrease before rapture. Figure 4.11 shows the plot graph of new extruded filament. The necking point of new filament specimen is nearly to 3% and extremely decrease to rapture.

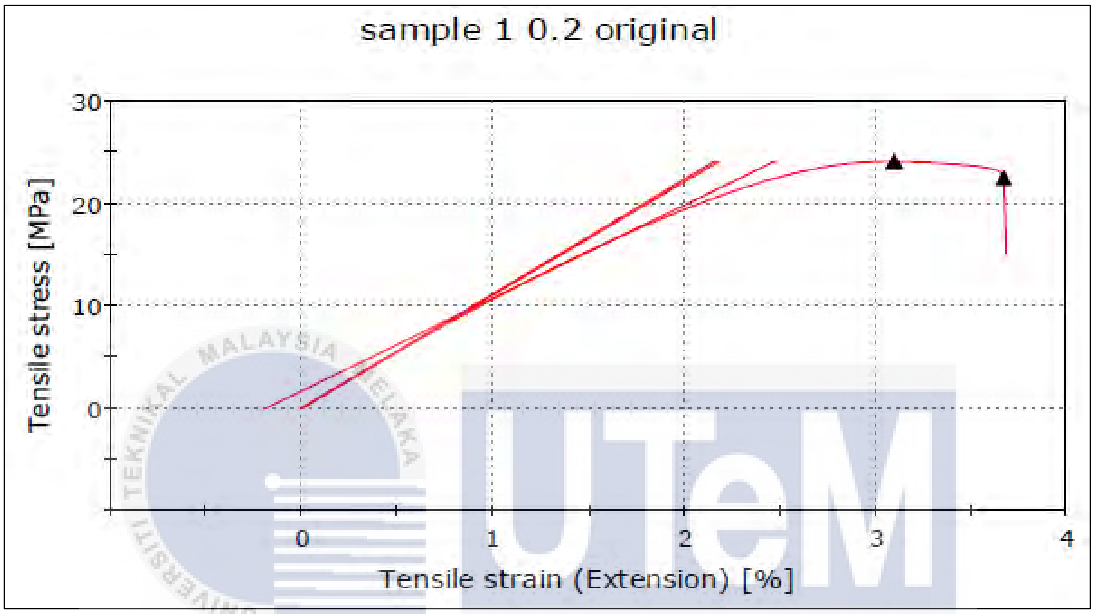

Figure 4.10: Result of original filament in tensile stress versus tensile strain.

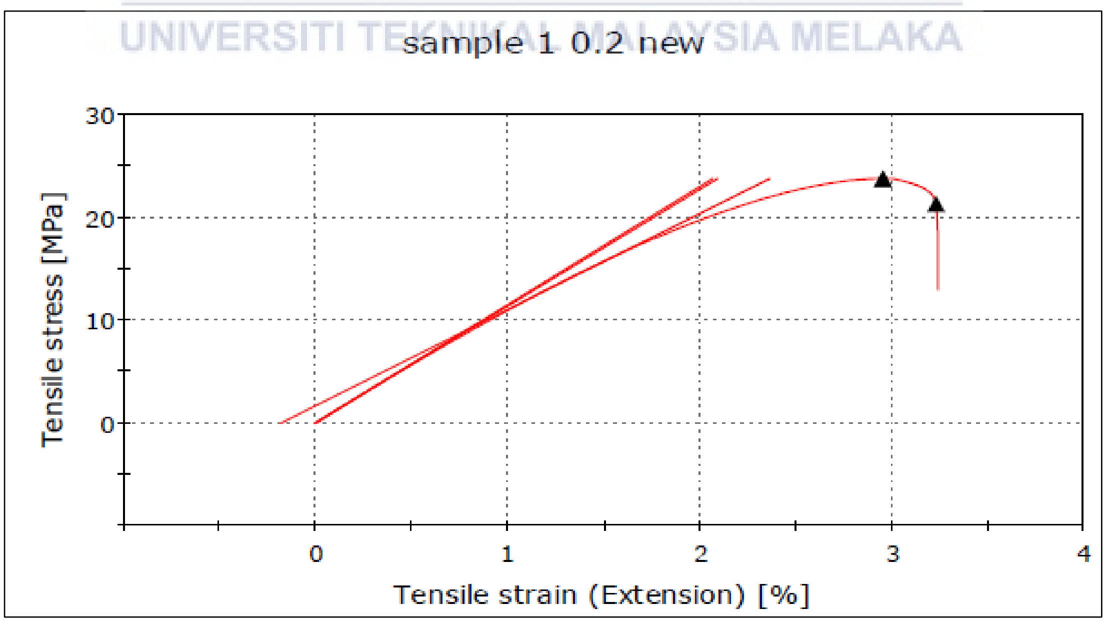

Figure 4.11: Result of new extruded filament in tensile stress versus tensile strain.

For easily comparing the mechanical properties between two filament, Table 4.8 and Table 4.9 shows the value of maximum load (N), tensile stress (MPa), tensile strain (mm/mm), and modulus young‘s.

Table 4.8: Mechanical properties data of original filament specimen.

	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	724.104	24.137	0.0309

	Load at Yield (Zero slope) [N]	Tensile stress at Yield (Zero slope) [MPa]	Tensile strain (Extension) at Yield (Zero slope) [mm/mm]
1	724.10	24.137	0.0309

	Load at Break (Standard) [N]	Tensile stress at Break (Standard) [MPa]	Tensile strain (Extension) at Break (Standard) [mm/mm]
1	676.350	22.545	0.0367

	Extension at Break (Standard) [mm]	Modulus (Automatic Young's) [MPa]	Modulus (Automatic) [MPa]
1	2.5645	1118.917	1105.626

Table 4.9: Mechanical properties data of new extruded filament specimen.

	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	713.517	23.784	0.0295

	Load at Yield (Zero slope) [N]	Tensile stress at Yield (Zero slope) [MPa]	Tensile strain (Extension) at Yield (Zero slope) [mm/mm]
1	713.52	23.784	0.0295

	Load at Break (Standard) [N]	Tensile stress at Break (Standard) [MPa]	Tensile strain (Extension) at Break (Standard) [mm/mm]
1	640.133	21.338	0.0323

	Extension at Break (Standard) [mm]	Modulus (Automatic Young's) [MPa]	Modulus (Automatic) [MPa]
1	2.2575	1150.559	1135.525

From the data of mechanical properties of original filament, the maximum load that specimen can accept is 724.104 (N). For tensile stress at maximum load is 24.137 (MPa) and value tensile strain at maximum load is 0.0309 (mm/mm). For data of mechanical properties of new extruded filament, the maximum load that specimen can accept is 713.517 (N). For tensile stress at maximum load is 23.784 (MPa) and value tensile strain at maximum load is 0.0295 (mm/mm). From data that have collected, modulus young's of this two material can be obtain. Modulus young's for original filament is 1118.917 (MPa) and for new extruded filament is 1150.599 (MPa). Table 4.10 shows the comparison value mechanical properties of these two filaments.

Table 4.10: Comparison value of mechanical properties.

	Original filament	New extruded filament	Percentage %
Maximum load (N)	724.14	713.517	1.47
Tensile stress (MPa)	24.137	23.784	1.46
Tensile strain (mm/mm)	0.0309	0.0295	4.53
Modulus young's (MPa)	1118.917	1150.599	2.83

The percentage given is a percentage difference value of original filament mechanical properties and new extruded filament mechanical properties. It shows that maximum load and tensile stress that these two filaments can absorb is nearly same with only 1.47% and 1.46% of difference percentage value. For changes in the length of the specimen at the maximum load given is shows that original filament is more elasticity than new extruded filament with 4.53% difference percentage value. Modulus young's get from value tensile stress over tensile strain. It shows that modulus young's of original filament is lower than new extruded filament with percentage of difference only 2.83%. Overall, we can conclude that there are only minor differences of mechanical properties of these two filaments.

CHAPTER 5

CONCLUSION AND RECCOMENDATION

5.1 Conclusion

Throughout the project, the three main objectives of parameters optimization in 3D printer recycle machine have been achieved. For Taguchi method analysis, the optimal extruding parameters have been show. Early step is not easy to obtain this data because many materials are used to be tested as a suitable material for this research. At the end, acrylonitrile butadiene styrene (ABS) material such as error printed product is used to be a recycle material. This is because it can be compare their mechanical properties with original filament. Taguchi's sturdy orthogonal array layout approach is suitable to research the diameter of filament (extruding process) problem as defined on this paper. Its miles discovered that the parameter design of the Taguchi method provides an easy, systematic, and green method for the optimization of the extruding parameters. The experimental results demonstrate that the speed is the main parameters among the three controllable factors (power, speed and temperature) that influence the diameter of filament in extruding process. Taguchi method analysis also give a predict regression equation to determine the optimal diameter for extruding filament. It show that the extruding parameters, use of low power (54.0 watt), high speed (0.005 m/s) and high temperature (235 ^{o}C) are recommended to obtain better dimensional for the specific test range. The filament was finally extruded even it does not follow the standard size. The filament that came out was of 1.79 ± 0.03 mm with 1.77mm as the thinnest while 1.82mm as the thickest. From that maximum thickness, it means that the error percentage is still below 5% from original dimensional filament. For objective three, show that only minor difference percentage of these two filaments with overall percentage below 5%. Last but not least, this project indicates that the optimization can be further improved for recycle 3D printing machine in order to help in minimizing the negative impact of plastic waste to the environment.

5.2 Recommendation

For the future improvement on this project, it is truly recommended that consider more factors (e.g., size of piece, materials, diameter of nozzle, etc.) in the research to see how the factors would affect diameter of extruded filament. Also, further study could consider the outcomes of Taguchi parameter design when it is implemented as a part of management decision-making processes. Beside, using a different material as a raw material for recycle such as plastic bottles is a good thing to analyses.

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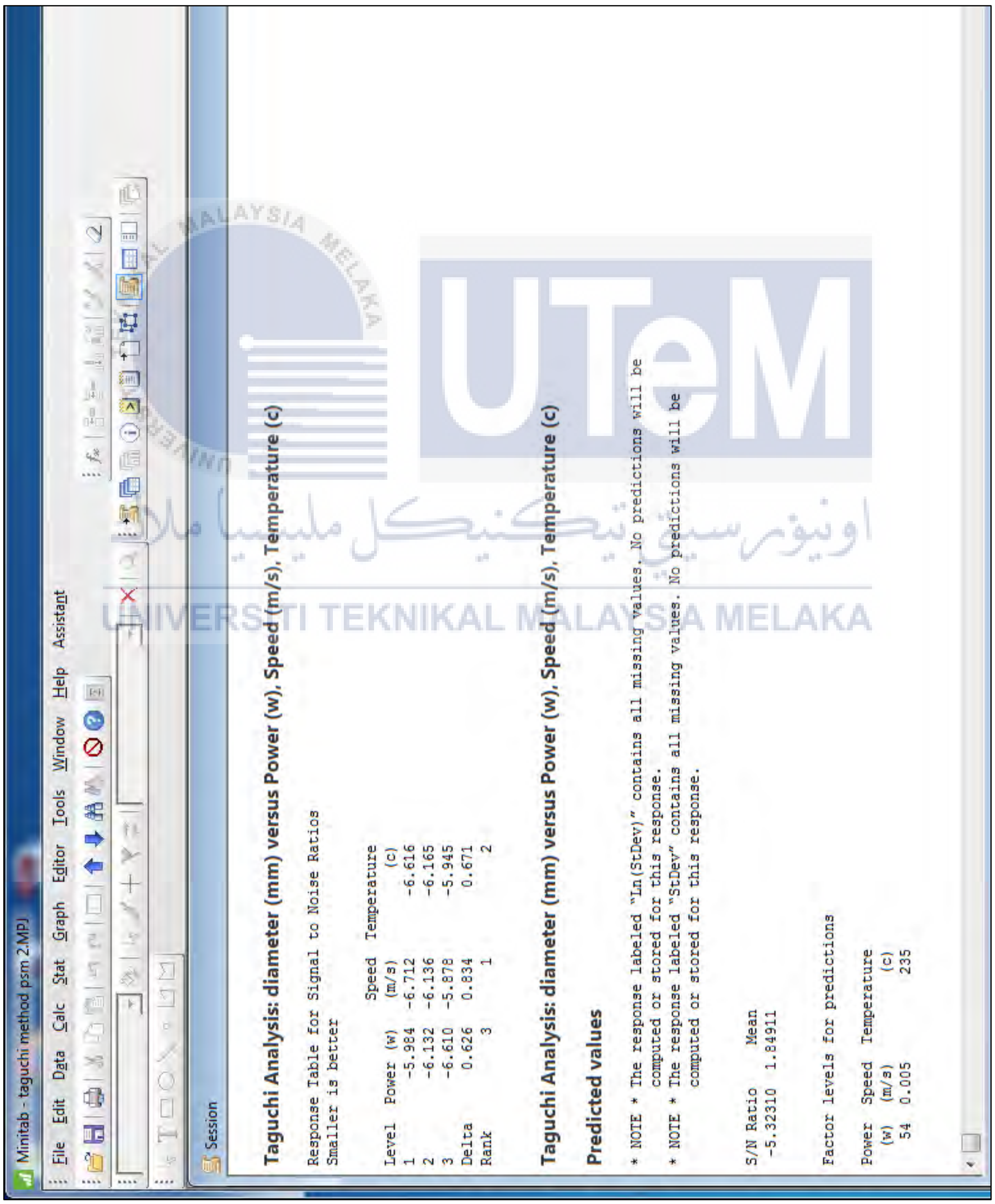
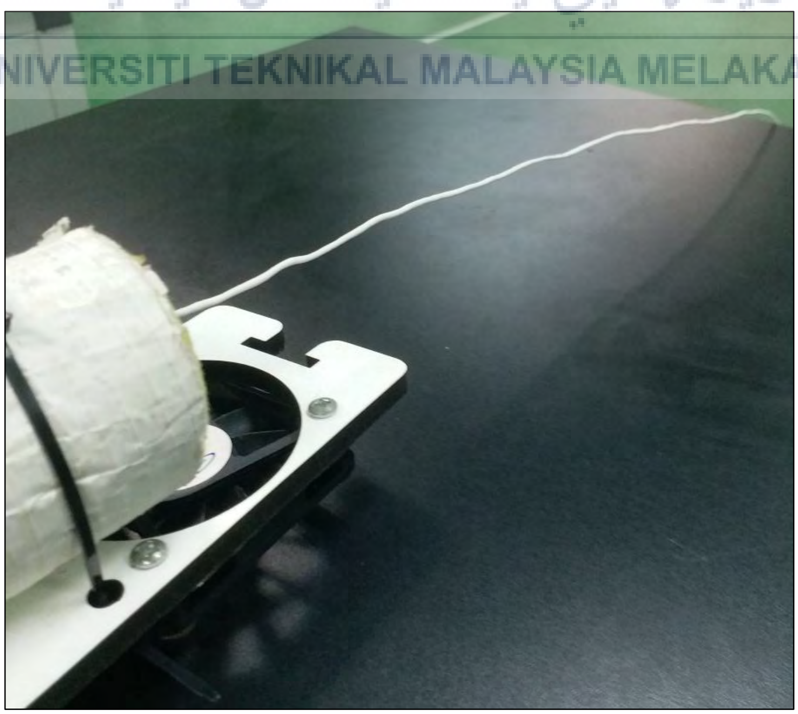
APPENDIX

APPENDIX A: Taguchi method analysis

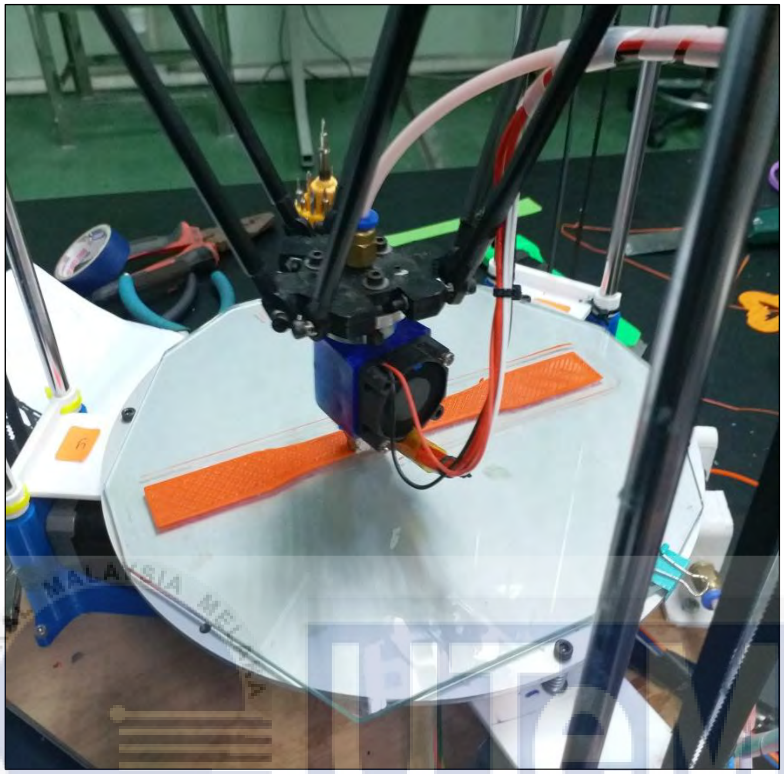


APPENDIX B1: Filastruder extruded new filament (ABS)

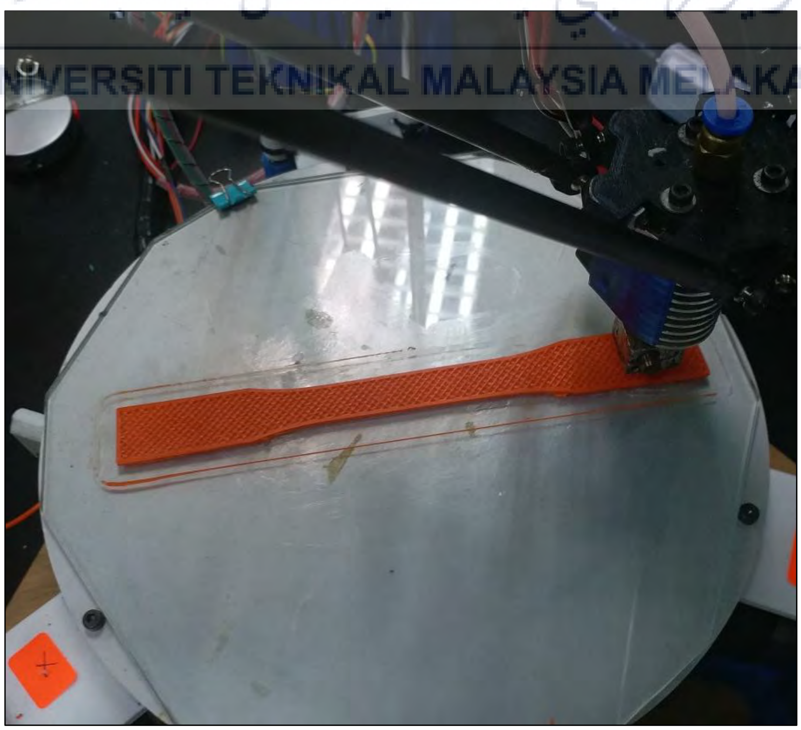
APPENDIX B2: Filastruder extruded new filament (HDPE)



APPENDIX C1: New extruded filament during printing process



APPENDIX C2: Original filament during printing process



APPENDIX D: Instron Material Testing machine used for tensile test