DESIGN OF INTEGRATED 3D PRINTER RECYCLE MACHINE

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A report submitted in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering (Design & Innovation)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declare that this project report entitled " Design of Integrated 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 (Design & Innovation).

Signature : ....

Supervisor's Name : ....

Date : ....

DEDICATION

To my beloved mom and dad, and those who always support me.

ABSTRACT

As the technology in this world has evolves rapidly, the 3D printing is not excluded from the growth as well as becoming one of the most postulate method in manufacturing process. Opposite to the standard manufacturing process which commonly is subtractive that produces a lot of waste, 3D printing 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 lot 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 increase due to high demand in market. In order to minimize the negative impact of plastic waste to the environment, a study on designing an integrated 3D printer recycle machine is done. Engineering design method is used to formulate and develop new concept design. Identification of current problems on the existing recycle machine is done to make design improvement on the new recycle machine. For the guideline of developing the recycle machine's design, preliminary result from three conceptual designs are used. There are three main components of the recycle machine which are shredder, hopper and extruder. For this study, its focus is on the hopper and extruder due to the objective on having success extrusion of filament. By using CATIA software, analysis has been made on the components and the assembled product. A prototype is built from 3D printed parts and reuse materials. Analysis of extruded filament was done for every 10 cm with minimum of 10 repetitions. Percentage of error for diameter of filament indicates 1.84mm diameter with 5.14% as the lowest error while diameter of 1.90mm with 8.57% as the highest error. So the objective to get below than 9% of percentage error is achieved and it gives hope for future improvement in this project of recycling waste of ABS polymer.

ABSTRAK

Seiring dengan perkembangan teknologi yang pesat, percetakan 3D tidak terkecuali dan turut menjadi salah satu kaedah yang mempunyai banyak permintaan dalam proses pembuatan. Bertentangan dengan proses pembuatan yang biasa seperti kaedah perluakan yang menghasilkan banyak sisa, percetakan 3D adalah jauh lebih mesra terhadap alam sekitar. Aplikasi kaedah pembuatan secara penambahan di dalam percetakan 3D telah menjurus kepada kurangnya atau tiada pembaziran bahan. Untuk teknologi berprospek cerah ini, pembangunan masih berlangsung terutamanya apabila terdapat banyak sumber terbuka untuk manusia mendapat akses dan meneroka teknologi pecetakan 3D. setiap ciptaan manusia, mesti terdapat masalah yang timbul.bagi percetakan 3D, penggunaan bahan plastik telah meningkat secara jelas oleh kerana permintaan yang tinggi di pasaran. Dalam mengurangkan kesan negatif plastik terbuang kepada alam sekitar, satu kajian keatas reka bentuk bersepadu mesin kitar semula untuk percetakan 3D telah dijalankan. Kaedah reka bentuk kejuruteraan telah digunakan untuk merumus dan membangunkan konsep reka bentuk yang baru. Pengenalpastian terhadap masalah semasa mesin kitar semula yang sedia ada telah dilaksanakan demi membuat penambahbaikan ke atas reka bentuk mesin kitar semula yang baru. Sebagai garis panduan untuk membangunkan mesin kitar semula tersebut, keputusan daripada tiga konsep reka bentuk awal telah digunakan. Terdapat tiga komponen utama mesin kitar semula tersebut iaitu pencincang, corong dan penyemperit. Kajian ini menjurus kepada corong dan penyemperit kerana matlamat kajian ialah memperoleh penyemperitan filamen yang berjaya. Analisis terhadap komponen yang siap dipasang telah dilakukan menggunakan perisian CATIA. Sebuah prototaip telah dibina daripada bahan guna semula dan mesin pencetak 3D. Analisis ke atas filamen yang terhasil dilakukan dengan mengambil bacaan setiap 10 cm untuk 10 ulangan. Ralat peratusan diameter filamen menunjukkan diameter 1.84mm bersamaan 5.14% sebagai ralat terendah manakala 1.90m diameter bersamaan 8.57% sebagai ralat tertinggi. Jadi, objektif untuk mendapatkan ralat peratusan di bawah 9% tercapai dan ini memberi harapan untuk penambahbaikan di masa hadapan untuk projek kitar semula sisa polimer ABS ini.

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LIST OF ABBREVIATIONS

PID	Proportional Integral Derivative
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene
CAD	Computer Aided Engineering
SSR	Solid State Relay
SIP	Society of Plastic Industry
DC	Direct Current
PIC	Plastic Identification Code

LIST OF SYMBOLS

ω	=	Angular velocity
α	=	Angular acceleration
π	=	Pi
N	=	Rotation per minute

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

These modern days, the technology of manufacturing has increase significantly. Rapid prototyping (RP) or mostly known as 3D printing is a good example of manufacturing technology which just not increase production rate but also saves time consumption and overall cost including cutting down labor cost. 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. Not all materials used for certain product are biodegradable and renewable. In addition, the new materials of filament is quite costly. That is why it is necessary to recycle the rejected products to prevent waste and to achieve cost effective production in 3D printing technology. Thus, in order to overcome this problem, development of integrated recycle machine gives a new hope to the waste material to be used again.

In the market, currently there are 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. The aim for this project is mainly to design a low cost integrated 3D printer recycle machine which could significantly reduce the usage of raw materials in making new filament and also decreasing the negative impact of plastic waste to the environment. Those can be achieved by recycling failed prints of 3D project by shredding and extruding process into new filament.

1.2 PROBLEM STATEMENT

Existing low cost 3D printing machine which is called Mendel 3D printer is used as reference model. It use polyethylene materials known as thermoplastic filament to print and build an object. The filament material are mixture of petroleum-based and plant-based source. To be clear, these materials are costing and not biodegradable. 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. 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 are the machine is too heavy to be attached to the 3D printer, there is no temperature control and nothing to insulate the heat produced by the heating element from reaching the hopper and other crucial parts. Therefore, this latest project is about to design a new and improved 3D printer recycle machine to overcome those problems.

1.3 OBJECTIVE

The objectives of this project are as listed below:

1. To design a new and improved integrated 3D printer recycle machine by using CATIA software.
2. To fabricate a prototype for the new integrated 3D printer recycle machine.
3. To extrude filament with percentage of error for diameter below 9%.

1.4 SCOPE OF PROJECT

The scopes of this project are as follow:

1. CATIA software will be used in the designing and development stages of the recycle machine.
2. The new recycle machine will implement the similar working principle of the previous one.
3. Fabrication of the 3D printer recycle machine will use metal on most of the body parts.

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. Wohlers *et al.* (2014) stated that in future, 3D printing is going to grow rapidly. In addition, manufacturers in various industries already implement the use of 3D printing due to its efficiency and faster rate of production. This 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. There are various model of open source for low cost 3D printer. One of it is Prusa. 3D printing is a technology with high potential to be cost effective with the production while keeping the waste material at low volume compared to conventional method (Lindemann and Reiher, 2015).

As the benefits of 3D printing has lure 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. 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. As for two developers related to 3D printing which are called as RecycleBot and Filamaker, they already made the early projects on the problem (Baechler *et al.*, 2013). 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 (Chase, 2004).

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 a low cost 3D printer 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 INJECTION MOULDING

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. For thermoplastic and thermosetting polymers production, this manufacturing method is suitable and reliable. Olmsted and Davis (2001) stated that all electric and hybrid injection moulding machine are the latest technology for injection moulding.

2.3.1 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 (Rauwendaal, 2001).

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

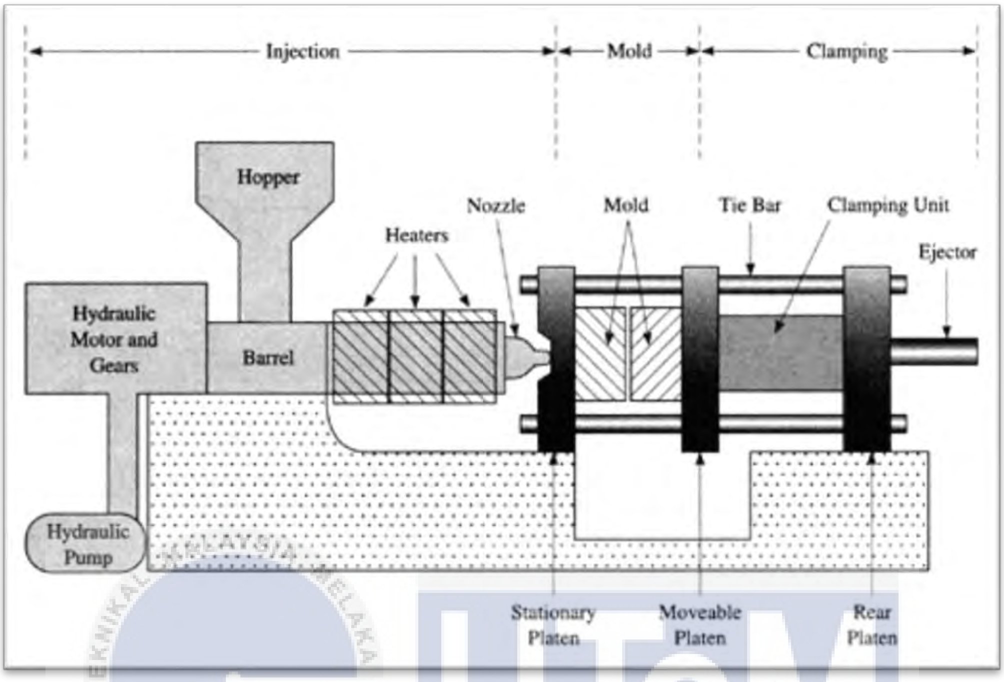


Figure 2.1: Single Stage Screw Machine (*deseng.ryerson.ca*)

2.4 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). Although there are lots of materials that had been explored for 3D printing because of its characteristic which is thermoplastic, but not all can pass the three distinct tests for qualification (Luke, 2013). The tests are beginning extrusion into plastic filament, next extrusion and trace-bind ability during the process of 3D printing. After the materials has pass all the three tests, then only it can be qualified to be used as filament for 3D printing.

2.4.1 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
Material base	Plant	Petroleum
Biodegradable	Yes	No
Warping tendency	Near warp-free	Large part tends to warp
Mechanical properties (Durability, malleability, flexibility)	Good	Excellent
Fumes / smells	Sweet like candy	Bad burnt plastic
Post-processing	good	Excellent
Surface treatment with acetone	Not possible	Possible
Field of application	Household items, toys, gadgets	Interlocking parts, pin-joints

Figure 2.2 shows the physical comparison on the surface of finish parts that were printed with the identical original 3D CAD dimension of 0.10 resolution. On the left side was printed using black PLA while on the right side was printed with black ABS.

Figure 2.2: Surface finish comparison of printed parts using PLA (left) and ABS (right) *(cubex3dprinting.blogspot.my)*

2.5 POLYMER

Affordable, durable and lightweight are the highlighted characteristics mentioned by Thompson et al. (2009a) for this plastics that are chemically made with numerous repeating units. Polymer has a large amount of contribution because it is always been chosen as the material used in manufacturing industries. That is why production of polymers have increase significantly to meet the demands of other manufacturers. Regarding to the finding from Hopewell et al. (2009), the amount of oil and gas being used for feedstock production of plastic and the amount of oil and gas to produce energy for manufacturing are almost at the same rate with 4% and 3-4% usage respectively.

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.

2.5.1 Thermoplastics

This chemically independent macromolecules have the simplest molecular structure, also known as linear polymer. Thermoplastics can undergoes several type of processes by heating which are softening, melting, shaping, forming and welding. Not to forget, it can be cooled down to make it solid. But need to remember, before processing the thermoplastics, it needs to be dried properly so that it do not release gases or water vapour. Several cycle of repeated heating and cooling processes would not affect the properties of thermoplastics. Due to that, thermoplastics can be recycled and reprocessed. Even the wastes are partially reusable as raw matter because of the physical softening and melting are reversible.

As the thermoplastics is used up as filament, the main advantages and disadvantages of this type of polymer are compulsory to be acknowledged. 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.

2.6 POLYMER RECYCLING

Transforming process for waste of plastics into beneficial products is referred to plastic recycling. The condition of recycled plastics, in terms of structure properties may not be as identical as it were before being recycled.

Due to the existence of non-biodegradable plastics, it specially has increase the need to recycle the plastic waste to prevent damage to the environment. The recycle process cannot be done randomly, but need to be specifically following the class or code for plastics that are referred to in recycling polymer.

2.6.1 Code Identification of Plastics

There are seven groups of plastics in polymer, with each having specific properties. These properties are used as a guideline in packaging applications. A number or a letter is outlined for each group as a code according to the Plastic Identification Code (PIC). These codes act as the guides for uniform identification system of various class of polymers. Table 2.3 shows the PIC with its properties, common uses and recycled form for other category where ABS and PLA are categorized.

Table 2.3: Plastic Identification Code (PIC) with Properties, Common Uses and Recycled Form *(www.econation.co.nz)*

SYMBOL	TYPE / PROPERTIES	COMMON USES	RECYCLED FORM
7 OTHER	Includes all other resins and multi materials (example: laminates). Example: acrylonitrile butadiene styrene (ABS), acrylic, nylon, polyurethane (PU), polycarbonates (PC) and phenolics.	Automotive, aircraft and boating, furniture, electrical and medical	Furniture fittings, wheels and castors. Fence posts, pallets, outdoor furniture and marine structures

2.6.2 Filament Recycling

Filament are made of PLA and ABS. They are classified in group 7 as other resins and multi materials. To recycle these materials, it need to follow each specific properties due to combination of plastics. The aim for recycling the filament is mainly to sustain the production of filament to meet the demands of 3D printer users. Besides that, it is of course to reduce the amount of plastic wastes due to failure in printing objects and keeping it as a cost effective production 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 already initiate the mission to recycle the plastic wastes. From there, various open source developers followed their steps in making the recycle technology better and comply with the target to reduce the impacts to the environment. One of the developed system is Lyman Filament Extruder that can be found at thingiverse.com, while some others are shown at instructables.com. This process of recycling filament has shown that less embodied energy is used for distributed recycling referring to the calculation made on the energy and carbon dioxide emissions by Kreiger et al. (2014).

2.7 DESIGN FORMULATION

For this stage, it is fundamental but crucial in design process especially when it comes to specification. This is where the observation and studies of the previous recycle machine are taking place. It is meant to determine the advantageous and disadvantageous of the machine in terms of its designs which will be used to generate ideas and solutions to put the limitations at bay.

2.7.1 Requirements by Customer

This is the guideline for the design process to take place. It will be used for the entire process with supervision. All the information to be listed in the requirement are obtained by several methods such as consultation, research on previous machine available in the market and also by the feedbacks of the users and others about the machine and related technology.

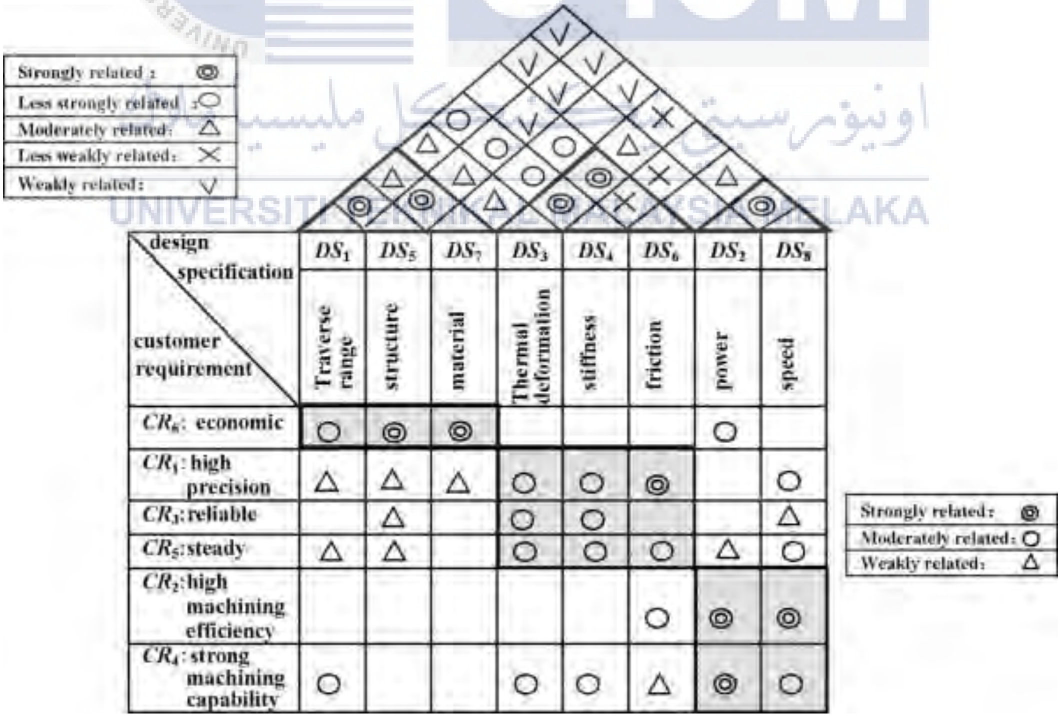
2.7.2 Interest Weightage

The purpose of this weightage is mainly to identify the priorities regarding to the customer requirements and it is percentage basis. The criteria that can be in the list are set from the designer's view of perspective that compliment with the analysis obtained from previous machine and also the characteristic that would affect the performance of the new recycle machine.

2.7.3 Quality Function Deployment (QFD)

QFD is a mode to form quantitative parameters that are converted from qualitative parameters. The aim for this method is to obtain the sequence of quality functions and the formula for quality design. House of Quality (HoQ) can be used to show the dependence between design specification and customer requirements. The example of HoQ is shown in the Table 2.4. As shown in the table, the relation of both design specification and customer requirement resulting the difference in the final choice of design with respect to the level of importance in each criteria.

Table 2.4: Example of the House of Quality (HoQ) *(asme.org)*



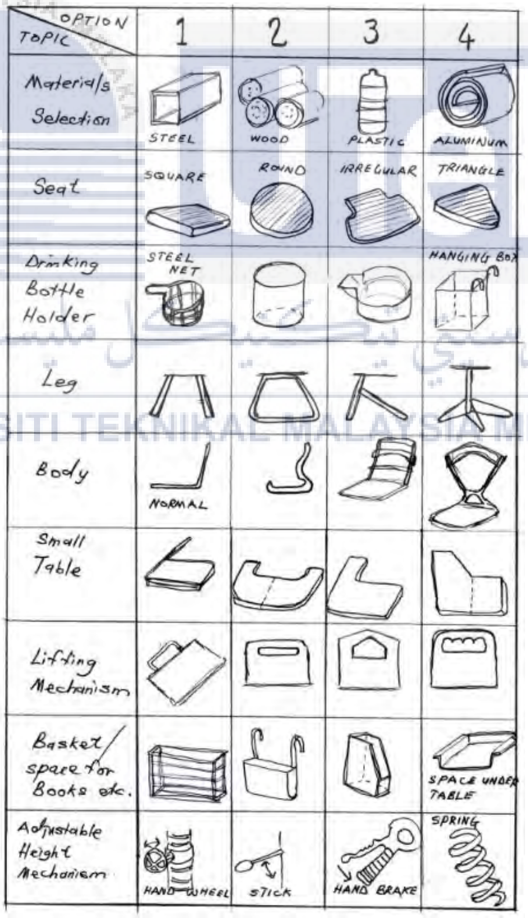
2.8 CONCEPT OF DESIGN

After design formulation, design of concept is the next stage which decision on machine's geometry, materials and parts are done. There will be several ideas that will be evaluated. After the final decision has been made, the machine will be designed based on the best series of ideas for each criteria.

2.8.1 Morphological Chart

It is a chart that is used for ideas or options tabulation according to the criteria needed for the design of the new 3D printer recycle machine. From the chart, various concept designs will be made by using the option listed. In the Table 2.5, it shows the example of how the morphological chart is done.

Table 2.5: Example of morphological chart *(4generate.blogspot.my)*



2.8.2 Conceptual Design

At this stage, various conceptual design for the 3D printer recycle machine will be done by referring to the morphological chart. There is no restriction for the concept designs. It can be any design made with any options, but only choose from the listed options in the chart. As shown in Figure 2.3, it is a few example of concept designs made up with reference to morphological chart.

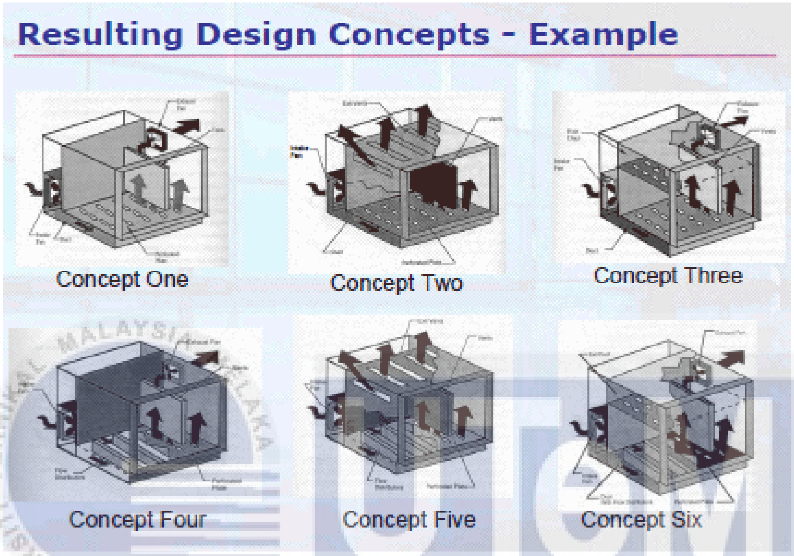


Figure 2.3: The example of concept designs according to the morphological chart. *(ogjc.osaka-gu.ac.jp)*

2.9 COMPUTER AIDED DESIGN (CAD) SOFTWARE

CAD is a computerized design technology that will make design and documentation faster and easier. It can be two dimensional (2D) or three dimensional (3D) drawing. One of the CAD software is CATIA which is a multi-platform software consists of CAD/CAM/CAE for 3D drawing construction. In addition, CATIA can also be used to do analysis on the model of design. The example of drawn model using CATIA is shown in Figure 2.4.

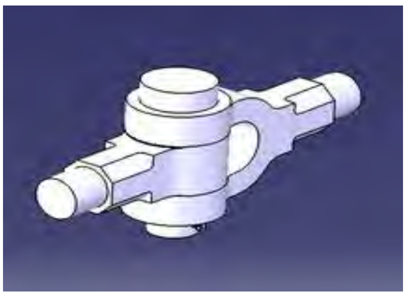


Figure 2.4: Example of drawing using CATIA. *(grabcad.com)*

2.10 PLASTIC DECOMPOSITION TECHNIQUE

Decaying or breaking down materials are 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.

2.10.1 Plastic Shredder

Plastic shredder is commonly build 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 are 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 2.5 shows the example of mini plastic shredder that is in process of shredding a Lego block.

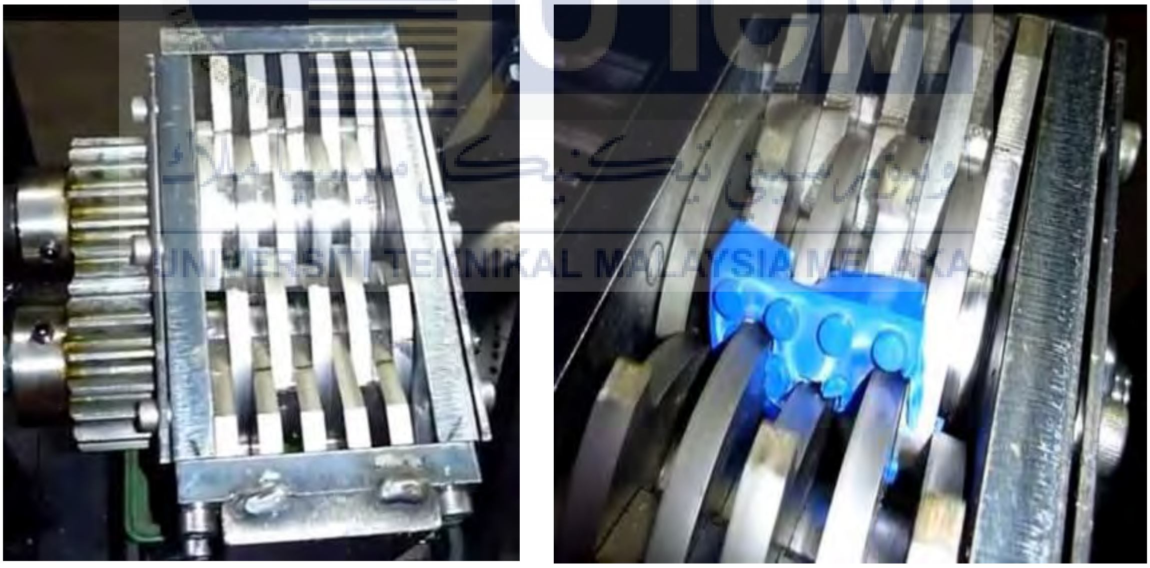


Figure 2.5: Mini Plastic Shredder (*inhabitat.com*)

2.11 TEMPERATURE CONTROL

The process of controlling temperature is not really a hard task nowadays. Not like the old days which need to use manual thermometer to get the temperature reading of desired condition. This method is not practical especially for some applications that are sensitive to temperature changes. As example machines that are being used in industries for manufacturing. That is why the existence of special device such as PID controller ease the process to measure the temperature and can control it as desired.

2.11.1 PID Controller

To use the Proportional Integral Derivative (PID) device as temperature controller, it needs to be aided with a Solid-State-Relay (SSR) and thermocouple. SSR is a device that open and close a circuit electronically while allowing the users to control high voltage AC loads form low voltage DC control circuit. For thermocouple it is functioning as a sensor to detect the temperature of an object or the surrounding.

Figure 2.6: PID Controller (*www.radixinstruments.com)*(LEFT); Solid-State-Relay (SSR) (*robolabor.ee*) (RIGHT)

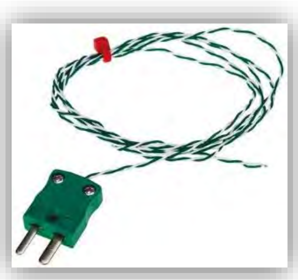


Figure 2.7: Thermocouple (*uk.rs-online.com*)

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 integrated 3D printer recycle machine. 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 design engineering can be applied. After the requirement on the recycle machine has been confirmed, it is the time for morphological chart as the guideline in obtaining several conceptual designs which will be evaluated to get the best of the best among them.

3.2 FLOW CHART

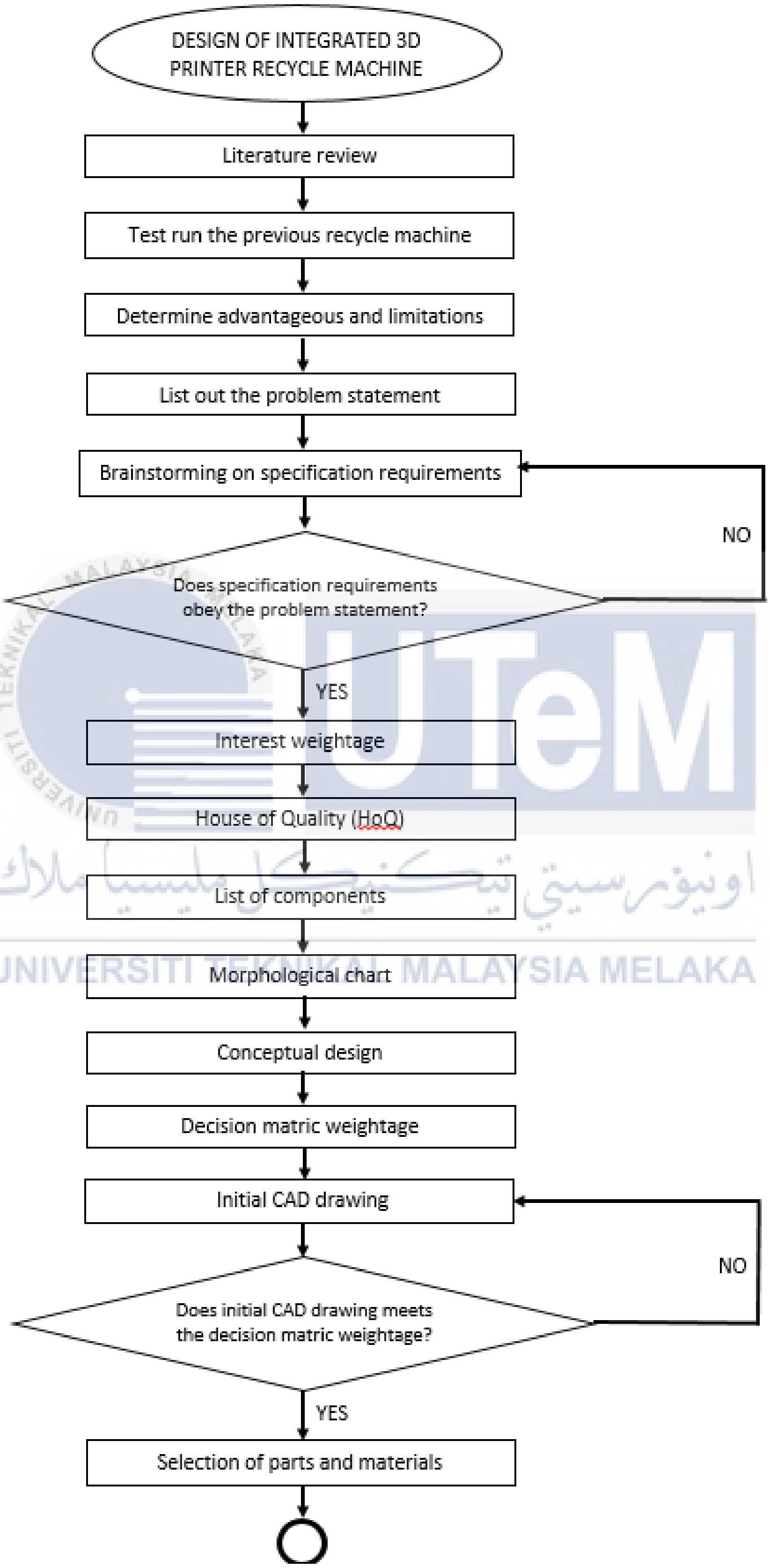


Figure 3.1: Flow chart of project

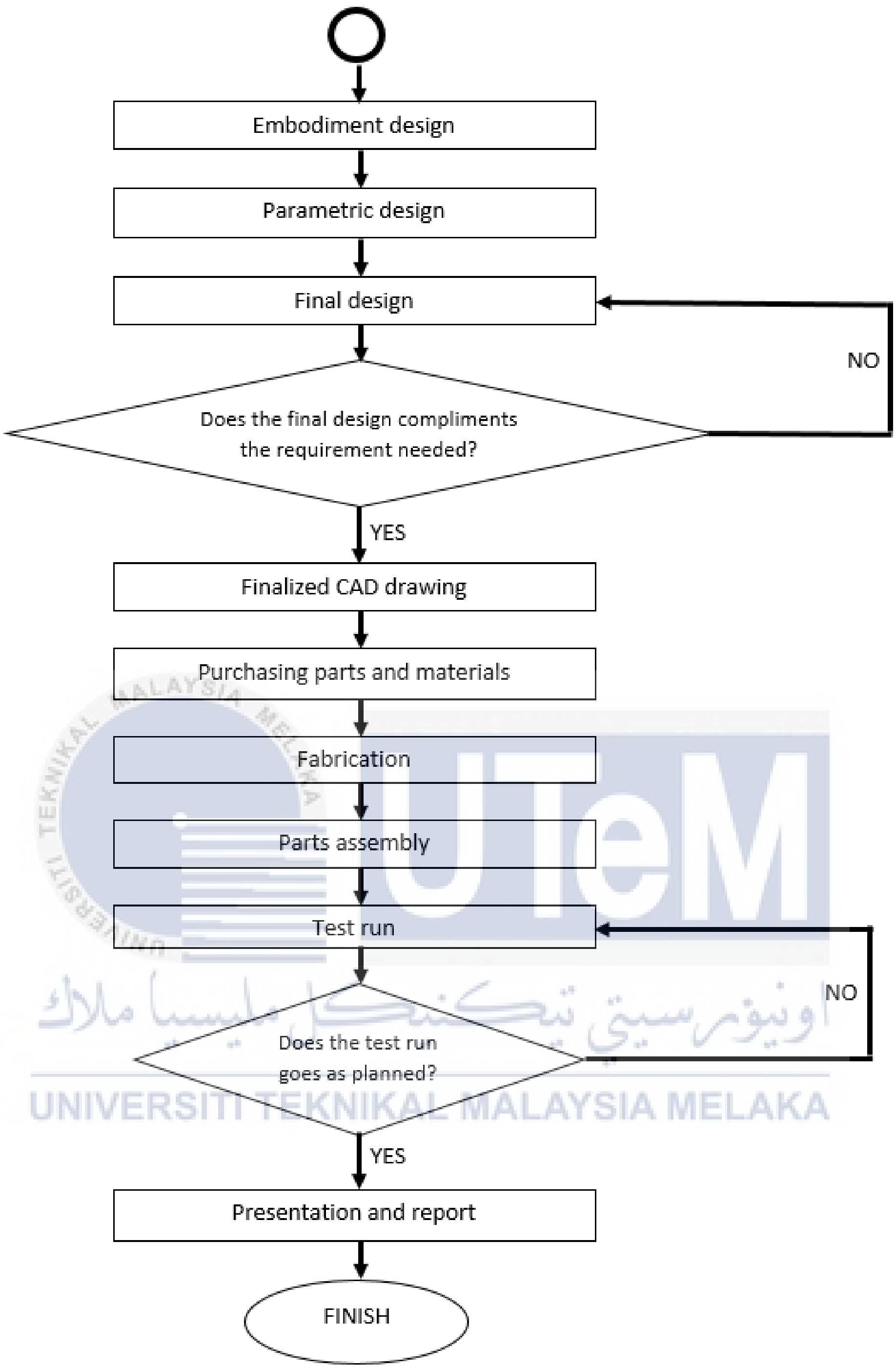


Figure 3.2: Flow chart of project (continued)

3.3 DESIGN FORMULATION

3.3.1 Product Requirements

In order to get the suitable requirements, series of test run were carried out on the previous 3D printer recycle machine. This method is to identify the advantageous and limitations of the previous machine so that modifications can be done on the new recycle machine for better performance and quality. Various methods were used during research period such as through discussions, articles, journals and lots of observation on the related field and on the previous 3D printer recycle machine. So, the product requirements are based on the conducted research. The criteria needed are listed and explained below.

For the new integrated 3D printer recycle machine, the system must be:

- **Safe to be operated**: machine is danger-free during on and off operation time. It includes the surrounding is no endangered by the existence of the recycle machine.
- **Low cost**: materials and parts are at reasonable price and affordable to be fabricated. The cost also includes the other expenses such as labor cost and basic necessities to run facilities for project development of recycle machine.
- **Able to produce filament**: waste plastics can be recycled and processed to be extruded as new filament that follows the standard size and is printable.
- **User friendly**: the physical of the recycle machine must be durable and portable. Besides, no need for expert to operate the recycle machine.
- **Easy for maintenance**: repairable in any problem that may occurred. Parts are also replaceable.
- **Lenient to set up**: no need for special tools to assemble or diassemble the recycle machine. Plug and play concept for easier integration to 3D printer machine.

3.3.2 Interest Weightage

This process is crucial because it will affect the final design of the recycle machine. That is why the research on the previous recycle machine are carried out. Besides that, surveys on target audience are done to collect their opinion and any improvement that can be applied on the new integrated 3D printer recycle machine. Table 3.1 shows the interest weightage constructed based on the research and surveys.

Table 3.1: Interest weightage.

CUSTOMER REQUIREMENTS	WEIGHT (%)
Safe to be operated	20
Low cost	25
Able to produce filament	20
User friendly	10
Easy for maintenance	15
Lenient to set up	10
Total	100

3.3.3 Quality Function Deployment (QFD)

At this section, House of Quality (HoQ) is put into use. Table 3.2 shows the House of Quality for requirement and design specification. This is to determine the alliance between both of it. So, the best interest can be clearly highlighted.

Table 3.2: House of Quality on the alliance between requirements and design specification.

			SPECIFICATIONS								
	Indicator Highly related: ▲=9 Moderately related: ●=6 Lowly related: ■=3	**Interest Weight (wt)**	Design	Type of material	Material durabilty	Minimum/ maximum motor speed (RPM)	Minimum/ maximum temperature (C)	Time required to produce filament (s)	Dimensions (m)	Weight (kg)	Nozzle diameter (m)
No	**REQUIREMENTS**		1	2	3	4	5	6	7	8	9
1	Safe to be operated	0.20	▲		●	■	●				
2	Low cost	0.25	▲	▲	▲						
3	Able to produce filament	0.20				●	●	●			▲
4	User friendly	0.10	▲						●	●	
5	Easy for maintenance	0.15	▲	▲					■	■	
6	Lenient to set up	0.10	▲	▲					●	●	
	Total interest weight	1.0									
	Rating		**7.2**	**4.5**	**3.45**	**1.8**	**2.4**	**1.2**	**1.65**	**1.65**	**1.8**
	Rank		**1**	**2**	**3**	**5**	**4**	**9**	**8**	**7**	**6**

3.4 CONCEPT DESIGN

3.4.1 Component Breakdown Diagram

This stage is to list out all the components that are required for the new integrated 3D printer recycle machine. Reference are based on the research made on the previous recycle machine. The diagram is as shown in Figure 3.3.

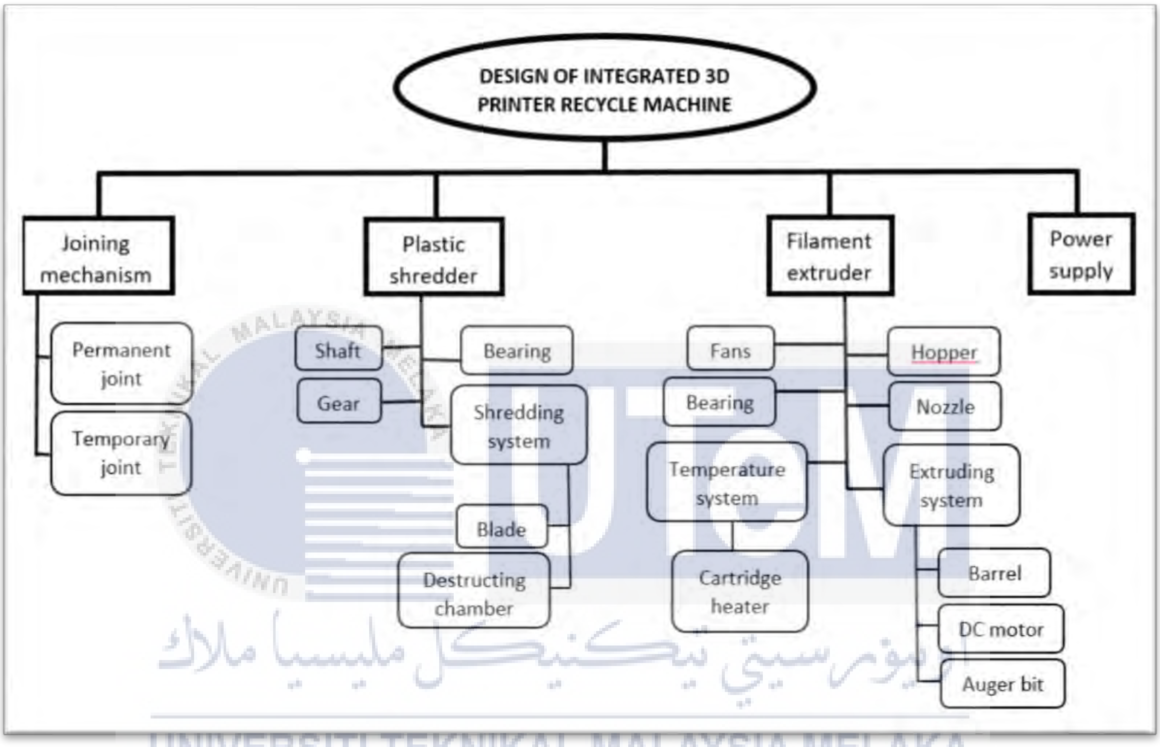
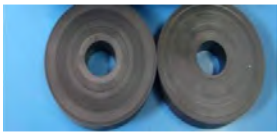
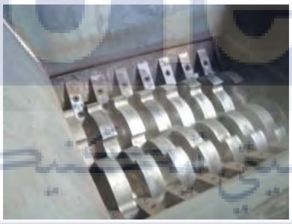


Figure 3.3: Component Breakdown Diagram.

3.4.2 Morphological Chart

Table 3.3: Morphological chart of the new recycle machine

Component	Option 1	Option 2	Option 3
Body material	 Steel / Aluminum	  Mixture of recycle materials and ABS	 PLA/ABS
Nozzle	 MAKERBOT nozzle	 DIY nozzle	 FILASTRUDER nozzle with integrated melt filter
Heater	 Band heater	 Cartridge heater	 Tubular heater

Insulator	 Fibreglass	 Mineral wool	 PU/rubber
Barrel	 Hollow steel rod	 Galvanized iron pipe	
Plastic Shredder	 Chopping blade	 Double-shafted shredder	 Metal cutter blade

3.4.3 Conceptual Design

Concept design 1:

Component		Option
Body material	:	Steel
Nozzle	:	Makerbot
Heater	:	Tubular heater
Insulator	:	PU / Rubber
Barrel	:	Hollow steel rod
Plastic shredder	:	Chopping blades

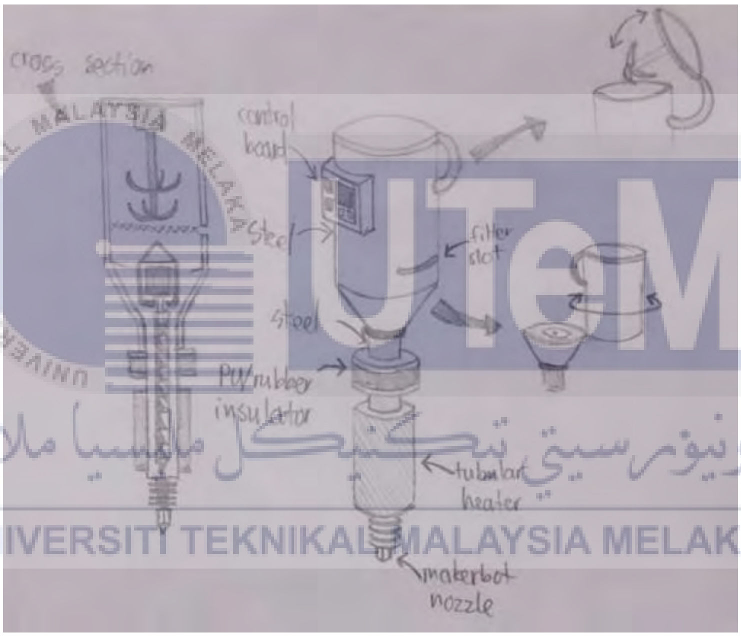


Figure 3.4: Concept design 1

The body is fabricate using steel plate because it can withstand the torque and force from the motor of the chopping blades. Besides, the lid with hinge can be welded together to the body so that it can stay intact even the lid is rapidly open or close. The nozzle used is ready made which is from Makerbot and can print directly with the optimum size for 3D printing. Tubular heater is used to give full and consistent coverage of heat along the barrel without having to worry of excess heat transfer to upper body because of the PU/rubber insulator. Hollow steel rod is used to compliment with the tubular heater due to high surface contact area. Two chopping blades are used to ensure the waste plastic can be chopped into small pieces before goes into the barrel.

Concet design 2:

Component		Option
Body material	:	Mixture of recycle materials and ABS
Nozzle	:	DIY
Heater	:	Band heater
Insulator	:	Fibre glass
Barrel	:	Galvanized iron pipe
Plastic shredder	:	Double-shafted shredder

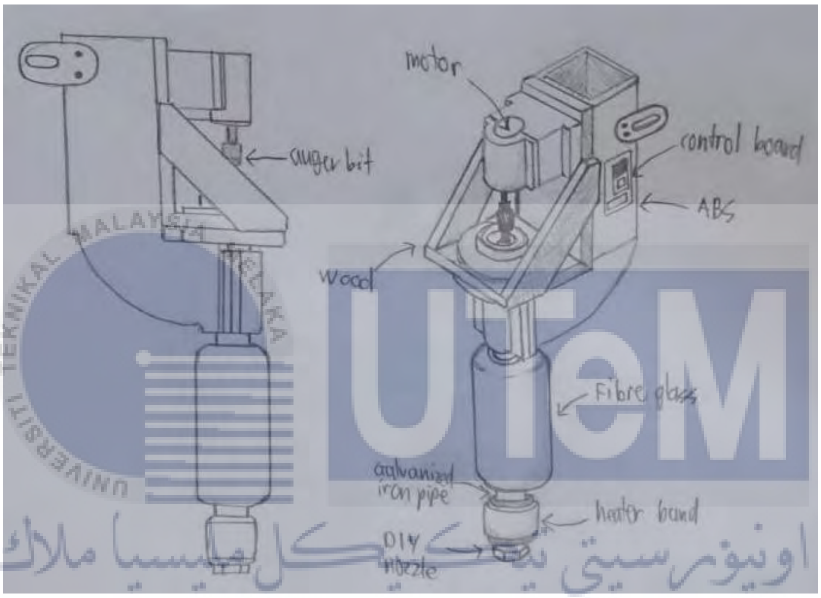


Figure 3.5: Concept design 2

The body is made of recycle material such as unused plywood besides 3D printed parts because it is more cost saving than full body metal fabrication. In addition, the nozzle is self-made. The band heater is used to give all-around heat supply to the galvanized iron barrel so that the waste plastic can be melted consistently before it is extruded through the nozzle with the help of the drill bit. To prevent the heat from heater band to reach the upper parts of the machine, the fibre glass insulator is wrapped around the barrel from end to end. This is to ensure the heat can be absorbed and release to the surrounding before it reach the 3D printed hopper clamp. To turn the waste plastics into tiny pieces before it being melted and extruded into new filament, the double-shafted shredder is used to ensure no waste could pass before turns into fine pieces.

Concept design 3:

Component		**Option**
Body material	:	ABS / PLA
Nozzle	:	FILASTRUDER
Heater	:	Cartridge heater
Insulator	:	Mineral wool
Barrel	:	Hollow steel rod
Plastic shredder	:	Double-shafted shredder

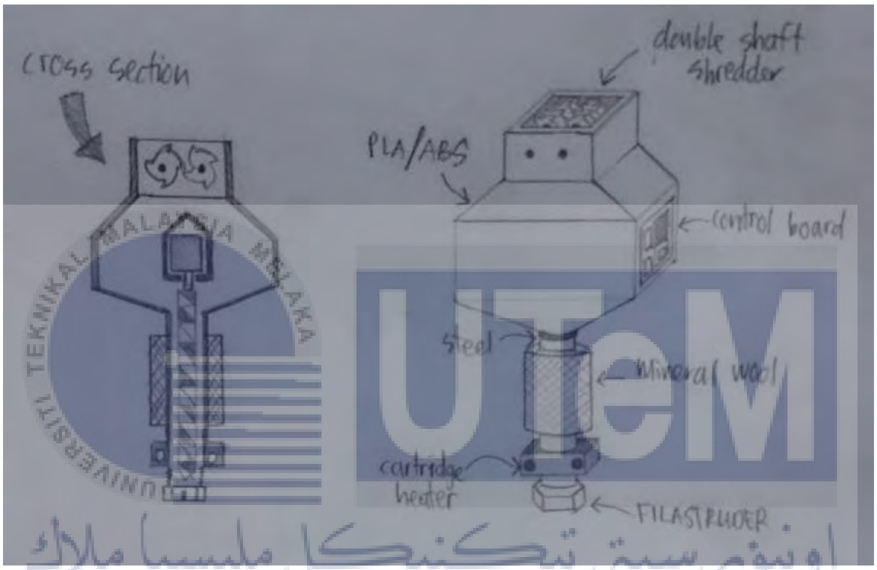


Figure 3.6: Concept design 3

Due to the complicated design of the body and the need to make it low cost machine, it would be better if the body is 3D printed because of its ability to print any design without having to spend a lot on it. The nozzle is from Filastruder which has built-in filter and can be used to extrude filament without problem. A pair of cartridge heater are attached to a metal block to give consistent heat to the waste plastic during the extrusion process. Mineral wool is used as the insulator because it has quite the same ability with the fibre glass. Besides, to go along well with the steel barrel to control the heat transfer rate, that is why the mineral wool is used. Double-shafted shredder is used to give total crushing process to the waste plastics for better and smooth process of filament extrusion.

3.4.4 Concept Evaluation

Decision Matrix weightage is applied in order to indentify the concept design that is most suitable with respect to the product requirements needed. In Table 3.4, it indicates the Decision Matrix Weightage between the concept designs.

Table 3.4: Decision Matrix Weightage.

			Concepts					
			Design 1		**Design 2**		**Design 3**	
No.	**Criteria**	**Interest weight**	**Wt.**	**Tot.**	**Wt.**	**Tot.**	**Wt.**	**Tot.**
1.	Safe to be operated.	0.20	4	**0.8**	4	**0.8**	4	**0.8**
2.	Low cost.	0.25	4	**1.0**	5	**1.25**	3	**0.75**
3.	Able to produce filament.	0.20	4	**0.8**	3	**0.6**	4	**0.8**
4.	User friendly.	0.10	2	**0.2**	4	**0.4**	3	**0.3**
5.	Easy for maintenance.	0.15	4	**0.6**	5	**0.75**	4	**0.6**
6.	Lenient to set up	0.10	2	**0.2**	4	**0.4**	2	**0.2**
		Total interest weight	20	**3.6**	25	**4.2**	20	**3.45**

*Weightage: 1 – 5

3.4.5 Finalize Concept Design

According to the decision matrix weightage, it indicates the concept design 2 is the best with total interest weight of 4.2, followed by concept design 1 with 3.6 in total and the last place with 3.45 total interest weight is concept design 3. By having a low fabrication cost, is an advantage to any design to be produced. That is why the interest weight is the highest compared to the other criteria. Besides, it will be even better if the maintenance process of the machine is easy to be done. Even if the filament being extruded is not in a constant standard size which is due to the usage of DIY nozzle, it is something that can be improvised as long as the machine can successfully produce filament that is printable. So, the concept design 2 will be designed in details in CAD format along with its specifications.

CHAPTER 4

RESULT & ANALYSIS

4.1 INTRODUCTION

In this chapter, the CAD drawings for the parts and components to be fabricated are being analysed. This process includes the steps from designing until the analysis stage before it being fabricated. All the dimensions for the parts are tested to best fit with each other so that there will be no error in assembling the recycle machine. The analysis on certain crucial parts such as blades for the plastic shredder, the auger bit, the motor, the spur gear and the main body are carried out in this chapter.

4.2 DETAIL DESIGN

This section will discuss more detail on the design improvement of the parts for the recycle machine. Because of this, the shredder's drawing is not included because it is not the main concern to be improved in this project, but the extruded filament. It is just not only about the design, but also the related factors such as pressure, force and torque that could affect the final product especially in term of mechanical parts. This is because it has a big influence on the success rate to recycle the waste materials and turn it into new filament.

4.2.1 Improved design

The improvement is done mostly on parts that are crucial to the performance of the recycle machine. As example, most of the build for the recycle machine are set to be made of steel when it is ready to be manufactured. Before doing so, it is best to use a mixture of recycle materials such as unused plywood and galvanized iron pipe besides ABS plastic. This is to ensure cost effective processes in obtaining the machine's sturdiness and reliability so that it can be manufactured for official usage instead of just being a prototype.

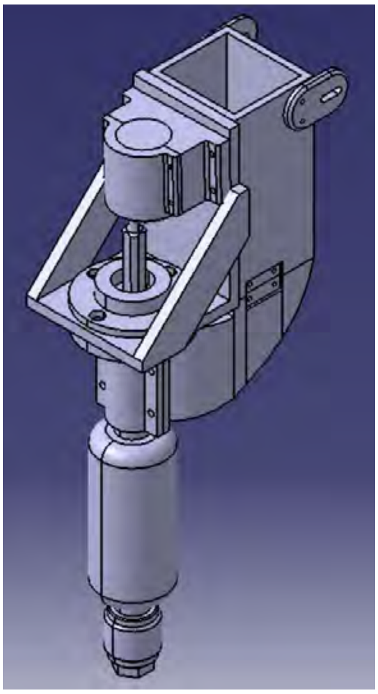
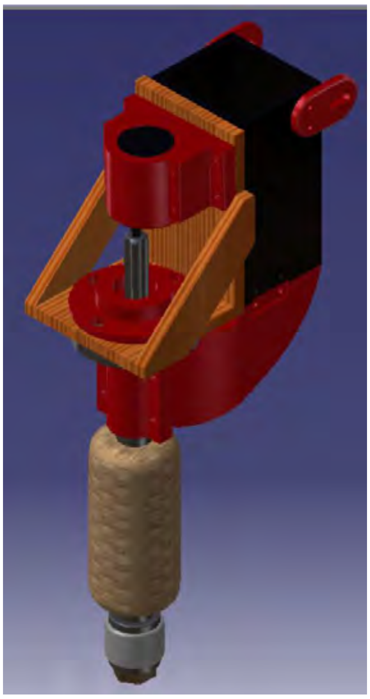
 

Figure 4.1: Shading with edges (left) and shading with materials (right)

As shown in Figure 4.1, they are the assembled parts of the improvised recycle machine in two different shadings. There are several types of materials being applied. Steel for motor, heater band, pipe base mount and drill bit. Galvanized iron is for barrel and connector. While ABS is for hopper, motor housing and bearing holder.

4.2.2 Part Design Analysis

To do a complete and detail analysis, parts with complete dimensions are needed. That is why the chosen concept design is converted into 3D CAD format. This will help define the design with correct specifications, dimensions and also the material that will be used for each part during fabrication process. By using the 3D drawing, finite element analysis is done on certain vital parts that have high tendency to influence the performance of the recycle machine. The results are used to improve any critical parts that could cause failure in design before all the parts are fabricated.

A) **Spur gear**

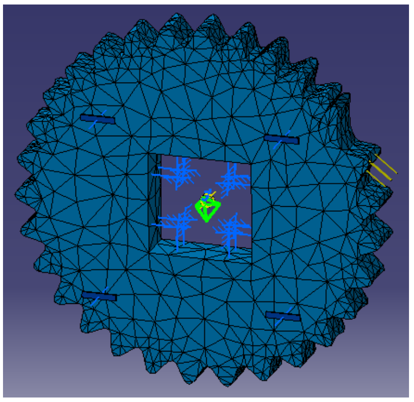


Figure 4.2: Deformation on the spur gear.

In the above figure, it shows a spur gear with a deformation result when a 20 N force is applied. The pressure on the spur gear is 4738.214 KPa. The material applied for the gear is steel. This result will help to find the correct motor with the required amount of torque to move the gear to operate the plastic shredder.

Figure 4.3 shows the analysis results for translational displacement vector while Figure 4.4 indicates the Von Mises stress on the spur gear.

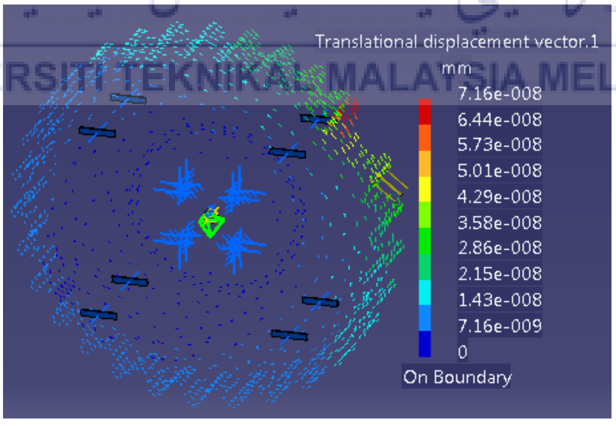


Figure 4.3: Translational displacement vector of spur gear.

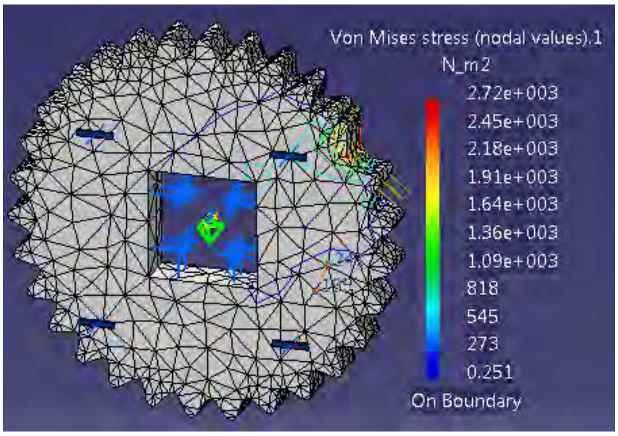


Figure 4.4: Von Mises stress of spur gear.

B) Shredding blade

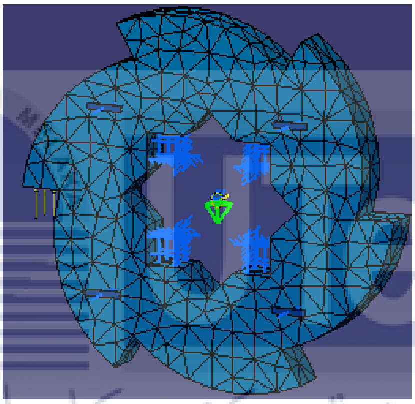


Figure 4.5: Deformation on the shredding blade.

Figure 4.5 shows the deformation result on the shredding blade when a 20 N load is applied on the end surface of the blade. The material used for the blade is steel. This result will help in knowing the maximum of force that can be withstand by the blade. The slot design for shaft is designed referring to the existing shredder in market. This design will influence the effectiveness of blade during shredding due to its continuous orientation. So, it has a nonstop plastic shredding process in order to get as finest as possible of waste.

Figure 4.6 and Figure 4.7 show the analysis results for translational displacement vector and Von Mises stress on the shredding blade, respectively.

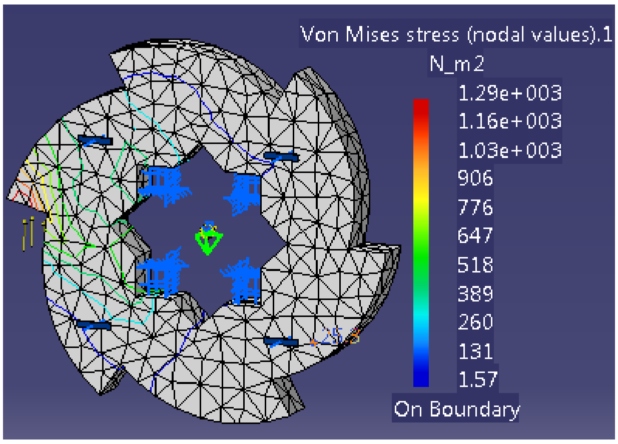


Figure 4.6: Von Mises stress of shredding blade.

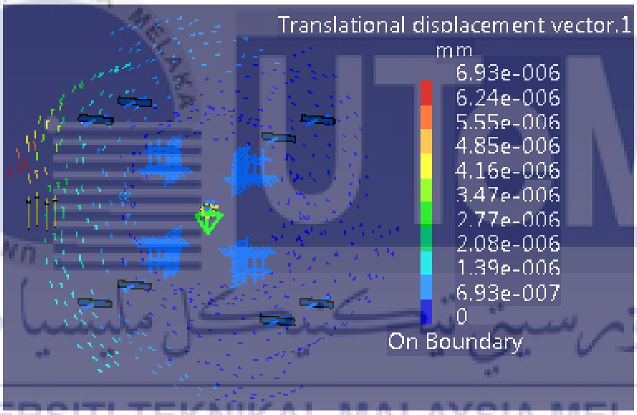


Figure 4.7: Translational displacement vector of shredding blade.

C) Wood Platform

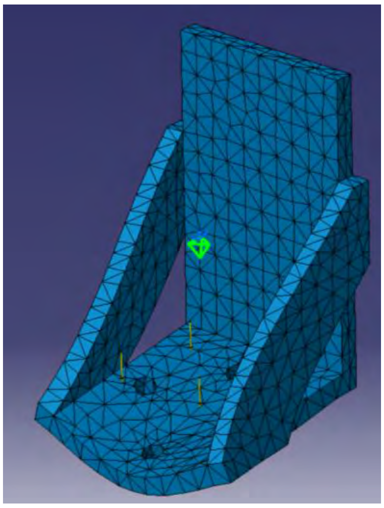


Figure 4.8: Deformation on the wood platform.

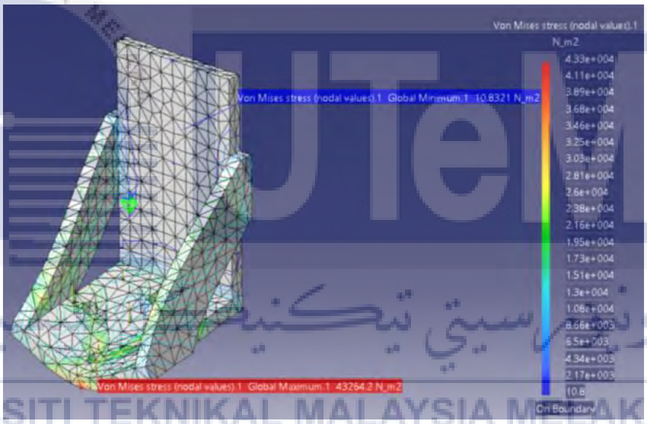


Figure 4.9: Von Mises stress of Wood platform.

In Figure 4.8, it shows the deformation result on the wood platform when a 10 N load is applied on the upper surface of the platform's base. The material used for the platform is plywood. This result will help in knowing the maximum of force that can be withstand by the platform and how it may looks when force is applied on it. Plywood is chosen as the material because it can be obtained easily from any junkyard. Besides, in order to withstand the torque applied by the motor, plywood is suitable instead of plastic to prevent rupture of support. Figure 4.9 shows the analysis results for Von Mises stress on the wood platform with minimum value of $10.8321Nm^2$ and maximum of $43264.2Nm^2$.

In the following Figure 4.10, it illustrates the result of translational displacement vector of wood platform with $4.717x10^{-4}$ mm as the maximum value.

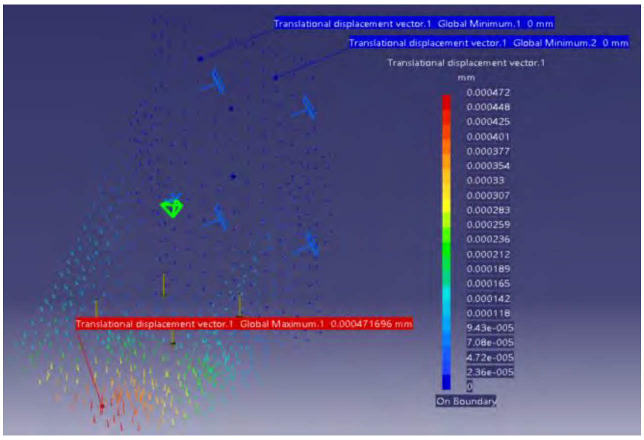


Figure 4.10: Translational displacement vector of wood platform.

D) Clip Hanger

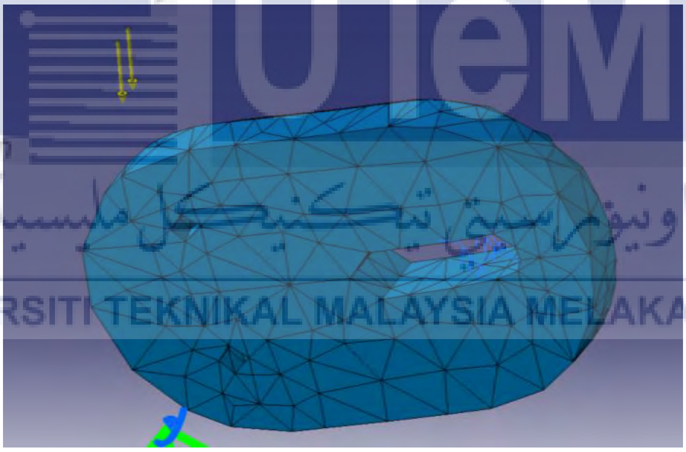


Figure 4.11: Deformation on the clip hanger.

As shown in the Figure 4.11, it is the deformation result on clip hanger when a downward 10 N load is set on the edge closer to the joint's point of the clip. ABS plastic is used as the material for the clip hanger. From this analysis, the possible form of the clip hanger after load is applied can be known besides of its maximum ability to withstand a given load. ABS plastic is used as the clip hanger can be fabricated using 3D printer. This method is significantly fast and cheaper instead of using metal fabrication. By using ABS, the design of the clip hanger can be changed and printed again in a short time if it is not able to withstand the load.

Figure 4.12 shows the analysis results for Von Mises stress on the clip hanger with minimum value of $1073.6Nm^2$ and maximum of $603403Nm^2$.

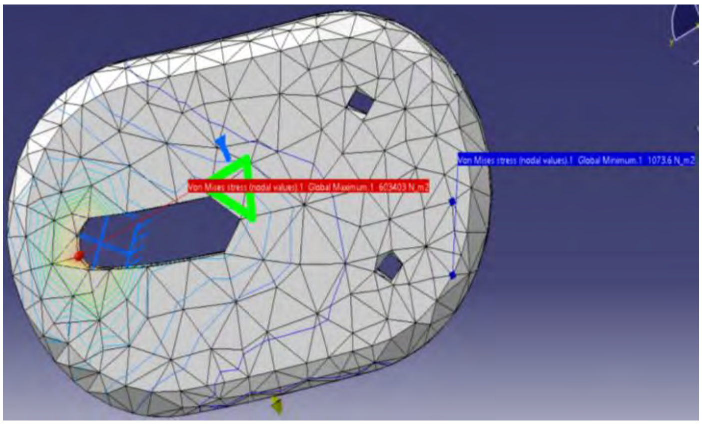


Figure 4.12: Von Mises stress of clip hanger.

Figure 4.13 shows the analysis results for translational displacement vector of the clip hanger with maximum value of 26.0203x10^{-3}mm.

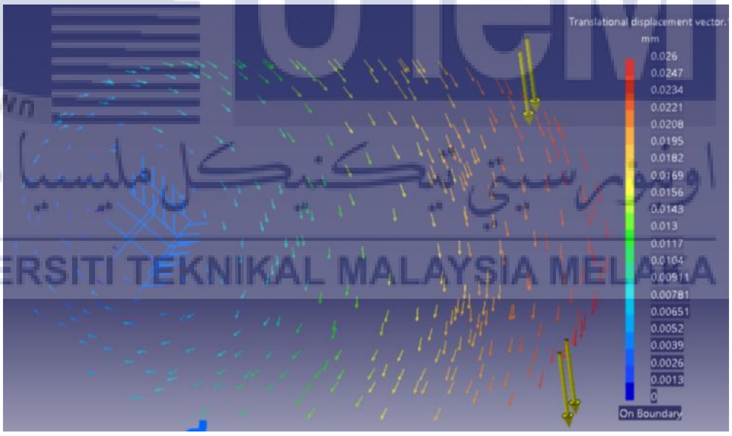


Figure 4.13: Translational displacement vector of clip hanger.

E) Motor

For waste material used which is ABS, the suitable screw speeds are ranging between 75 to 153 rpm. So a geared-DC motor with 120 rpm is used to drive the auger bit. Figure 4.8 shows the motor used for the recycle machine.

Figure 4.14: DC geared motor.

Calculation on the motor is done regarding to its angular velocity and also the angular acceleration by using the 120 rpm value. The calculations for both factors are as shown below:

$$Angular\ velocity, \omega = \frac{2\pi N}{60}$$

$$= \frac{2\pi(120)}{60}$$

$$= 12.5664\ rad/s \qquad 4.2.1(a)$$

$$Angular\ acceleration, \alpha = \frac{\omega}{60}$$

$$= \frac{12.5664 rad/s}{60}$$

$$= 0.2094\ rad/s^2 \qquad 4.2.1(b)$$

F) Drill bit

To get the best outcome from the use of auger bit, the application of power screw formula is very helpful in order to get the required amount of torque to move the waste down the thread, torque needed without friction and not to forget the suitable power required to drive the screw.

The calculations for all the required factors are shown below. The thread of tooth profiles for the auger bit is square with size of 3.81 cm, with minor diameter of 3.07 cm, and coefficient friction is assumed to be 0.20. The load is set to be 5 N.

a) Torque required to move the waste down the thread:

Firstly, need to determine the value of pitch diameter, $\boldsymbol{D_p}$

$$\boldsymbol{D_p = \frac{D + D_m}{2}}$$

$$= \frac{3.81 + 3.07}{2}$$

$$= 3.44 \text{ cm}$$

$$\boldsymbol{T_d} = \frac{\boldsymbol{F \cdot D_p}}{2} \left[\frac{\boldsymbol{\pi \cdot f \cdot D_p - L}}{\boldsymbol{\pi \cdot D_p + f \cdot L}} \right]$$

$$= \frac{5 \times 0.034}{2} \left[\frac{\pi \times 0.2 \times 0.034 - 0.00847}{\pi \times 0.034 + 0.2 \times 0.00847} \right]$$

$$= \mathbf{5.049 \times 10^{-3} \ Nm}$$

b) Torque required without friction:

$$\boldsymbol{T' = \frac{F.L}{2 \cdot \pi}}$$

$$= \frac{5 \times 0.00847}{2 \times \pi}$$

$$= \mathbf{6.7402 \times 10^{-3} \ Nm}$$

c) Power required to drive the power screw:

$$\boldsymbol{P = \frac{T \cdot n}{63000}}$$

$$= \frac{5.049 \times 10^{-3} \cdot 120}{63000}$$

$$\boldsymbol{= 9.6171 \times 10^{-6} W}$$

4.2.3 Assembled Drawing

At this stage, all the parts of the recycle machine have been assembled. This is to ensure the fitting of each part is correct to with each other without any error of dimension. Besides, this method is important especially before the fabrication initiated. By doing this, there will be no waste of time during fabrication due to unnecessary error. In Figure 4.9, it shows the final assembly of the CAD drawing for chosen design concept 2 and the exploded view of the assembled drawing.

Figure 4.15: Final assembly of concept design 2's CAD drawing

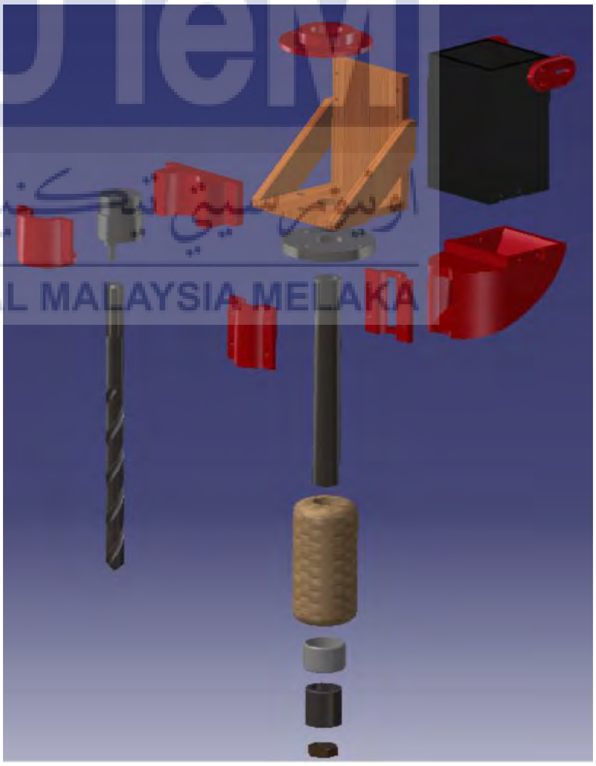


Figure 4.16: Exploded view of concept design 2's drawing

4.2.4 Technical Drawing

In this section, the details information about the product assembly are shown. The purpose of this technical drawing is to ease the fabrication process by providing information of the product such as the detail dimension of each part besides isometric, top, side and front views of the product. In Figure 4.10 shows the technical drawing of the recycle machine.

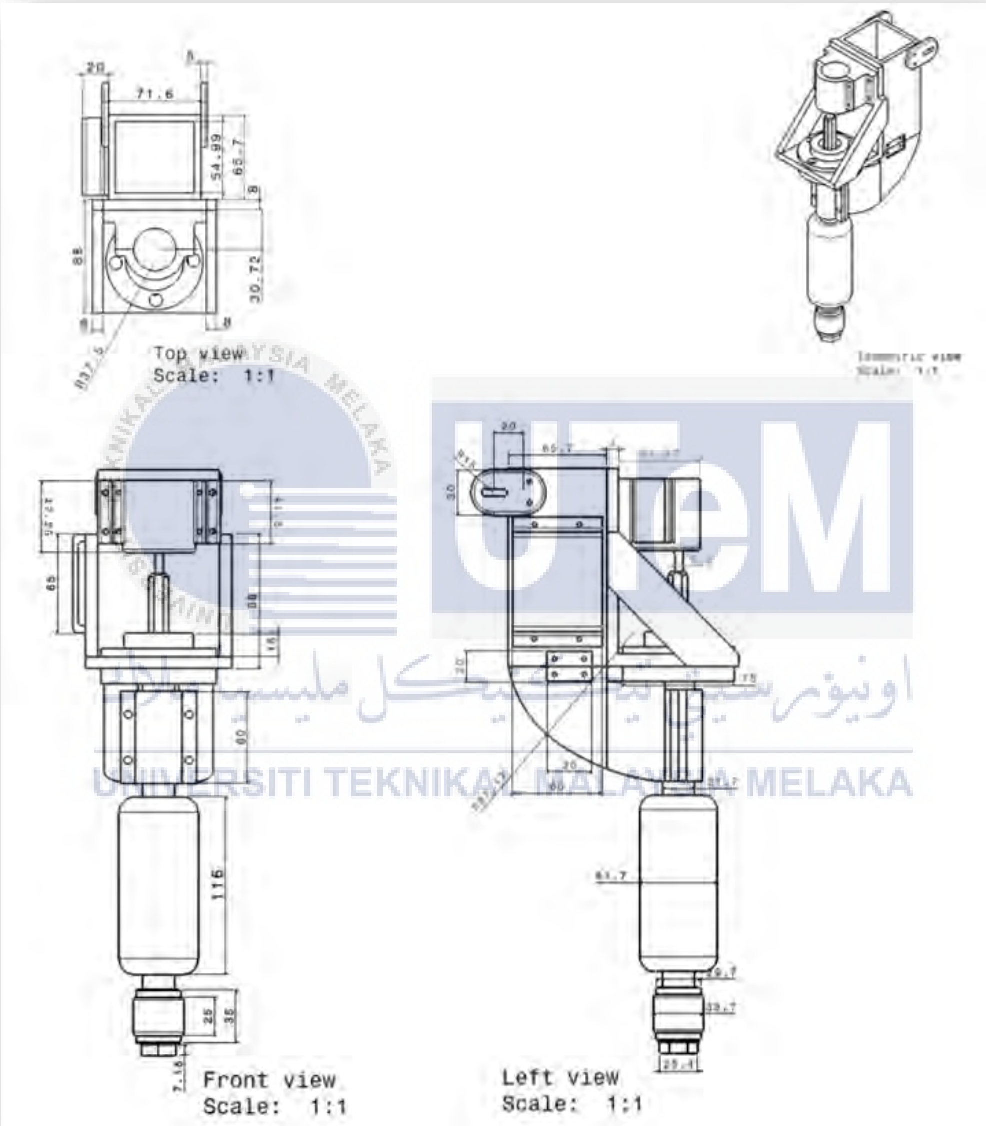
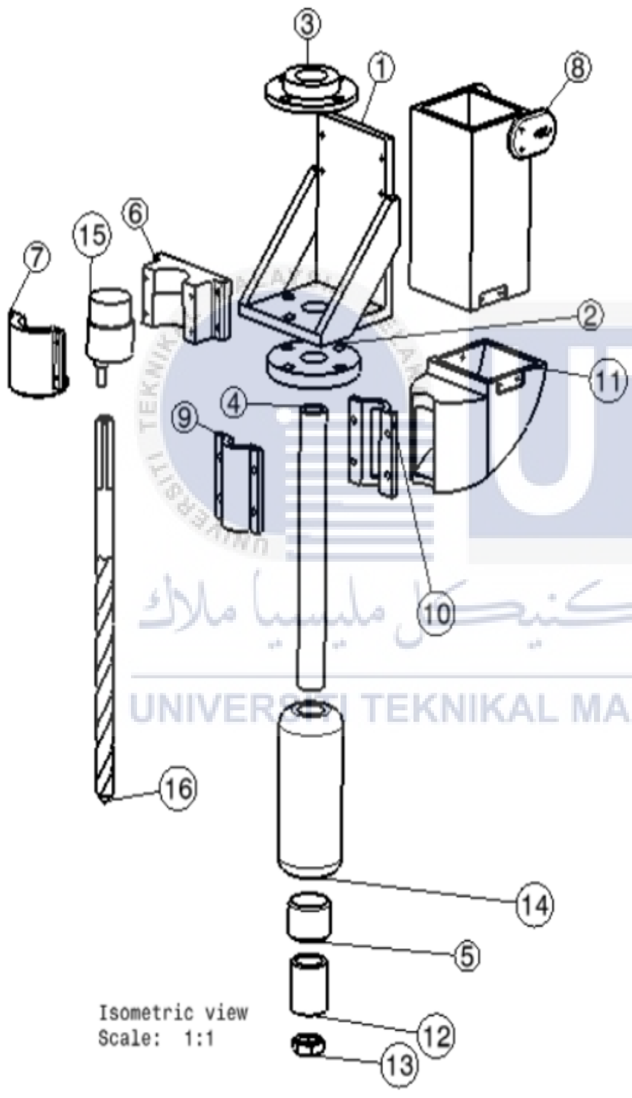


Figure 4.17: Technical drawing of recycle machine

4.2.5 Bill of Material

In order to build a complete product, it is compulsory to list all of the parts as per requirement in design engineering. This list of parts with details or called as bill of material will really ease the process to obtain the materials without having to worry to miss any of it. Besides, it can also reduce the time required to obtain all the materials. In Figure 4.11 shows the bill of material drafted on the exploded view for clear view of each part.



Bill of Material: 3D printer recycle machine

Number	Quantity	Part Number	Type
1	1	wood frame	Part
2	1	pipe holder base	Part
3	1	bearing holder	Part
4	1	barrel	Part
5	1	heater band	Part
6	1	clamp motor (BELOW)	Part
7	1	clamp motor (TOP)	Part
8	1	hopper with clip hanger	Part
9	1	hopper clamp	Part
10	1	hopper clamp with hole	Part
11	1	lower part hopper	Part
12	1	connector	Part
13	1	nozzle	Part
14	1	insulator	Part
15	1	motor	Part
16	1	drill bit	Part

Figure 4.18: Bill of material on the exploded view

4.3 PROTOTYPE

Prototype is a preface model and act as sort of a guideline for future works. It provides occasion for other people to make improvements from the studies on the current design. This is to ensure a product can be manufactured with its functions are reliable.

4.3.1 Fabrication

For the fabrication of the recycle machine, it involves the use of electronic parts and various materials from wood, metal and polymer. The wood being used is unused plywood, metal parts bought are ready-made galvanized iron and also brass while ABS polymer is used in 3D printing to print majority of the recycle machine's parts. The 3D printer used is the CubePro Duo. For the parts that needs to be 3D printed, the CAD drawings are sliced layer by layer before proceeds with the printing.

The integrated 3D printer recycle machine has three main components which are shredder, extruder and hopper. As mentioned in the earlier part of this project, shredder component would not be explained or fabricated again because the priority is to improve the hopper and the extruding system. In Figure 4.19, it shows the 3D printing process of the bearing holder by using CubePro Duo. Printing duration is different for each part depending on the size and density. Besides, the print quality setting also affect the time required to print parts. It includes layer resolution, print strength and print pattern. If to use finest resolution, solid and honeycomb's pattern, it would take hours even for a small part.

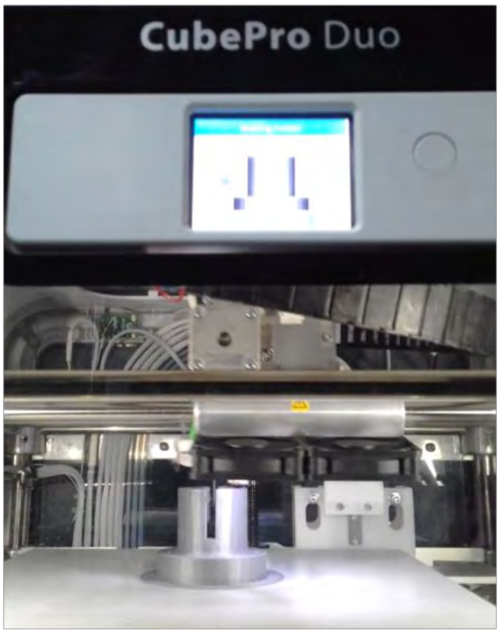


FIGURE 4.19: Bearing holder part printed using CubePro Duo 3D printer.

There is a reason why some parts are bought ready-made especially the metal parts. In order to withstand very high temperature from the heater band during extruding process, it is wise to use metal parts instead of ABS-printed parts. It is because the waste polymer that is going to be shredded, melted and extruded into new filament is the same ABS type polymer so it will melt no matter what. Besides that, wood is not suitable because the extruding system is built with cylinder-shaped barrel and threaded parts. It will consumes a lot of time to customize the wood into the barrel and other tiny parts. Ball bearing as shown in Figure 4.20 is used to provide smooth rotational motion of the drill bit during extrusion process.

FIGURE 4.20: Ball bearing for the drill bit shaft.

Warping is one of the problem that could happen in any 3D printing process. When it happens, it will change the geometry of the desired part. Due to that, it will cause failure in assembly process especially when it comes to joint two different parts together. Sometimes, the warped part may not be a total defect if only the assembly process can be done according to the requirement. If it is not possible, then reprinting the part is the only way along with slight modification on the gluing amount and maybe the printing orientation of the part.

The assembly process is begun once all the 3D printed parts are correctly printed, barrel is already bored and plywood is cut into desired pieces according to individual's dimension. Figure 4.21 shows all the parts that will be assembled together to become a 3D printer recycle machine.

FIGURE 4.21: Parts for the assembly process.

Temporary joint is the type of joint mechanism used in assembling the recycle machine. The reason to use only temporary joint is because the ability to reassemble the recycle machine with other parts if there is a problem occurs during the assembly process. Besides that, it allows implementation of any improvement to the design due to the fact the recycle machine is still a prototype. So, there is no need to fabricate a whole new set of recycle machine. Bolts and nuts, as shown in Figure 4.22 are the main momentary joint mechanism used in assembling the recycle machine.

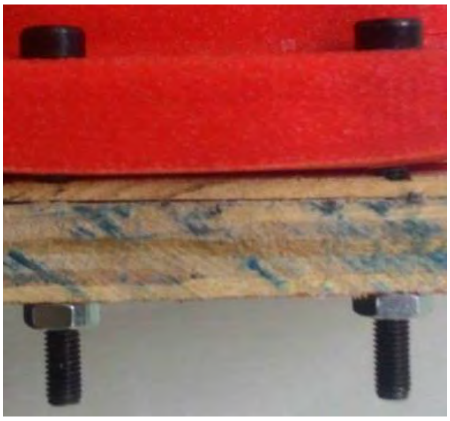


FIGURE 4.22: Bolts and nuts for temporary joint.

Aside from screws that are also being used in the assembly process, thread is included as the joint mechanism. Threading is used to join the parts of extruding system such as barrel, barrel holder, connector and the nozzle. Figure 4.23 shows the parts with threaded end for joining purposes.

FIGURE 4.23: Extrusion system's parts with threaded ends.

A coupler is custom made to fit the motor's shaft and the drill bit's shaft. Due to the difference in diameter between the two shafts, it is necessary to use coupler as its purposes is to connect units that are manufactured individually. Besides that, the reason to use coupler is to ensure the axis of rotation for both shafts are locked and centred to prevent swirling movement of the drill bit during extrusion process which could cause vibration that might leads to failure of the recycle machine. In Figure 4.24, it shows the coupler of spider coupling type with customized internal diameters that is used to connect both motor and drill bit's shafts.

FIGURE 4.24: Spider coupling type for the shafts of the motor and drill bit.

For the assembly process, the 3D printed parts are assembled individually for each component such as the hopper, the motor housing and the barrel clamp. After that, the assembled 3D printed parts are attached to respective components. As example, the clamp is installed around the barrel at the bored area just like in the Figure 4.25.

FIGURE 4.25: Installation of 3D printed clamp around the barrel.

After that, part of the extrusion system's components are assembled together as shown in Figure 4.26, which include barrel, connector, drill bit and nozzle. Drill bit is put through the barrel from the front where connector is attached due to the size of bit of the drill do not fit the barrel. Then, the wood platform is built. Barrel holder, bearing holder and motor housing are also assembled onto the wood platform. This is to ensure strong hold and easy joining process between the individual parts.

FIGURE 4.26: Assembly for part of the extrusion system.

After that, the assembled barrel are screwed onto the barrel holder followed by joining the hopper onto the wood platform by using bolts and nuts. By using the customized coupler, connect the motor's shaft with the drill bit's shaft and tighten the screw to lock the position of the shafts. The temperature controller and the switches are installed on the side of the hopper. For the heater band, it is clamped around the connector along with the sensor which acts as the thermocouple. Next is the crucial step which is the electrical setup. Correct wiring is needed to connect heater band, sensor, motor, switches and temperature controller together in order to run the recycle machine without having any failure or safety issue. The complete assembly of the 3D printer recycle machine is shown in Figure 4.27.

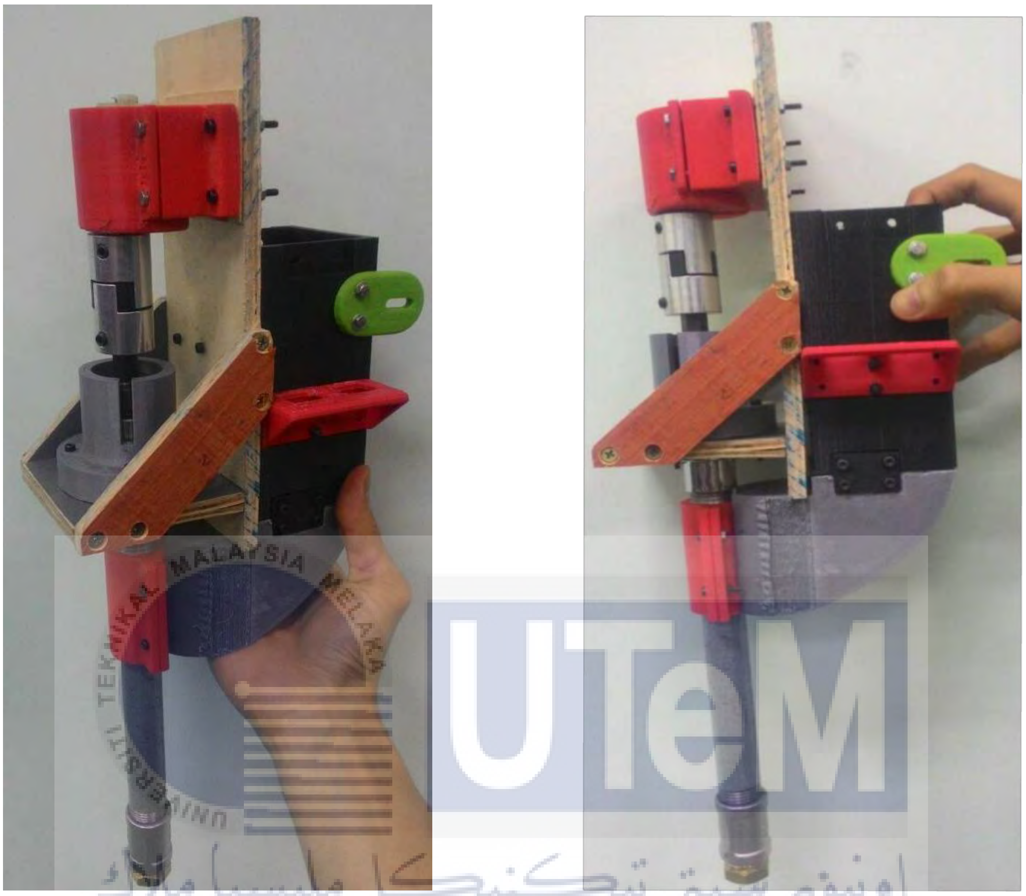


FIGURE 4.27: Full assembly of the 3D printer recycle machine.

4.3.2 Testing

The recycle machine is put on several test runs in order to observe and analyse its condition during the operation. 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. ABS waste polymer that are pre-crashed into granules form are prepared.

Based on the background study on ABS filament, the suitable temperature of 250℃ is set as the minimum temperature in order to melt the waste polymer without ruining its chemical properties. 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.

As expected, 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.

4.3.3 Filament Extrusion

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. Initial temperature was set at 250°C. After a while about three to four minutes, the waste granules is poured into the hopper and delivered into the barrel before the motor's switch is turned on to let the drill transports the waste granules into the end part of the nozzle. At this stage, the granules are being melted by the heat from heater band. That is why it took a while for the filament to be extruded through the nozzle. Figure 4.28 shows the extruded filament.

FIGURE 4.28: Extruded filament out of the nozzle.

In order to analyse the size of extruded filament with respect to the standard measurement, diameter of the filament was measured after every 100 mm. 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:

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

For each temperature, the readings were taken five times to get the average measurement. Table 4.1 shows the results of percentage error for each set of temperature.

TABLE 4.1: Results of percentage error for diameter of filament.

Diameter of filament for 100 mm	Percentage of error (%)
1.87	6.86
1.90	8.57
1.88	7.42
1.86	6.29
1.90	8.57
1.84	5.14
1.88	7.43
1.85	5.71
1.86	6.26
1.88	7.43

Measurement for each filament's diameter is done by using vernier calliper. 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 9% of error. The lowest error is 1.84mm diameter with 5.14% while the highest error is 1.90mm diameter that equals to 8.57%.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Throughout the project, the three main objectives of designing an integrated 3D printer recycle machine have been achieved. For design engineering, it is initiated with design formulation followed by conceptual design in order to be the guideline for further design in detail according to the required specifications. The incisive stage is the detail design and prototyping. It is because ideas are produced which also lead to the problem statement. To solve the problems, sometimes it takes hours or even days in order to come out with solutions. As example, to determine how to connect the motor with the drill bit without compromising the physical of each part. Several tests was conducted. Test after test until the idea to make a coupler arose. In the way to obtain the solution, there was a long and tough journey to go through because every single possible solution was tested and failed. To ensure the success of this project, nothing can prevent the will to achieve the goal. For the prototype of the extrusion, the actual material which is galvanized iron pipe was used in order to get the actual data and results of filament extrusion. This is because the main goal of this project is to ensure the new filament is extruded through the nozzle. In the way to achieve that goal, safety was not forgotten. Safety always is the priority. That is why the PID was used in order to control the temperature. So the heater band would not exceed the temperature limit during operation to prevent any casualties happen during the run. The cost of the prototype is way cheaper than hiring the tinsmith to fabricate the actual recycle machine. By fabricating recycle machine using the available resources, it really is a cost saving method especially when in experimental stage. The filament was finally extruded even it does not follow the standard size. The filament that came out were of 1.87 ± 0.05 mm with 1.84mm as the thinnest while 1.90mm as the thickest. From that maximum thickness, it means that the objective to obtain below than 9% percentage error of filament diameter is a success. Last but not least, this project indicates that the concept can be further improved 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 the motor speed should be controlled. By having a speed controller, the ideal extrusion rate can be identified along with the correct temperature. By having both in control, the filament that can be extruded would be following the standard size and with consistency. Besides, the design of the recycle machine can be further simplified to make it portable, lightweight and easy to use. Last but not least, the size of the nozzle can be further optimize to get the suitable size for consistent diameter of filament extruded.

REFERENCES

Christian Baechler, Matthew DeVuono, Joshua M. Pearce Distributed recycling of waste polymer into RepRap feedstock, Rapid Prototyping Journal 19:2, 118-125, 2013

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. Philosophical Transactions Of The Royal Society B: Biological Sciences, 364(1526), 2115-2126. http://dx.doi.org/10.1098/rstb.2008.0311

Klein, R. (2011). Laser Welding of Plastics (pp. 3-8). Wiley-VCH Verlag GmbH & Co. KGaA.

Lindemann, C., Reiher, T., Jahnke, U., & Koch, R. (2015). Towards a sustainable and economic selection of part candidates for additive manufacturing. Rapid Prototyping Journal, 21(2), 216-227. http://dx.doi.org/10.1108/rpj-12-2014-0179

Lipson, H. (2014). The Future of 3D Printing. Presented at SITE: Society for Information Technology & Teacher Education International Conference 2014.)

Malte, G., Schoot UiterkampAnton J.M., S., & Cindy, V. (2014). A global sustainability perspective on 3D printing technologies. Energy Policy, 74(c), 158-167.

Mohd Iskandar Bin Jailani. (2015). Development Of Integrated Recycle System For Low Cost 3D Printer, 1, 1-3.

NI Xiangyang (2005) Dynamic Modeling and Optimization Design of Gantry Style Machining Center [D]. NanJing:Southeast University

Olmsted, B., & Davis, M. (2001). Practical injection molding. New York: Marcel Dekker

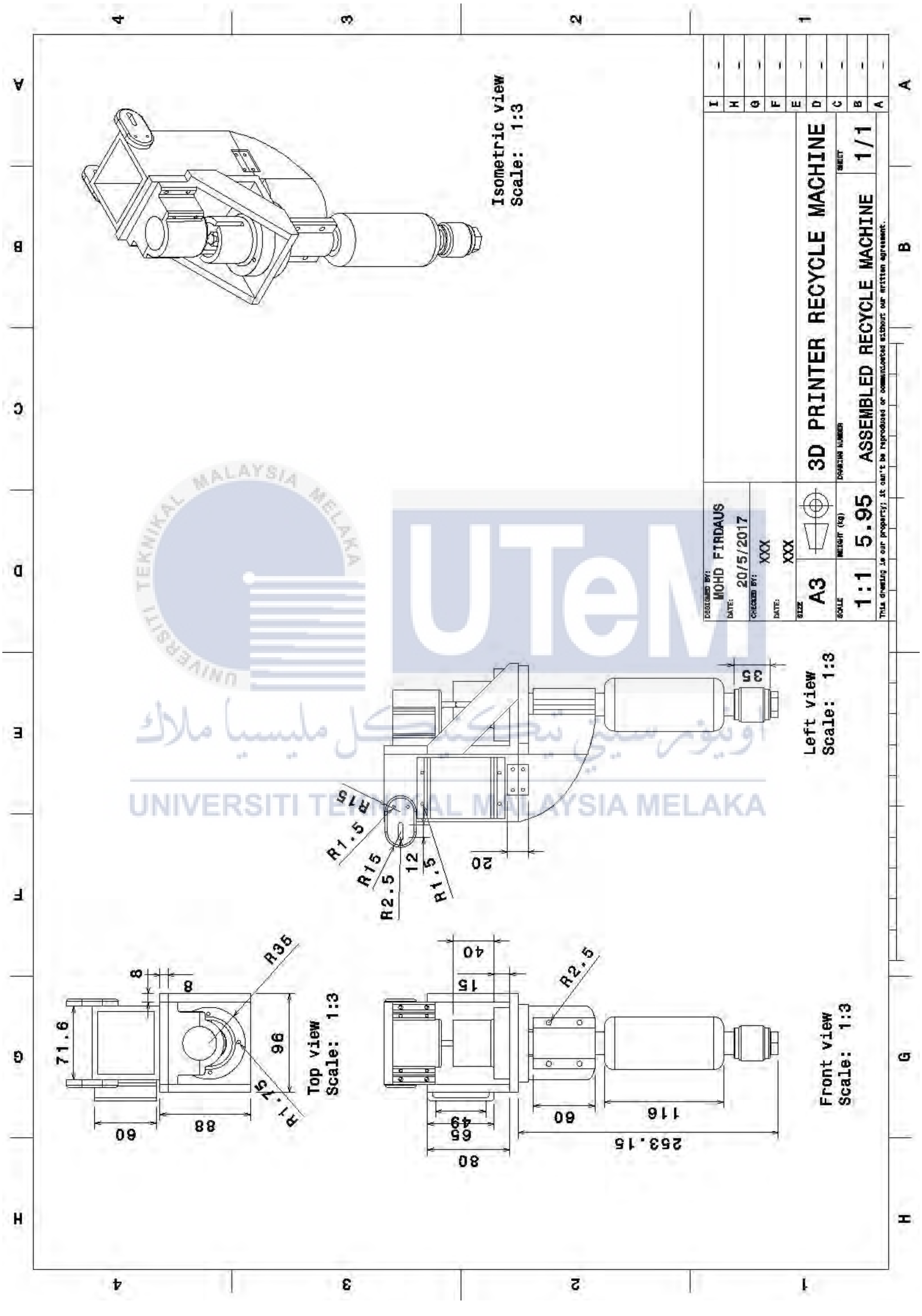
Printing, T., & Chilson, L. (2015). The Difference Between ABS and PLA for 3D Printing. ProtoParadigm. Retrieved 19 October 2015, from http://www.protoparadigm.com/news-updates/the-difference-between-abs-and-pla-for-3d-printing/

Ramli F.R., Jailani M.I., Unjar H., Alkahari M.R., Abdullah M.A. (2015) Integrated recycle system concept for low cost 3D-printer sustainability. Proceedings of Mechanical Engineering Research Day March 2015. Universiti Teknikal Malaysia Melaka, pp. 77-78

Rosato, D., Rosato, M., & Schott, N. (2010). Plastics technology handbook. [New York, N.Y.] (222 East 46th Street, New York, NY 10017): Momentum Press

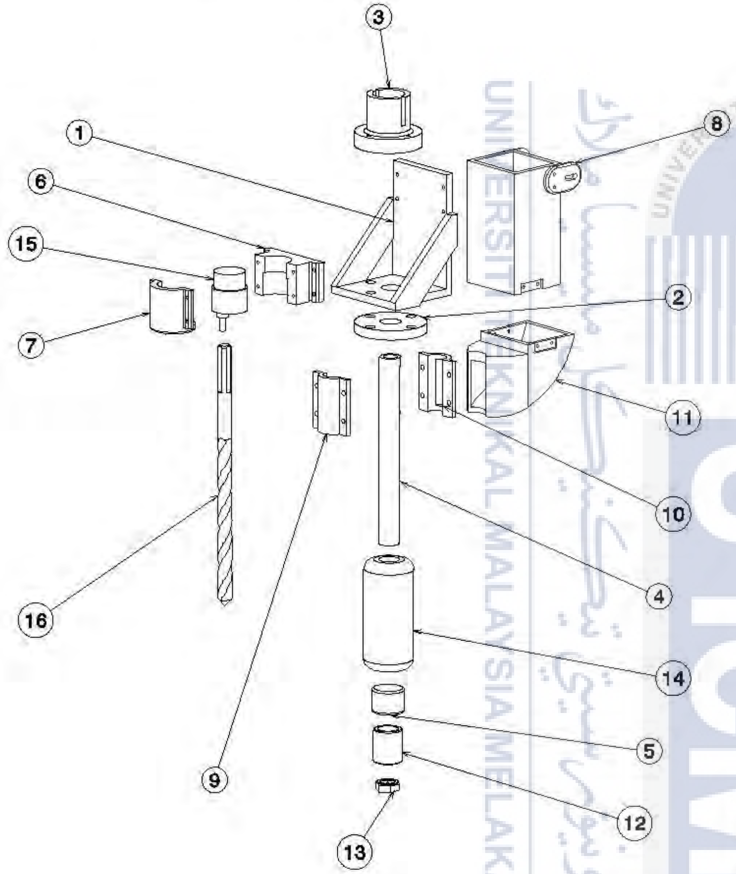
Thompson, R. C., Swan, S. H., Moore, C. J. & vom Saal, F. S. 2009a Our plastic age. Phil. Trans. R. Soc. B 364, 1973–1976. (doi:10.1098/rstb.2009.0054)

APPENDIX A1



Isometric view
Scale: 1:3
Left view
Scale: 1:3
Top view
Scale: 1:3
Front view
Scale: 1:3
3D PRINTER RECYCLE MACHINE
ASSEMBLED RECYCLE MACHINE
DESIGNED BY: MOHD FIRDAUS
DATE: 20/5/2017
CHECKED BY: XXX
DATE: XXX
A3
1:1
5.95
1/1

APPENDIX A2



Isometric view
Scale: 1:4

Bill of Material: 3D PRINTER RECYCLE MACHINE

Number	Part Number	Quantity	Type
1	wood frame	1	Part
2	pipe holder base	1	Part
3	bearing holder	1	Part
4	barrel	1	Part
5	heater band	1	Part
6	clamp motor (BELOW)	1	Part
7	clamp motor (TOP)	1	Part
8	hopper with clip hanger	1	Part
9	hopper clamp	1	Part
10	hopper clamp with hole	1	Part
11	lower part hopper	1	Part
12	connector	1	Part
13	nozzle	1	Part
14	insulator	1	Part
15	motor	1	Part
16	drill bit	1	Part

DESIGNED BY: MOHD FIRDAUS
DATE: 20/5/2017
CHECKED BY: XXX
DATE: XXX

SIZE: A3
3D PRINTER RECYCLE MACHINE
SCALE: 1:1
WEIGHT (kg): 5.71
DRAWING NUMBER: EXPLODED VIEW WITH BOM
SHEET: 1/2

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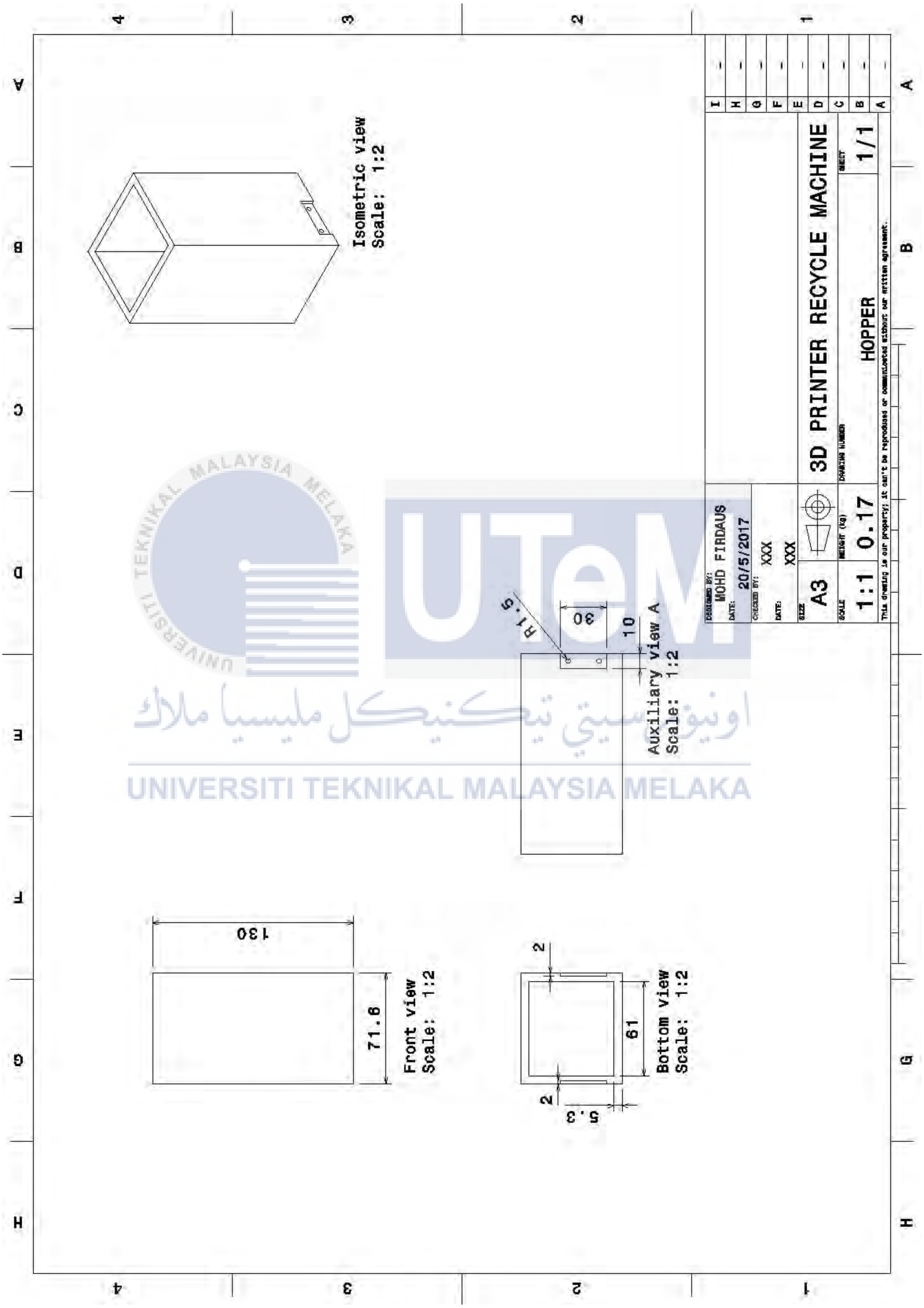
APPENDIX A3


Isometric view
Scale: 1:2
Auxiliary view A
Scale: 1:2
R1.5
30
10
Front view
Scale: 1:2
130
71.6
Bottom view
Scale: 1:2
2
61
2
5.3
DESIGNED BY:
MOHD FIRDAUS
DATE:
20/5/2017
CHECKED BY:
XXX
DATE:
XXX
SIZE
A3
SCALE
1:1
WEIGHT (kg)
0.17
DRAWING NUMBER
3D PRINTER RECYCLE MACHINE
HOPPER
SHEET
1/1
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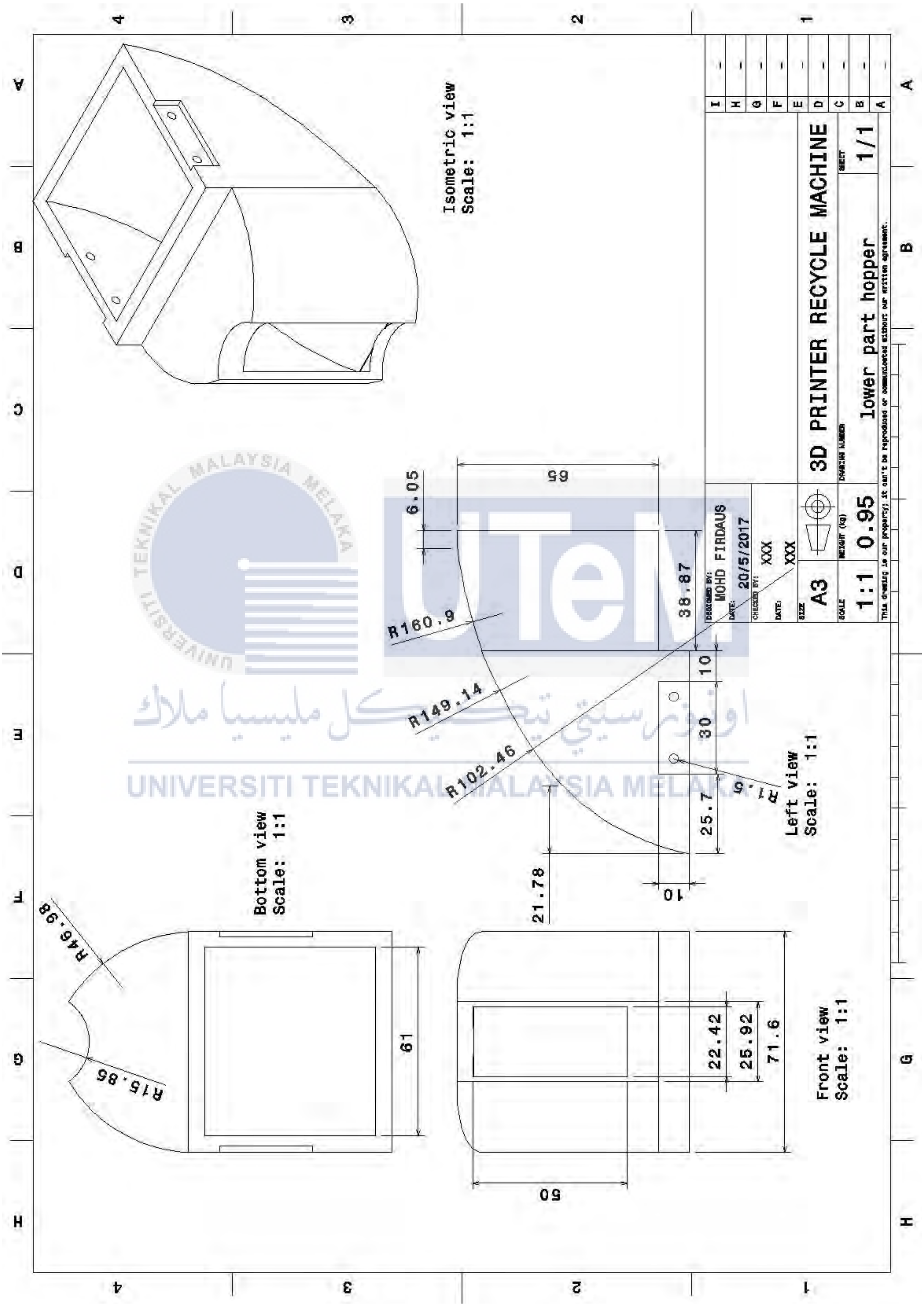
APPENDIX A4


Isometric view
Scale: 1:1
Bottom view
Scale: 1:1
Left view
Scale: 1:1
Front view
Scale: 1:1
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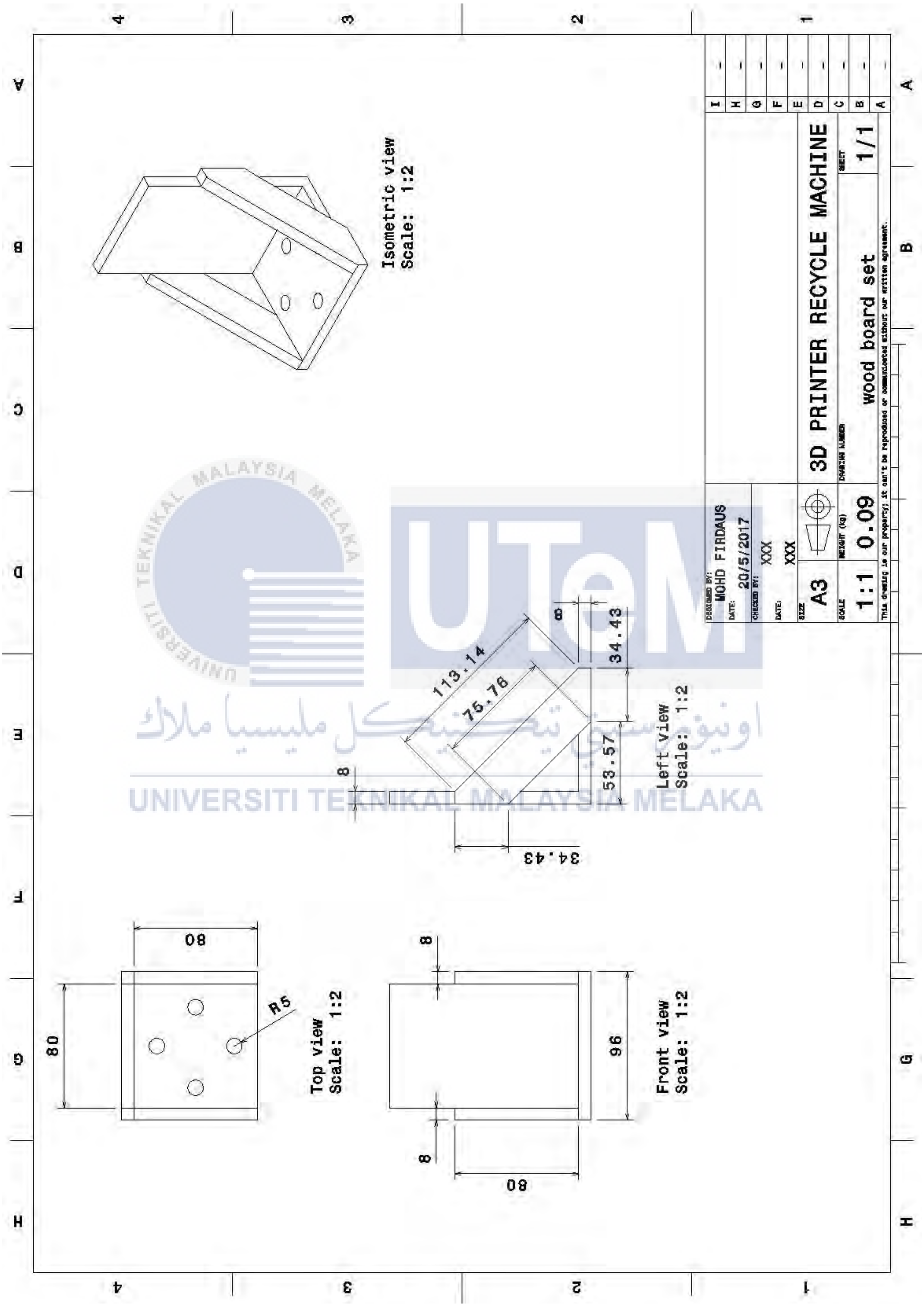
6.05
38.87
10
30
25.7
10
21.78
R160.9
R149.14
R102.46
R1.5
R46.98
R15.85
61
22.42
25.92
71.6
50
DESIGNED BY:
MOHD FIRDAUS
DATE:
20/5/2017
CHECKED BY:
XXX
DATE:
XXX
SIZE
A3
SCALE
1:1
WEIGHT (kg)
0.95
DRAWING NUMBER
3D PRINTER RECYCLE MACHINE
lower part hopper
SHEET
1/1

APPENDIX A5



Isometric view
Scale: 1:2
Left view
Scale: 1:2
Top view
Scale: 1:2
Front view
Scale: 1:2
113.14
75.76
34.43
53.57
34.43
8
8
80
80
R5
96
8
8
80
DESIGNED BY:
MOHD FIRDAUS
DATE:
20/5/2017
CHECKED BY:
XXX
DATE:
XXX
SIZE
A3
3D PRINTER RECYCLE MACHINE
SCALE
1:1
WEIGHT (kg)
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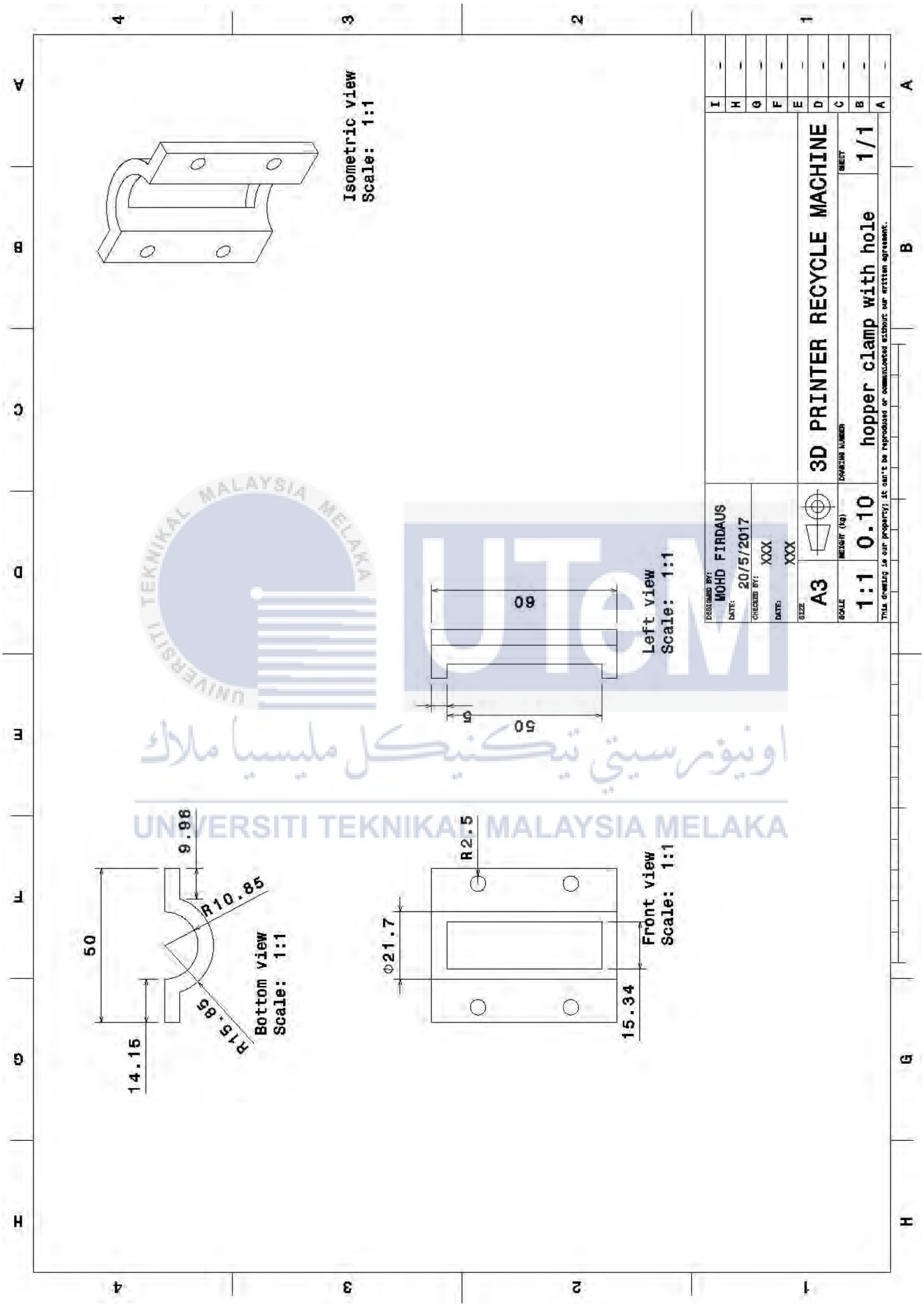
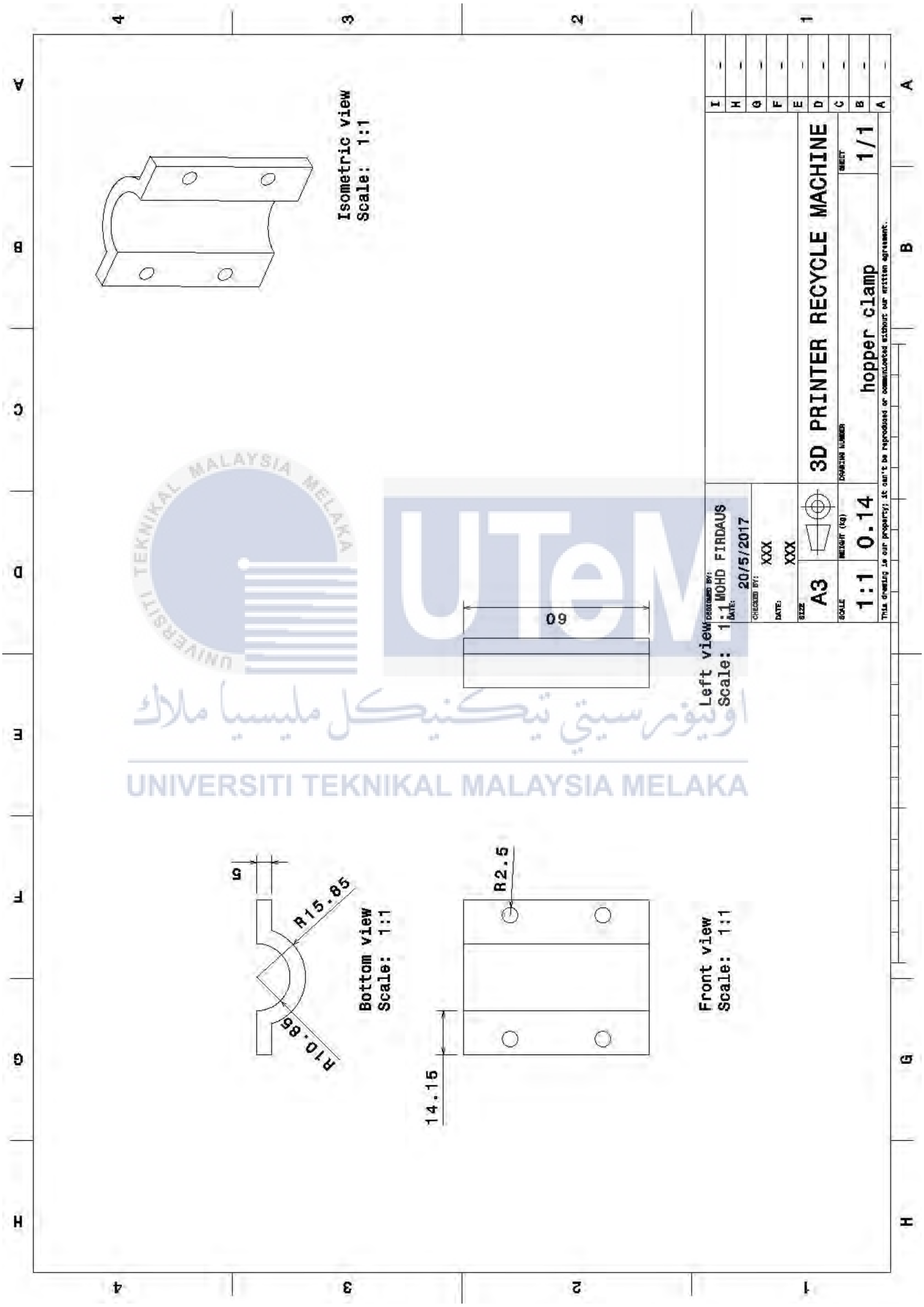
DRAWING NUMBER
wood board set
SHEET
1/1

APPENDIX A6


Isometric view
Scale: 1:1
Left view
Scale: 1:1
60
50
5
Bottom view
Scale: 1:1
50
9.98
R10.85
R15.85
14.15
Front view
Scale: 1:1
R2.5
⌀21.7
15.34
DESIGNED BY:
MOHD FIRDAUS
DATE: 20/5/2017
CHECKED BY: XXX
DATE: XXX
A3
3D PRINTER RECYCLE MACHINE
1:1
0.10
hopper clamp with hole
1/1

APPENDIX A7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Scale: 1:1
Left view
Scale: 1:1
60
Bottom view
Scale: 1:1
R15.85
R10.85
5
Front view
Scale: 1:1
R2.5
14.15
DESIGNED BY: MOHD FIRDAUS
DATE: 20/5/2017
CHECKED BY: XXX
DATE: XXX
SIZE A3
3D PRINTER RECYCLE MACHINE
SCALE 1:1
WEIGHT (kg) 0.14
hopper clamp
SHEET 1/1
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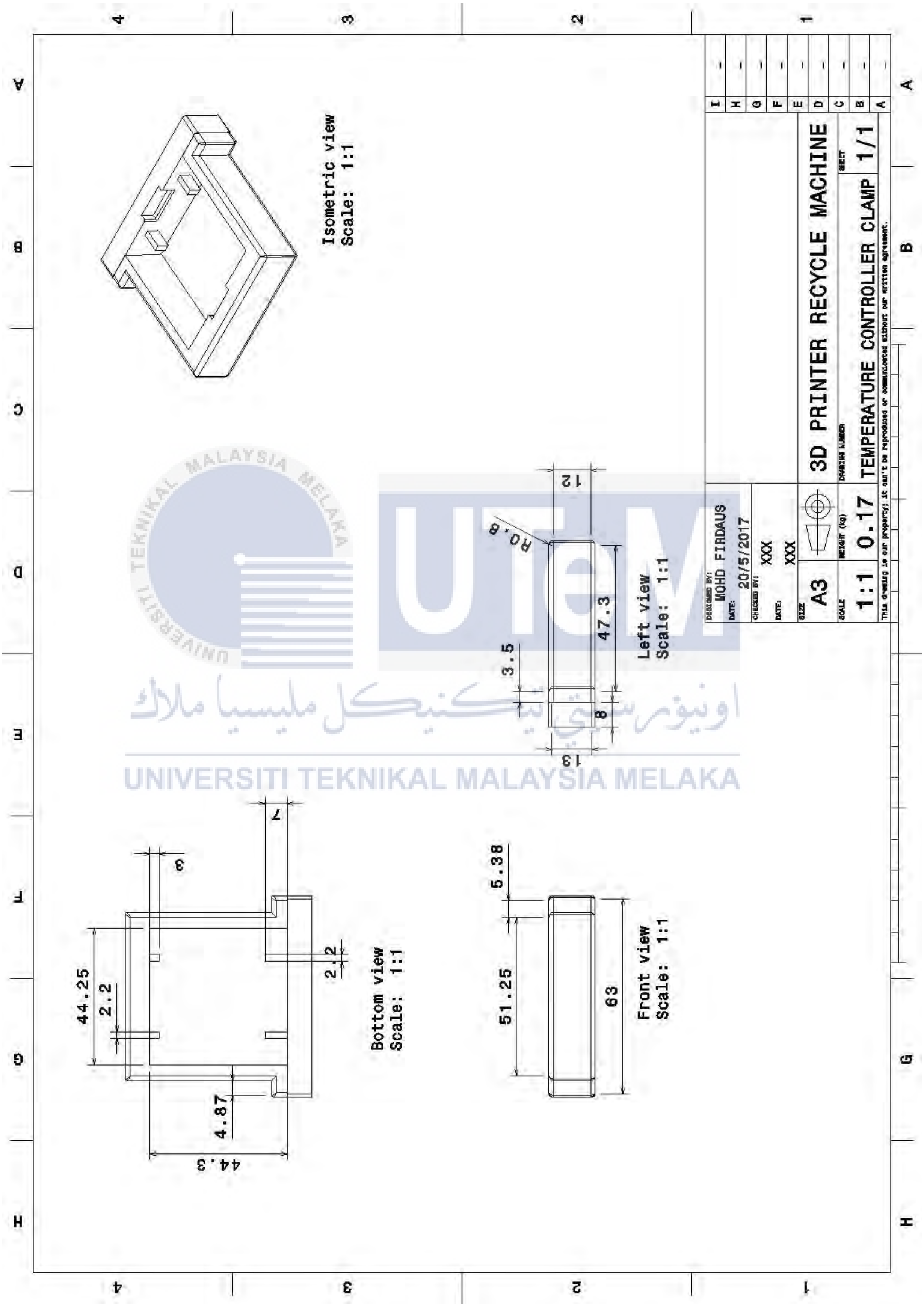
APPENDIX A8



Isometric view
Scale: 1:1
Left view
Scale: 1:1
Bottom view
Scale: 1:1
Front view
Scale: 1:1
R0.8
12
47.3
3.5
8
13
7
3
5.38
44.25
2.2
2.2
51.25
63
4.87
44.3
DESIGNED BY:
MOHD FIRDAUS
DATE:
20/5/2017
CHECKED BY:
XXX
DATE:
XXX
SIZE
A3
SCALE
1:1
WEIGHT (kg)
0.17
DRAWING NUMBER
3D PRINTER RECYCLE MACHINE
TEMPERATURE CONTROLLER CLAMP
SHEET
1/1
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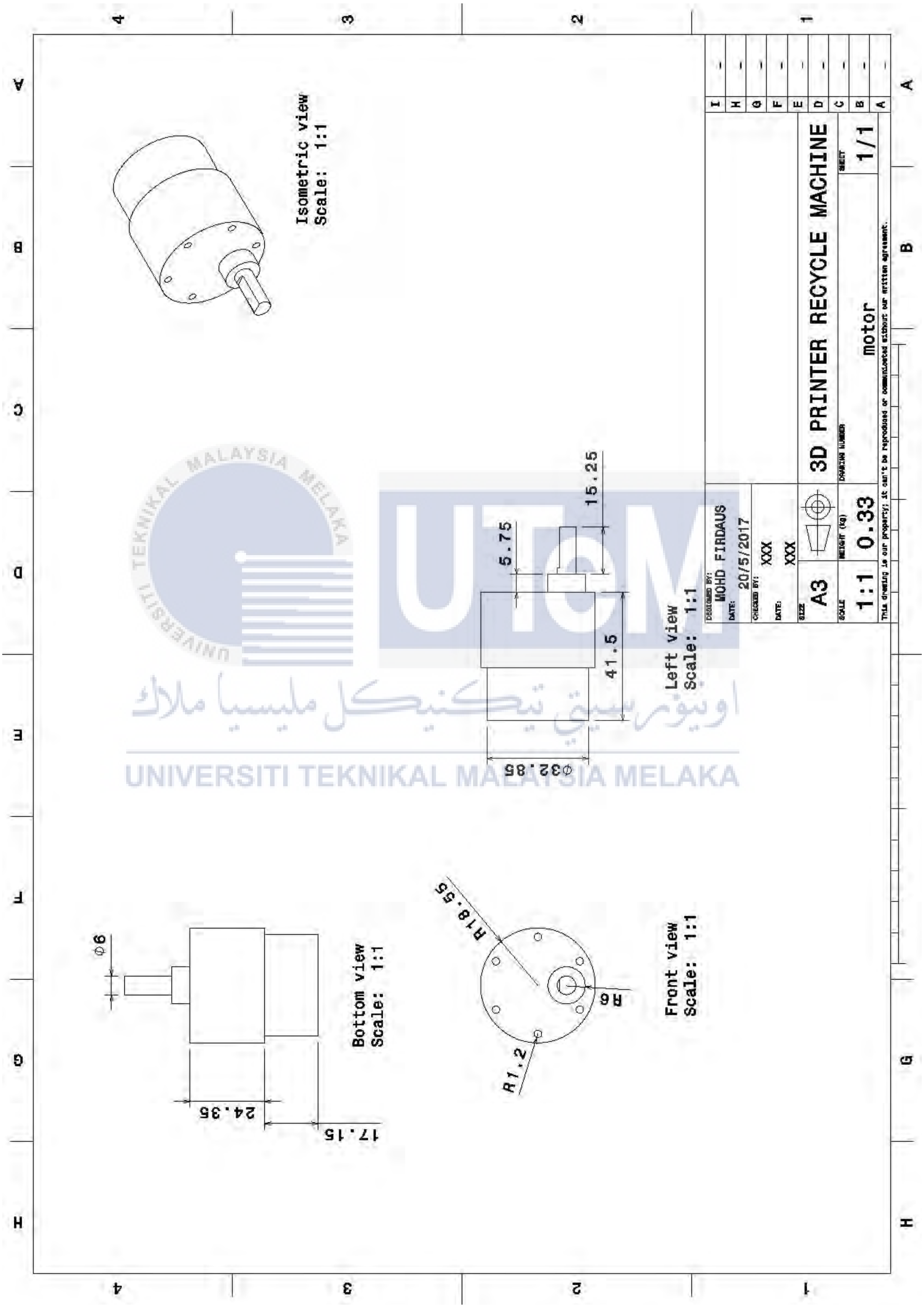
APPENDIX A9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Left view
Scale: 1:1
15.25
5.75
41.5
Φ32.85
Bottom view
Scale: 1:1
Φ6
24.35
17.15
Front view
Scale: 1:1
R18.55
R6
R1.2
DESIGNED BY:
MOHD FIRDAUS
DATE:
20/5/2017
CHECKED BY:
XXX
DATE:
XXX
SIZE
A3
SCALE
1:1
WEIGHT (kg)
0.33
DRAWING NUMBER
3D PRINTER RECYCLE MACHINE
motor
SHEET
1/1
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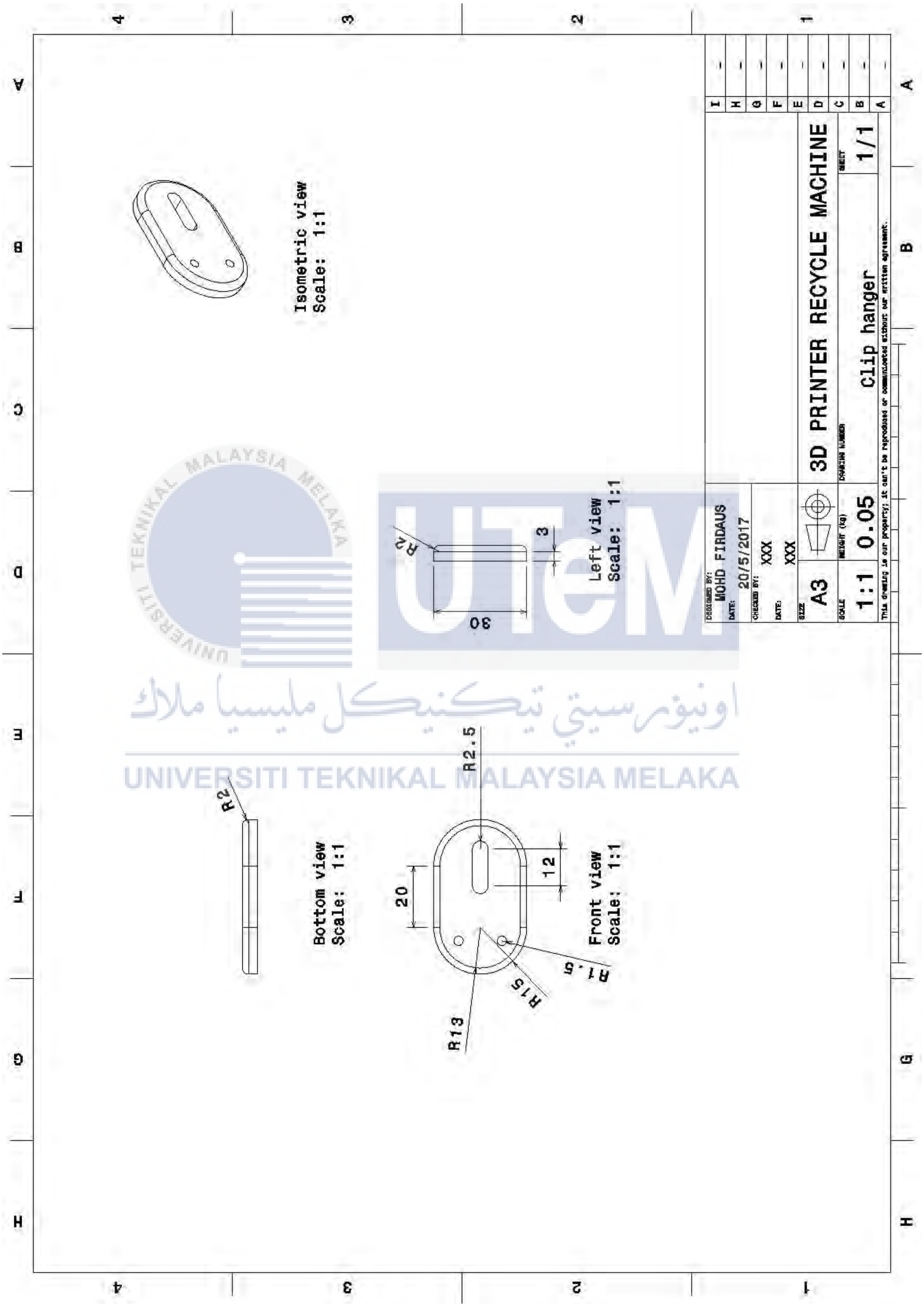
APPENDIX A10



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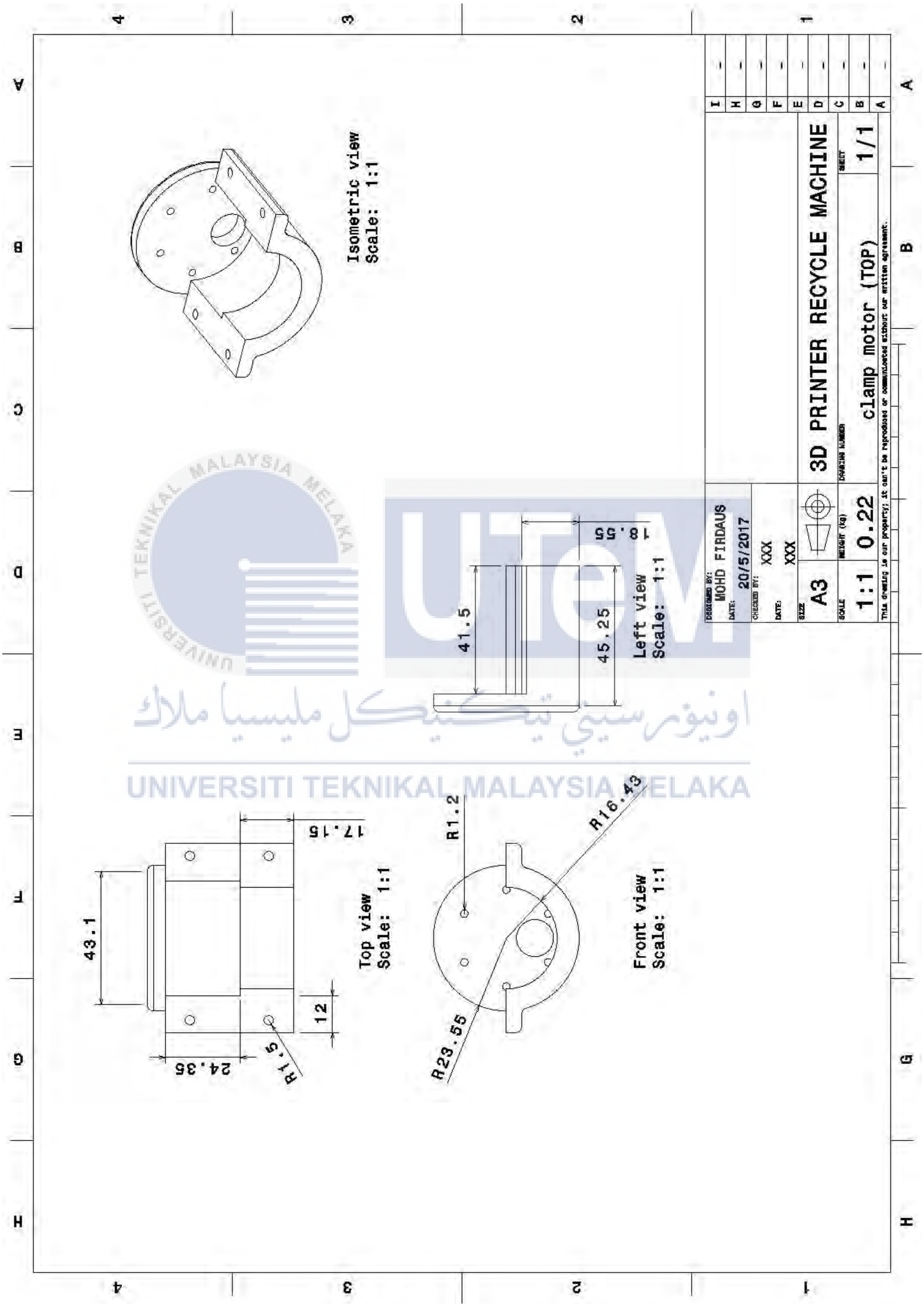
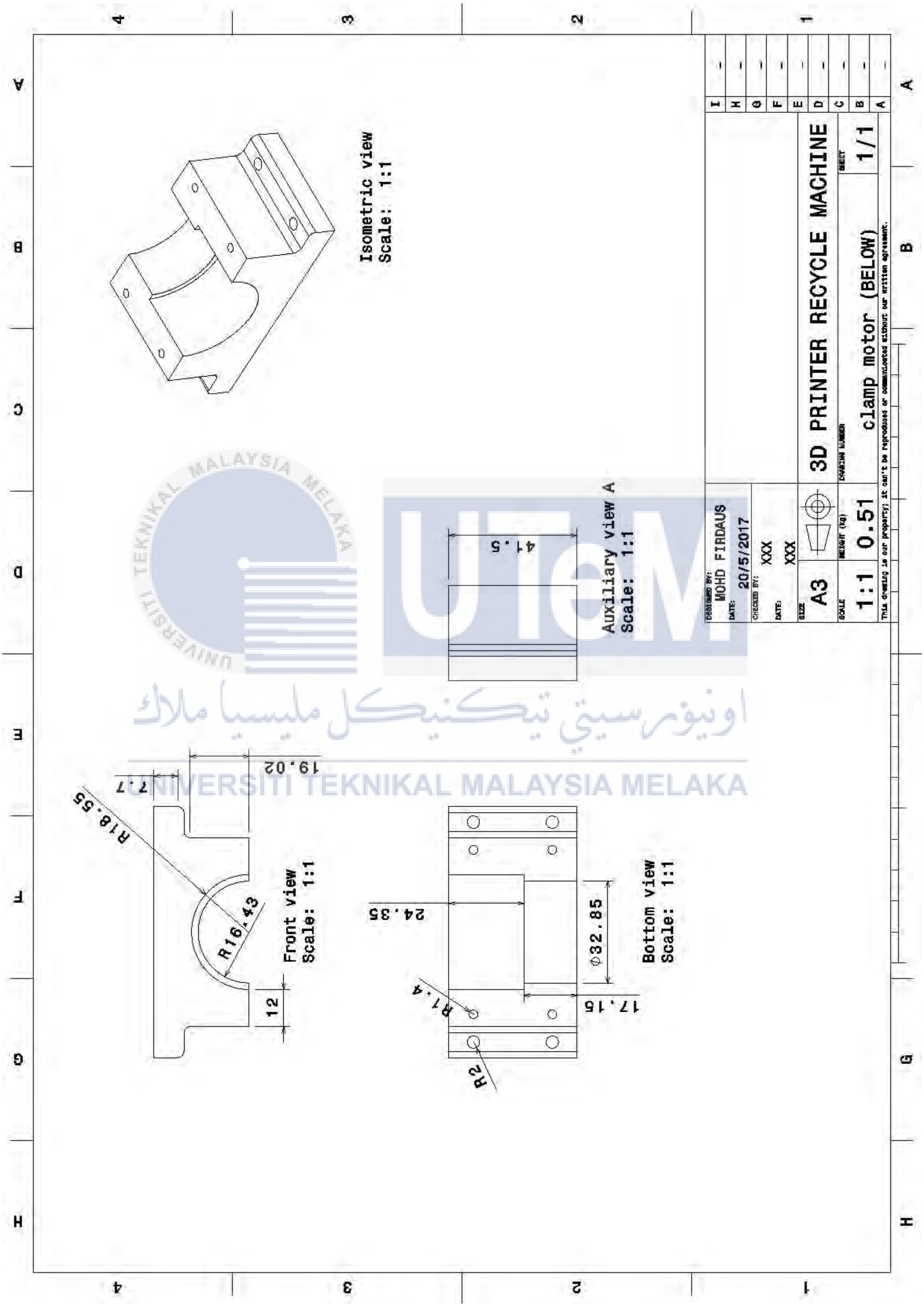


APPENDIX A12



APPENDIX A13