Master Thesis

Master's Programme in Mechanical Engineering, 60 credits

Experimental Investigation on Filament Extrusion using recycled materials.

Thesis in Mechanical Engineering , 15 Credits

Halmstad 2020-02-24
Syed Muhammad Raza, Dilawar Singh

HALMSTAD UNIVERSITY

PREFACE

Plastic pollution is a serious problem in the world. It has adverse effects on the environment; human life, sea life, wildlife. The plastic takes hundreds of years to break down and therefore is a threat to the environment. Researchers have been working on recycling plastic products and reduce the impact on environment. There are various techniques to re-use and recycle the waste thermoplastics into a useful product and extrusion of filaments for 3D printing from recycled plastics is one of them.

3D printing is a break-through technique in material addition manufacturing processes. It is a computer-controlled process to solidify or print a three-dimensional object as per the design specifications. 3D printing or Fused Deposition Modeling mostly uses plastic filaments as raw materials. The plastic filaments can be of various types and are made by following the process of heating, extruding and cooling plastic. Several researches have been conducted to produce useful 3D printing filaments from recycled plastics. Many industries have adapted re-using waste plastic products for the same purpose.

In the proposed study, failed 3D printed objects and support structures is recycled in order to produce filaments for 3D printers. The material under study includes recycled PLA (Polylactic Acid). These waste materials from failed prints are shredded in a shredder and then extruded into filaments of desired size and dimensions. The quality of the extruded filaments is checked by visual and dimensional methods, further, these are inspected for performance by using them in a conventional 3D printer.

ABSTRACT

Plastics have become an essential part of our lives whether it is a food container or a high-tech medical instrument or just ordinary household item. Various advantages and disadvantages of plastics co-exist and hence it is difficult to eliminate the usage of plastic materials in everyday life. It is favorable because of its low weight, durability, flexibility, ease of processing etc. At the same time, it is not recommended due to health and safety hazards related to it. Plastics made from renewable resources are high in demand for recycling application and one such thermoplastic is PLA.

Polylactic Acid (PLA) is biodegradable, transparent polymer derived from 100% renewable resources, such as corn and sugar beets. Its application ranges from simple packaging of food to biomedical applications. It has also become an essential part of 3D printing due to its ease of use compared to other thermoplastics. 3D printing is an additive manufacturing tool that uses layer by layer deposition phenomenon to print a 3D object. Using CAD software, the object is designed as per dimensional requirements and then the printer converts it into an object by deposition of material.

This study is an initiative to reuse discarded plastic products into something useful. Thus, failed prints of PLA material are used as the raw material and processed to get filaments of desired thickness in order to be used for 3D printing again. The 3D printed objects with dimensional irregularities or functional failures were crushed using a shredder and the shredded pieces were then sieved in order to eliminate the bigger pieces of material. The shredded material was then fed into the extruder and processed with high temperature and variation of speed of the extruder to get filaments of desired dimensions. The tests were performed in different settings that included variation of speed and temperature of heater. It is seen that both the parameter; speed and temperature, have a strong effect on the filament thickness.

Contents

1 INTRODUCTION 1
1.1 Background 1
1.2 Aim of the Project 1
1.2.1 Problem Definition 1
1.3 Limitations 2
1.4 Individual Responsibility and Efforts during the Project 2
1.5 Study Environment 2
2 Method 3
2.1 Alternative Methods 3
2.2 Selected Methodology 3
2.2.1 Materials 4
2.3 Preparations and Data Collection 4
2.3.1 Shredding, Sieving and Dehumidification 4
2.3.2 Manufacturing of Filaments 6
2.3.3 Quality Testing of Filaments 7
2.3.4 Set of Experiments 8
3 Theory 9
3.1 Literature Review 9
3.1.1 Fused Deposition Modeling (FDM) 9
3.1.2 3D Printing Materials 9
3.1.3 Polylactic Acid (PLA) 10
3.1.4 PLA applications 10
3.1.5 PLA as Filament for 3D Printing 11
3.1.6 Extrusion 12
3.1.7 Recycling plastics into 3D printing filaments 12
4 Results 13
4.1 Presentation of Results 13
4.1.1 Trial 1 13
4.1.2 Setting 1 14
4.1.3 Setting 2 15
4.1.4 Setting 3 16

4.2 Discussion of Results 17
5 CONCLUSION 18
5.1 Conclusions 18
5.2 Future Work 18
6 Critical Review 19

List of Figures

Figure 2-1- Methodology 4
Figure 2-2 3Devo Shr3Dit 5
Figure 2-3 - Sieving Process 5
Figure 2-4 - Process of Dehumidification 6
Figure 2-5 3Devo Composer 450 filament extruder 6
Figure 2-6 – Filament thickness with respect to Time 7
Figure 3-1 PLA as a 3D printing filament [21] 11
Figure 4-1Filament Thickness (trial 1) 13
Figure 4-2 RPM variation of extruder (trial 1) 14
Figure 4-3 Filament thickness (Setting 1) 14
Figure 4-4 RPM variation (Setting 1) 15
Figure 4-5 Filament thickness (Setting 2) 15
Figure 4-6 RPM Variation (Setting 2) 16
Figure 4-7 Filament thickness (Setting 3) 16
Figure 4-8 RPM Variation (Setting 3) 17

1 INTRODUCTION

This chapter consists of the background and passion behind the proposed project. The details about the concept of the project and related aims and limitation are discussed in the following chapter.

1.1 Background

The idea behind the proposed project is to re-use the waste plastic from the environment as it is causing serious threat to the ecological systems be it humans, wildlife or sea-life. The durable qualities of plastic make it a vulnerable material in the industry especially for packaging and transport. It is lightweight, flexible yet strong and inexpensive therefore it attracts the masses pertaining to over-consumption of plastic goods at the level of mass production.

This waste is life threatening to the birds living nearby and for the sea-life itself. Materials made of plastic are widely visible in our surroundings, a small walk on the beach leads to witness a large amount of plastic waste being thrown into the sea or near it.

The project team supports the cause of re-using and recycling the plastic waste into a beneficial material. A research was carried as to what ideas can be undertaken considering the expertise and availability of resources. The team ended up with the idea of re-using the plastic waste to make filaments for 3D printer.

3D printing is one of the most promising technologies in current and future years. Various categories of 3D printers can produce wide range of objects from children toys to fossil models by just having a 3D CAD (Computer Aided Design) model of the object.

1.2 Aim of the Project

FabLab is an experimentation hub for rapid prototyping. As a part of experimental investigation there will certainly be PLA failed prints hence the aim of this project is to re-use plastic waste products to produce 3D printer filaments. Once the filaments are made from extrusion process, their suitability and durability are tested.

Some of the objectives of the project are:

- To investigate shredding of plastics into pellets.
- To investigate the extrusion of shredded plastics into filaments
- To examine and characterize the quality of the extruded filaments.
- To identify the influence of shredded materials and extrusion settings on the filament quality.

1.2.1 Problem Definition

3D printing can be done by using various filaments that are made with extrusion process. As part of sustainability drive in FabLab, the project team aims to recycle failed 3D prints made of PLA (Polylactic Acid) into useful filaments. The major factors that affect the production of filaments are the temperature of the heaters in extruder and the speed. The experiments yield the significance of speed and temperature of the extruder in uniform filament thickness.

1.3 Limitations

In order to achieve the target results, it is essential to understand the methodology to be followed as well as the limitations the group may face while performing the tasks related to the project. Some of the limitations that were encountered during the project are listed below:

- The flowability of material that are shredded is less than the virgin material purchased from the market
- The contamination of recycled shredded plastic will affect the quality of filament hence compromising the quality of 3D prints.
- Large parts must be cut into smaller size before feeding to the shredder.

1.4 Individual Responsibility and Efforts during the Project

The project is a mutual effort of all the members of the team. Each member has given their best in order to achieve the targets as per the deadline. Timely delivery of the project goals is important for each member and hence that determines the passion of each individual towards this subject.

Each individual was assigned a task according to necessity of the project, all the activities were done in turns keeping in mind that every individual gets to have hands on experience on every task of the project. For example: If a team member is working on gathering the material and shredding it, the other member works on filament and vice-versa. This approach was used considering the fact that each individual having complete knowledge about the project. Also, each individual was responsible for compilation of the results to form the project report

Each individual contributed to the project and therefore it is a group project in true sense.

1.5 Study Environment

Study environment is important in order to achieve the target results on time and timely delivery of the project and its application.

Major experimentation is carried out in FabLab, Rydberg Laboratory at the Halmstad University. The FabLab is a sub-laboratory of the Rydberg Lab which consists of state-of-the-art facilities for the students. It has various application 3D printers for additive manufacturing in order to facilitate the students as well as the industry. This lab provides a good opportunity for the students and industrial experts to work together in various projects.

Due to the presence of a focused lab on 3D printing the group was able to work in harmony and focus for their project.

2 Method

This chapter explains the method being followed in order to get desired results. In addition, it also describes the alternate methods that can be acquired.

2.1 Alternative Methods

Methods to generate 3D printed models using plastic are widely adapted in the world. These filaments, if store bought, are slightly expensive therefore, it benefits economically and environmentally to use the failed prints as raw material after processing them. Industry has been an active user of 3D printers lately for rapid prototyping within a time frame and hence spools of plastic filaments are bought and used for 3D printing.

General methodology to make failed prints useful is same but variations lie in the type of extruder being used. A DIY extruder is also being used as a low-cost equipment for less precision 3D printed models. The drawback of these extruders is that they do not account for air movement or any other external force and hence the filament size acquired is not very accurate. Another popular extruder is the Lyman Filament Extruder, which is also a low-cost extruder in addition to its being an open-ended source for those who want to build their extruders as per specifications.

There are other extruders that allow to spool the filament as it is being extruded. It has a sensor attached in order to adjust the winder in accordance with the filament's position. It prevents the filament to get tangled and damaged. Filabot is a popular and widely used extruder. It works on the principle of compression, where force is applied between barrel wall and the plastic, enhancing the mixing capabilities (B. Obudho 2019).

2.2 Selected Methodology

According to the methodology described in Figure 2.1, the following steps are involved in this project:

1. Failed/ discarded plastic prints (PLA material) are collected and segregated based on material types.
2. These segregated 3D prints are cut into smaller pieces and then shredded using 3Devo's Shr3dit.
3. The shredded material is filtered based on their size using a sieve and the bigger particles are passed to re-shredding.
4. The filtered plastic pieces are extruded using 3Devo's composer 450 filament extruder which comprises of controlled filament extrusion and spooling of filaments.
5. The quality of the filament is analyzed based on both the visual inspection and recordings of filament thickness data obtained from the software integrated with the filament extruder.

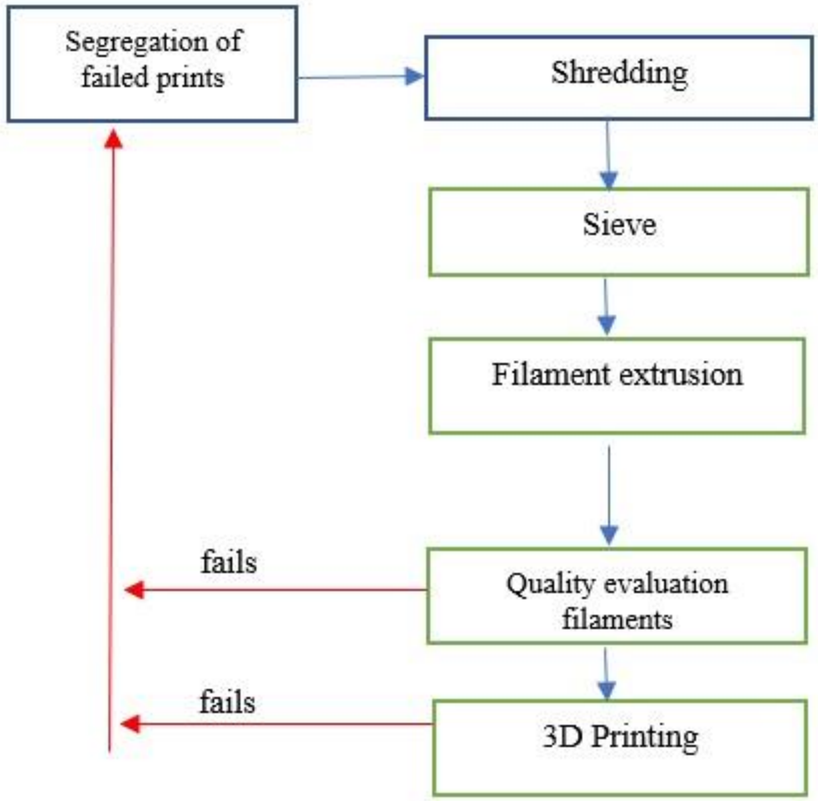

Figure 2-1- Methodology

2.2.1 Materials

Various forms of plastic material such as Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Polypropylene (PP), Polystyrene (PS), Thermo-plastic Elastomers (TPU) and also high-performance thermoplastics, Poly-ether-ether-ketone (PEEK) can be used as filament for 3D printing machines. One of the most common material that is being used by industry as well as academic institutes is PLA. In this project, the aim is to recycle the PLA based failed 3D printed objects to filaments for 3D printing by following a process of extrusion. PLA (Polylactic Acid) is a common thermoplastic and is made from renewable sources such as corn starch. It is also an important material to make medical implants, food packaging etc. In this project, the discarded/ failed 3D printed models of PLA are used as raw material and processed to make useful filaments for 3D printing.

2.3 Preparations and Data Collection

A series of processes are followed in order to prepare for the samples and collect relevant data for analysis and useful output.

2.3.1 Shredding, Sieving and Dehumidification

The raw material used in this project are the failed 3D prints of PLA material. These materials are segregated according to color and material in the first step. Once the materials of same color and material are collected, they are shredded using a shredder to small pieces suitable for extrusion.

The shredded pieces are further sieved in order to get a homogenous size distribution of PLA pieces. Further the sieved material is dehumidified using oven at 80°C for 2 hours to dry out any possible moisture content. Figure 2-2 shows the shredder that is used in this project. The PLA raw material is sieved and segregated in the first step and further shredded using 3Devo's shr3dIt in order to get uniform particles

Figure 2-2 3Devo Shr3Dit

Figure 2-3 - Sieving Process

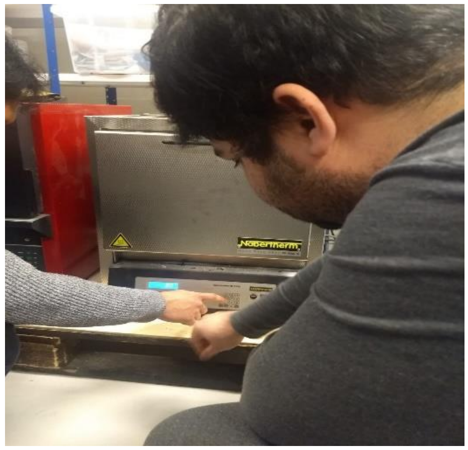

Figure 2-4 - Process of Dehumidification

2.3.2 Manufacturing of Filaments

Figure 2-5 shows the extruder used in this project. This extruder is easy to use with simple user interface equipment that has easily accessible display settings and convenient standard materials pre-sets. The ideal temperature range and extrusion speed for extrusion of certain material is necessary in order to get desired and consistent filament thickness. The extruder has four heating zones and from the default melting temperatures of PLA, the ideal temperature range for recycled PLA is narrowed down. From the lower end of this narrowed range, the range was then increased gradually with an increment of 10^{o}C to identify the ideal temperature for consistent thickness.

The extruder can be easily connected to the laptop/desktop via USB and displays the results on the filament thickness and the process settings using the Arduino software. The effect of temperature and extrusion speed are recorded along with the corresponding filament thickness.

Figure 2-5 3Devo Composer 450 filament extruder

2.3.3 Quality Testing of Filaments

After the manufacturing of filaments, their quality is to be tested whether it is suitable to use them for 3D printing application or not. For that matter, the filaments were tested on various parameters.

- **Filament Thickness and Uniformity**

The most important factor that is considered for an extruded filament is its thickness. The thickness of the filament depends majorly on the speed of extruder and the temperature of the heaters. In general, the acceptable thickness of the filament is 1.75mm with a tolerance of ±0.05mm. Higher variations in the filament will lead to either under extrusion or over extrusion.

- **Filament Roundness**

Filament roundness is one of the important quality parameters considered to verify the suitability of filament for 3D printing. The filament that is extruded out of nozzle is usually in semi-solid state which might flatten out when spooled immediately. This might create 3D printing issues. So, it is important to cool the filament properly before it is spooled and maintain a circular cross-section. Furthermore, uniformity of the filament is also verified by using the data log of the filament thickness recorded using the Arduino software integrating with filament extruder.

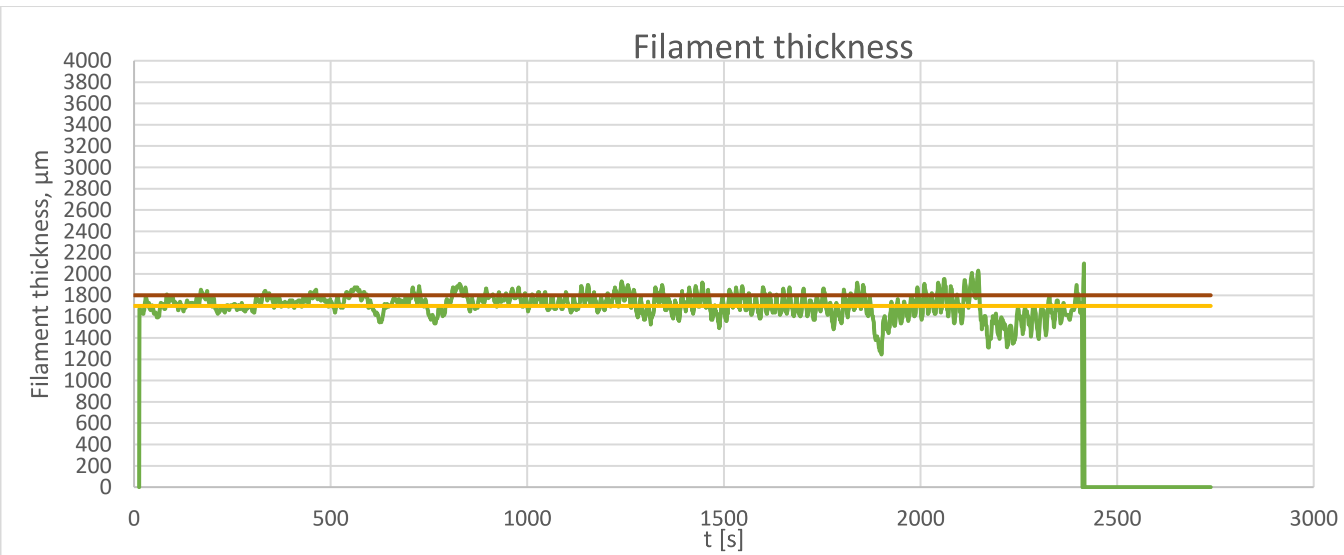

Figure 2-6 – Filament thickness with respect to Time

The filament extruder has tolerance puller which pulls the filament from the nozzle and sends it to the spooling unit. So basically, the filament extruder works in a closed loop control system with the speed of the tolerance puller depends on the filament thickness. Further, the spooling speed depends on the speed of the tolerance puller. The figure 2.6 shows the variation of filament thickness for a certain amount of time recorded by the Arduino software connected to the filament extruder. The red and the yellow lines in the graph indicate the tolerance of the filament thickness, 1.7mm and 1.8mm respectively.

2.3.4 Set of Experiments

The set of experimental investigations carried out are listed in the table 1. The H1, H2, H3 and H4 represent the four heater zones of the extruder.

Table 1 – Experimental scheme

		Temperature °C				Average Speed rpm
		H1	H2	H3	H4	
Trial 1		180	200	195	190	3.5
Trial 2	Settings 1	180	200	195	190	4
	Settings 2	180	200	195	190	8
	Settings 3	185	205	200	195	6

3 Theory

This chapter is a brief literature survey of the topic along with a brief description about the problem statement of the project.

3.1 Literature Review

Fused Deposition Modeling (FDM) by Fused Deposition Modeling (FDM) is an essential tool in additive manufacturing and literature is based on context of manufacturing process, material, recycling plastics and the equipment used in the research. Therefore, the literature review has been divided in sub sections in order to have a clear view about the recycling of materials to get 3D printed objects.

3.1.1 Fused Deposition Modeling (FDM)

Fused Deposition Modeling (FDM) is an additive manufacturing process that includes layer-by-layer deposition of material, via a series of cross-sectional slices. In order to print 3D objects, a CAD software is used where the object is designed as per specifications and consequently the design is fed into 3D printer where the object is printed by layer by layer deposition of raw material (B. Bermann 2012). A software is used to slice the object horizontally into layers, showing the print order. After which the 3D printer uses the sliced design to make the desired shape and dimensions object.

The art of 3D printing was introduced in the 1980s and It was first introduced by Chuck Hull as he patented Stereolithography apparatus (SLA) (C.W. Hull 1986). It is a method of printing programmed layers of ultraviolet (UV) curable liquid/beam of UV lightning creating a solid cross-section of the object. This apparatus uses layer by layer deposition technique, hence forming a solidified 3D object. One of the first products made by this apparatus was a 'cup' (C.W. Hull 1986). During the last four decades the field has been developing rapidly, as every day new applications are being discovered and developed. The objects formed using 3D printers are aesthetically different compared to the conventional methods and more flexible than other manufacturing processes and therefore, it has become one of the major breakthroughs in manufacturing industry over the years. Furthermore, FDM is a trend setter in the manufacturing industry as well as in the society. (3D Hubs 2018) (M. Despiesse et al 2017).

3.1.2 3D Printing Materials

Materials used for 3D printing depend upon the application of the printed object. There are various kinds of materials that are used as raw material for 3D printing, for example, polymers, metals, concrete, ceramics, paper and certain edibles (e.g. chocolate). Out of these listed above, polymers are the most common materials used and are often produced in the shape of a large wire rolled on a spool, commonly known as a filament. Polymers can be used as a powder and liquid resin as well in 3D printing. Further, among polymers are a wide range of raw materials in accordance with the application (3D Printing 2018).

Most common raw material for 3D printing is considered to be ABS and PLA. Both the materials are thermo-plastics, where ABS is a petroleum-based thermoplastic having high resistance to temperatures and therefore ABS is used in applications where a high temperature resistant object is required. In addition to its temperature resistant property, it is also cheap. The disadvantage of ABS is that it is non-biodegradable. Whereas PLA is a biodegradable thermoplastic made from renewable resources. Therefore, it is also one of the desirable raw materials in 3D printing considering it is also not high priced and easy to handle for a user due to its flexibility (3D Printing 2018).

3.1.3 Polylactic Acid (PLA)

It is a known fact that plastic products are non-degradable and are a biggest cause of solid-waste management in the world. The world produces the 181 million metric tons of synthetic plastics each year. With an average of 300,000 metric tons of bioplastics. There are various other environmental issues related to plastic products apart from their non-degradable property. Therefore, it has become a necessity to find new alternatives for the development of world sustainability. Nowadays, many renewable biomaterials are available, which can be used for both bioenergy and bioproducts (R.P. Wool et al 2005) (K.M. Nampoothiri 2010).

Plastic products derived from biological resources such as starch, cellulose fatty acids, sugars, proteins, and other sources that can be consumed by microorganisms are termed as bioplastics or bio-based polymers (G.Q. Chen et al 2012). PLA is made from lactides into an ultimate petrochemical derived product. This product can be produced on a large scale by fermentation process of agricultural by products (R.P. Wool 2005).

As mentioned above, PLA is made from renewable resources, such as sugar beets and corn and hence it is a versatile, biodegradable thermoplastic. The material has a high melting point pertaining to high strength and low elongation and hence low breakage during operation. At first the material was used in only biomedical application but now the material is gaining popularity in almost every field due to its availability, flexibility and degradability. Its high stiffness and strength can be compared to one of polystyrene (PS) at room temperature. Furthermore, there can be many different techniques used for processing PLA, including extrusion and injection moulding (A. Hakkarainen 2011) (R.E. Drumright et al 2000) (S. H. Lee and Wang 2006).

In 1845, a French chemist Theophile-Jules Pelouze first synthesized PLA material using poly-condensation process of Lactic Acid into low molecular weight PLA (L.T. Lim et al 2008). Later, DuPont’s chemist Wallace Hume Carothers, inventor of nylon, enhanced the production process by further decreasing the molecular weight PLA (W.H. Carothers 1932). Later in 1989, Dr. Patrick R. Gruber invented a low-cost commercial process for producing high molecular weight PLA that paved way for using this material in various commercial applications such as agricultural sheets and biodegradable disposable plastic bags (R.E. Drumright 2000) (D Silva 2018).

3.1.4 PLA applications

Most common application of PLA material is in the field of biomedical. Due to its biodegradability it has become a promising raw material in the field of packaging as well. Furthermore, its favorable properties include transparency, high strength, and good thermal and mechanical properties. While it has its advantages, there are some disadvantages associated with PLA as well. Major disadvantage includes its degradation rate which is low in order to meet a lot of applications, and there are no cell recognition sites for tissue compatibility on the surface of PLA application on tissue engineering. Also, PLA material, when used for packaging directly, has shown brittle behavior (Y. Cheng et al 2009).

In packaging industry, PLA is used to make cups, bottles and containers for fluids like water, milk and oil. One of the applications is in textile industry due to its low moisture absorption and low flammability properties. In textile, its application ranges from shirt, furniture, pillows, wipes, carpets, curtains, sportswear etc. as well as disposal garments, diapers etc. In addition, its resistance to UV light makes it suitable for outdoor applications. All in all PLA is a versatile material that has a potential in various fields including transportation, textile, packaging etc. (All3DP 2017)

In the field of medical, PLA is already a widely used material. It is being used in application including suture, fixation of bone material, drug delivery and tissue engineering. Further research is being carried out on the material to be used in this field in more applications (K.M. Nampoothiri 2010).

3.1.5 PLA as Filament for 3D Printing

3D Printing uses filaments of raw material in order to make an object by layer-by-layer deposition. Most common raw materials are ABS and PLA. The reason why these materials are considered common is because it is easy for a user to print with these materials due to their flexibility. PLA works best as a filament for making straight dimensional objects whereas printing of objects like phone cases, tool handles must be avoided with PLA filament. Furthermore, objects that need to withstand high temperature must also be avoided to be made with PLA filament due to its low threshold to high temperature (L. Chilson 2017).

It is important to dry the PLA raw material before using it as a filament in 3D printing in order to avoid its reaction with water at high temperature and undergo de-polymerization. This can lead to bubble formation in the filament as well as discoloration and reduction in 3D printed object.

As compared to ABS, PLA demonstrates less part warping therefore it does not need to have a heated bed for printing. In addition, PLA tends to form liquid particles when heated and therefore increasing the binding between layers consequently a stronger 3D printed object is formed. But at the same time, the object needs to be cooled using a fan in order to get better detail of the object without cracking (L. Chilson 2017).

Figure 3-1 PLA as a 3D printing filament [21]

3.1.6 Extrusion

Extrusion is the process in which material in the form of granulates or shredded raw material is fed into the extruder and heated using several heaters after a plasticized material is forced out from the extruder in the form of wires of desired shape. Flexible and rigid materials are usually used for this process, such as vinyl, ABS, PS, polypropylene (PP), and polyethylene (PE), as well as nylon, polycarbonate, polysulfone, acetal, and polyphenylene (R.E. Drumright 2000).

The extrusion process can be briefly described in steps as follows; first step is to place the shredded material after it is sieved properly into the hopper in form of a powder or pellets. In the second step the heater inside the extruder are set in accordance with the desired thickness of the filament. The temperature of the heater is controlled by different temperature zones. The screw rotates carrying the material through the cylinder. At the end of the machine, die is attached which eventually presses out the wire shaped material filament. The extruded filament is then properly cooled and cut into desirable length and then finally the filament is rolled over the spool (KS Boparai 2016).

The extruder used in this project is 3Devo Composer 450 Filament Extruder. It is one of the best desktop extruders to create professional filament material. It is widely used due to its user-friendly interface and effortless operation. The project team has combined the operation of 3Devo shredder with the extruder in order to get best possible results. It is an industrial grade shredder that works best in combination with 3Devo extruder.

3.1.7 Recycling plastics into 3D printing filaments

Plastic waste has been causing damage to the environment since many years and therefore reduction in plastic products and recycling the existing products is one of the major concerns of health and safety authorities around the world. One of the major recycling of plastic waste is done for producing filaments for 3D printing. Recyclable plastics are either thermosets or thermoplastics. As oppose to thermosets, thermoplastics are workable after being melted past their melting temperatures and therefore, these are widely used as filaments for 3D printing (M. Jones 2019).

The most commonly used plastic filaments are ABS and PLA. When the prints from ABS and PLA filaments go wrong, they can be re-used as a filament instead of throwing them away and increasing plastic waste. The process of recycling filaments from failed prints has been explained in section 2.

In order to reduce the production of plastic waste from 3D printing process, it is advisable to reduce the support structures. The structures provide support to the 3D printed model and therefore it is wise to slice the model in such a way that support structures are reduced. In addition, it is also not advisable to print multiple products at once in order to maintain the accuracy of the printer (i. Anderson 2017).

4 Results

This section covers the results obtained from the various settings of RPM and its effect on the thickness of the filament produced from the extruder.

4.1 Presentation of Results

The samples of failed 3D printed products of PLA material are the raw material in this project. The raw material is shredded and then sieved to get good quality and smaller size particles of the raw material. The raw material is then extruded using an extruder. When the raw material is fed into the extruder, various settings are tested in order to identify the relation of screw speed of extruder and the filament thickness. Results of various settings is presented in the sub-headings below:

4.1.1 Trial 1

The extruder screw speed was kept at an average of 3.5 rpm over a period. The variation in speed causes filament thickness to vary significantly. The mean filament thickness for this experiment is found to be 1.5mm with a standard deviation of 0.564 mm. As observed in figure 4-1, the deviations in the filament thickness are higher than the tolerance limits plotted by yellow and red line.

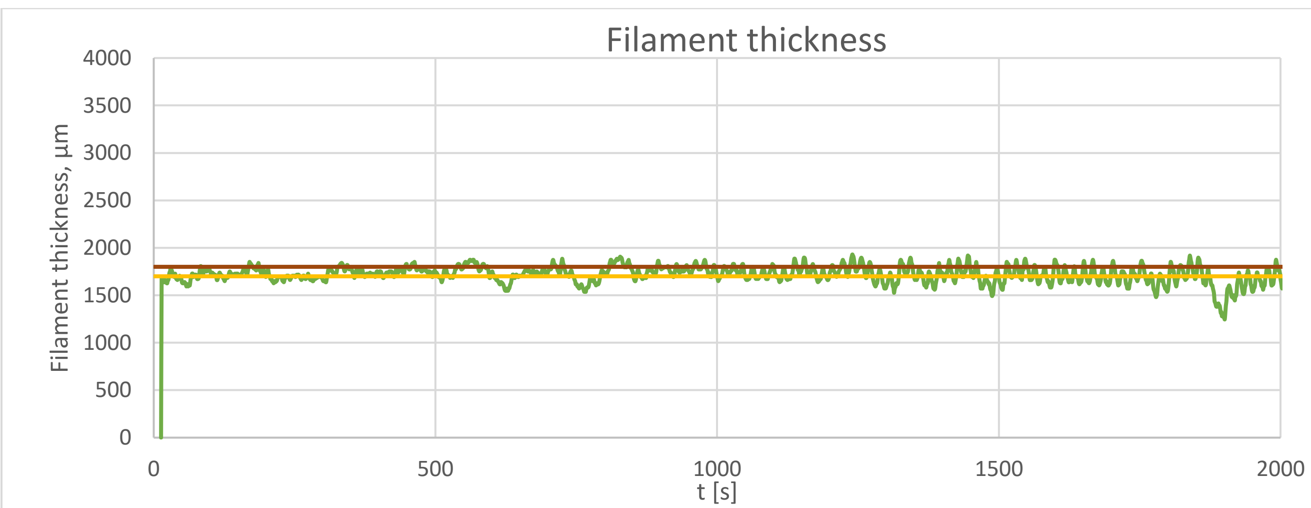

Figure 4-1Filament Thickness (trial 1)

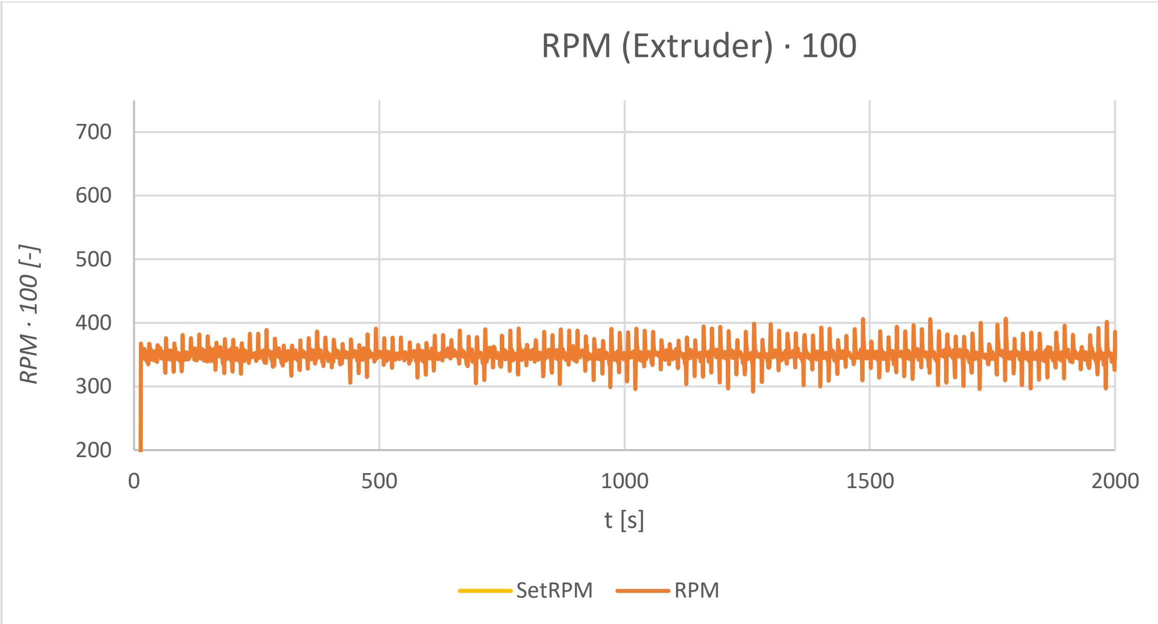

Figure 4-2 RPM variation of extruder (trial 1)

4.1.2 Setting 1

In setting 1, the screw speed of extruder is gradually varied over a period of time ranging from 5rpm to 3.5rpm and corresponding mean of filament thickness is 1.5mm with a standard deviation of 0.572mm. As observed in figure 4-3, the deviations in the filament thickness are higher than the tolerance limits.

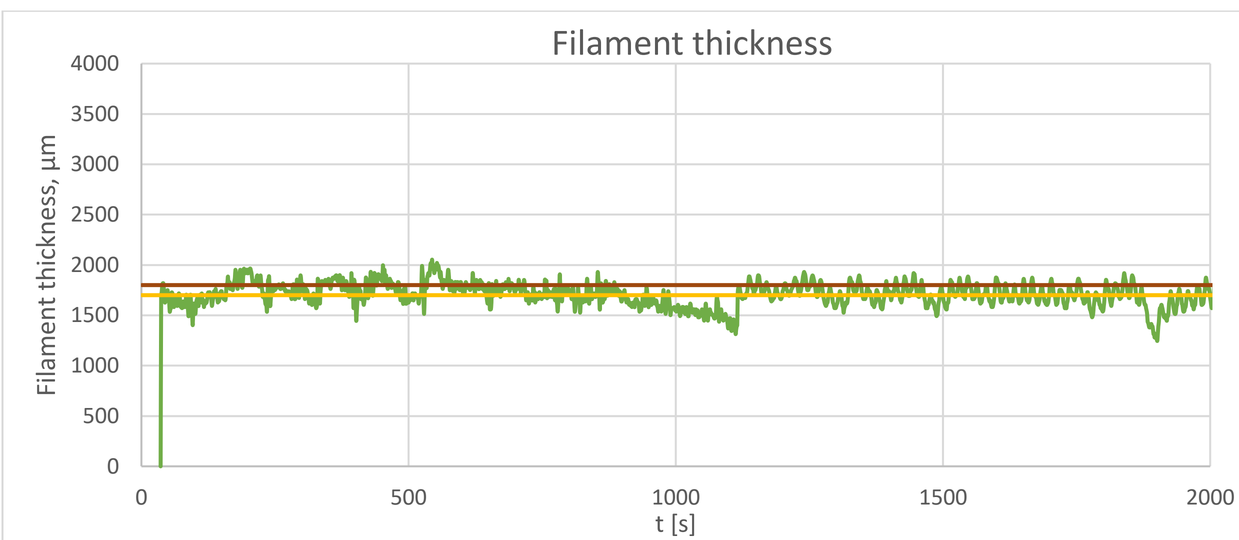

Figure 4-3 Filament thickness (Setting 1)

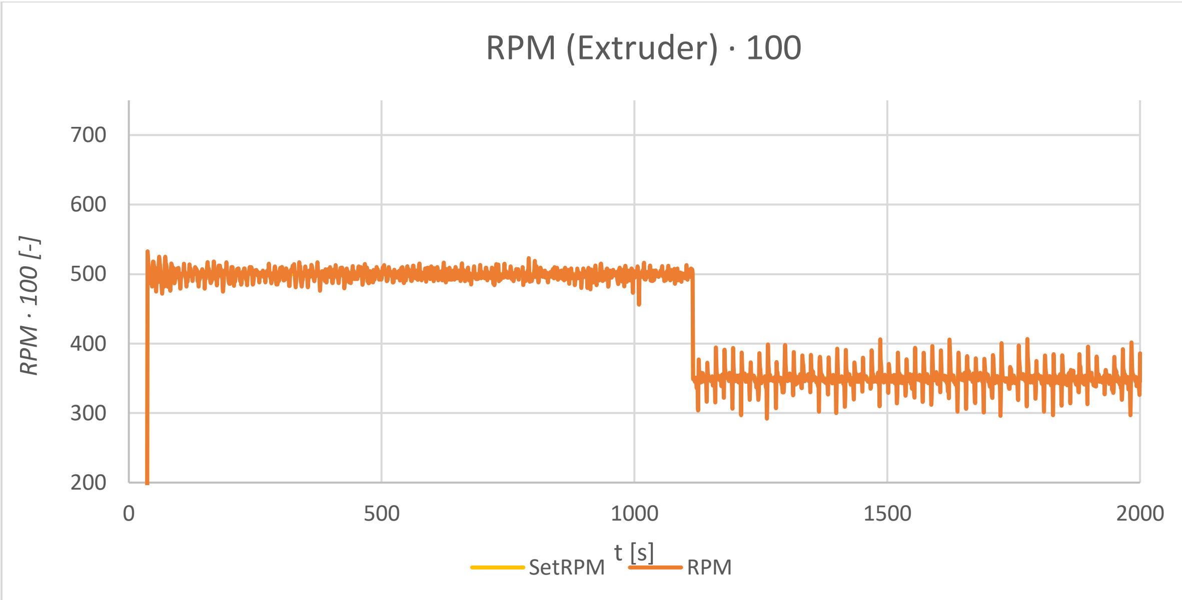

Figure 4-4 RPM variation (Setting 1)

4.1.3 Setting 2

For the second experiment, the speed of the extruder is kept constant at 8 rpm and the mean filament thickness is recorded to be 1.77mm with a standard deviation of 0.235mm. But from the figure 4-5, the higher inconsistency in the filament thickness is observed.

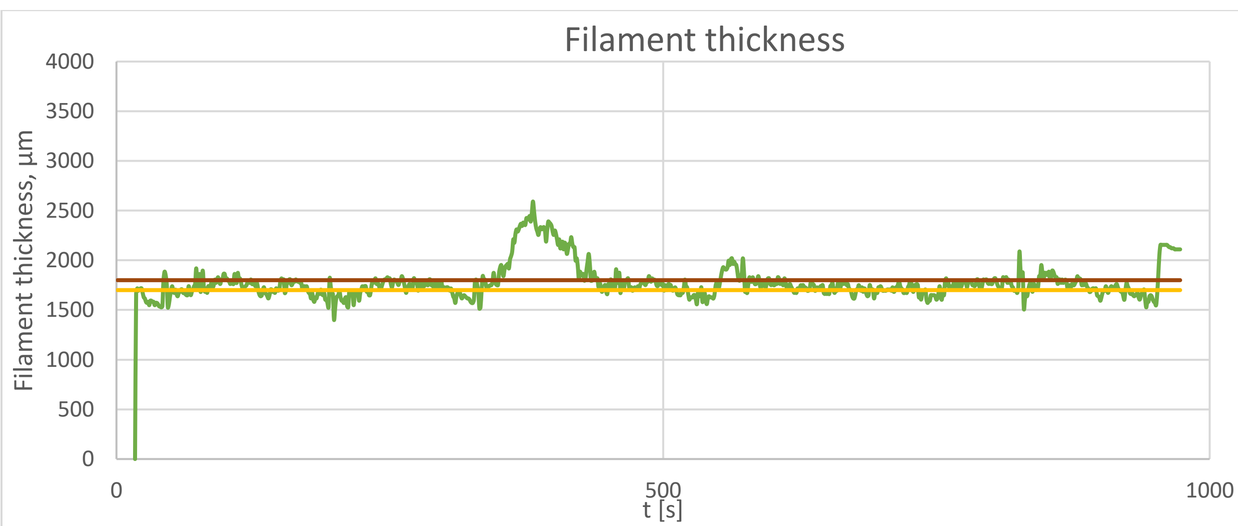

Figure 4-5 Filament thickness (Setting 2)

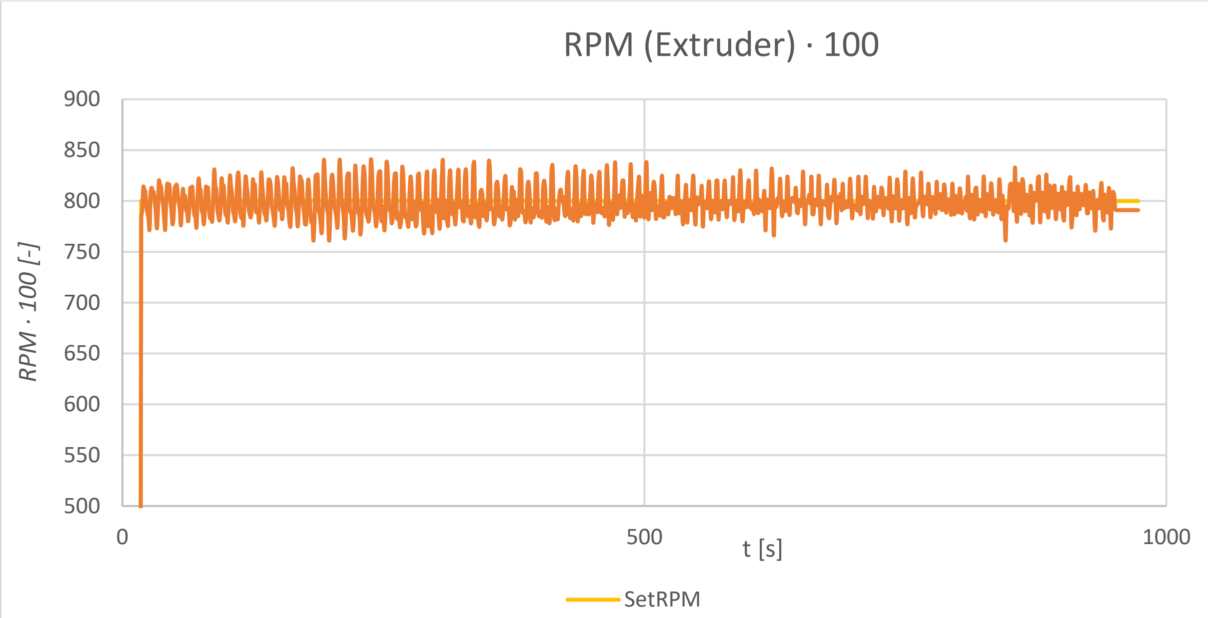

Figure 4-6 RPM Variation (Setting 2)

4.1.4 Setting 3

In the third experiment, the RPM of the extruder is set at 8 RPM for some time and then lowered down to 3.50 rpm, after a brief run of about 500 seconds and the speed is again increased to 5 rpm. The mean RPM is recorded to be 5.97 whereas mean filament thickness is 1.61 with a standard deviation of 0.295. Higher inconsistency is observed irrespective of the extruder speed.

Figure 4-7 Filament thickness (Setting 3)

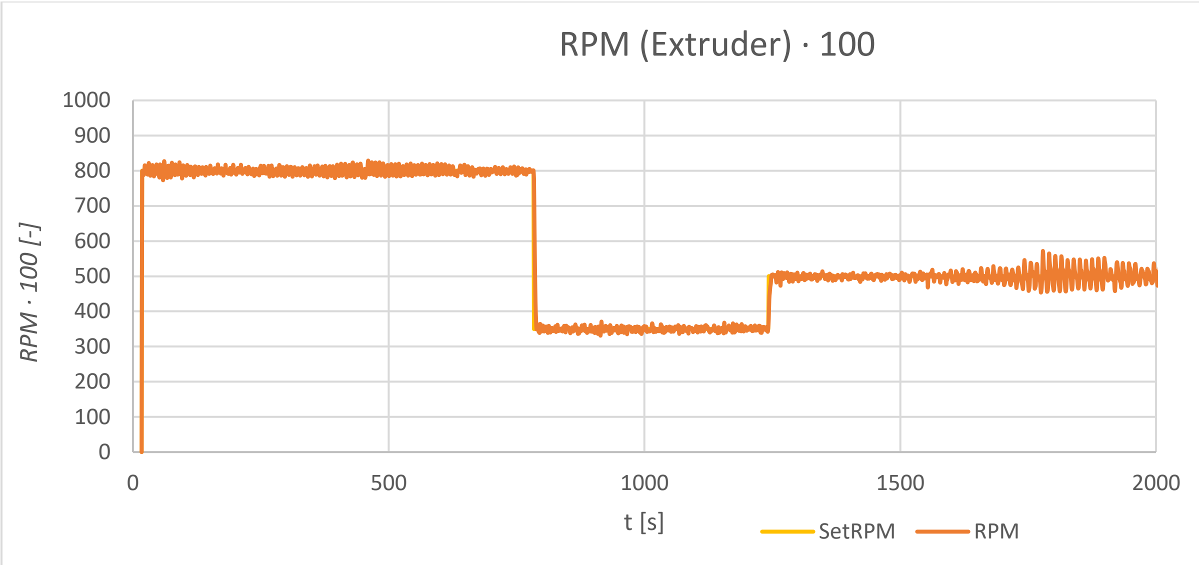

Figure 4-8 RPM Variation (Setting 3)

4.2 Discussion of Results

Various sets of experiments are performed in order to get desired thickness of PLA filaments. The heater temperatures are varied as well as the speed of the extruder in order to get better results of thickness of filament. An upper and lower limit of 1700 µm and 1800 µm respectively is set for desirable thickness of the filaments.

The results of the standard deviation graph show that the thickness of filament is widely spread out for setting 4 while it is moderately spread out for setting 1 and trial 1. Whereas the least spread out thickness of filament is found to be in setting 3 and 2.

The filaments of recycled PLA extruded are non-uniform with respect to the diameter and exceeded the tolerance limits. From the experimental observations, it is noticed that the stable speed (rpm) is required to achieve a stable extrusion process and with recycled PLA, the flow of pieces and the melting were affecting the rate of extrusion.

5 CONCLUSION

This chapter covers the conclusions drawn from the experimentation as well as the future possibilities to further enhance the process.

5.1 Conclusions

The experiment is performed in order to extract the desirable thickness of filament for usage in 3D printing by using an extruder.

The conclusions that can be drawn from the experiments performed are as follows:

- The thickness of the filament is dependent on the speed of the extruder as well as the temperature of the heater.
- The thickness of the filament remains in the threshold thickness value set when the temperatures and speed of the extruder remains constant throughout the process.
- The standard deviation of the series is least when the speed (rpm) of the extruder is kept constant.

5.2 Future Work

More experiments should be carried out in order to optimize the variable parameters like heater temperature and speed of the extruder. The experiment should result in a desirable low thickness filament of recycled PLA to be used for 3D printing facility.

It is advisable to have to better way to cool the filament in order to prevent it from getting damaged and losing its shape.

The raw material for extrusion must also be tested for moisture content and dehumidified.

6 Critical Review

The basic purpose of the study is to re-use plastic material that has been wasted as failed prints from a 3D printer. The world has acknowledged the importance of recycling and reusing and hence it is being promoted worldwide in almost every field of life. The benefits of recycling include safety of the environment from various kinds of pollution, economic benefits to the country, and social benefits to the people. Plastic material is desirable as a recycle material and hence it has great importance as a reusable material.

3D printing is an essential tool in additive manufacturing and hence it has been adapted by industries as well as educational institutions. In addition to installation of 3D printers, just like normal paper printers, it also produces fail objects with dimensional discrepancy or other faults. Such objects, instead of being discarded, are used by the project team in order to use them again as filaments for 3D printers. In this case, PLA material was chosen to be the raw material as per the requirement of the 3D printing facility. Filament making procedure is followed from scratch where the PLA based objects are crushed and sieved and further extrusion process is carried out in various settings in order to get the best result.

This study paves way for industries to adapt the recycling of 3D printed failed objects rather than ending up in landfills. In this way, they can also flourish financially as the need to purchase raw material for 3D printing becomes low.

7 REFERENCES

[1] B. Obudho, (2019) “6 Best filament extruders to build or buy”, available online at (https://all3dp.com/2/6-best-filament-extruders-to-build-or-buy/)

[2] B. Berman (2012) “*3-D printing: The new industrial revolution,” Bus. Horiz*., 55 (2), pp. 155–162

[3] C. W. Hull (1986) *“Apparatus for production of three-dimensional objects by stereolithography,” US Pat. 4,575,330,* pp. 1–16

[4] 3D Hubs, “The Advantages of 3D Printing.” [Online]. Available: https://www.3dhubs.com/knowledge-base/advantages-3d-printing. [Accessed: 20-Feb-2018].

[5] M. Despeisse et al. (2017) *“Unlocking value for a circular economy through 3D printing: A research agenda,” Technol. Forecast. Soc. Change*, 115, pp. 75–84

[6] R. P. Wool and X. S. Sun (2005) *Bio-Based Polymers and Composites*.

[7] K. Madhavan Nampoothiri, N. R. Nair, and R. P. John (2010) *“An overview of the recent REFERENCES 48 developments in polylactide (PLA) research,” Bioresour. Technol.,* 101 (22), pp. 8493–8501

[8] G.-Q. Chen and M. K. Patel (2012) *“Plastics Derived from Biological Sources: Present and Future: A Technical and Environmental Review,” Chem. Rev.,* 112 (4), pp. 2082–2099

[9] A. Hakkarainen, Minna Finne-Wistrand (2011) *Update on Polylactide Based Materials. Smithers Rapra, 2011*.

[10] R. E. Drumright, P. R. Gruber, and D. E. Henton (2000) *“Polylactic Acid Technology,” Adv. Mater.,* 12 (23), pp. 1841–1846

[11] S.-H. Lee and S. Wang (2006) *“Biodegradable polymers/bamboo fiber biocomposite with bio-based coupling agent,” Compos. Part A Appl. Sci. Manuf.,* 37 (1), pp. 80–91

[12] L.T. Lim, R. Auras, M. Rubino (2008) “*Processing technologies for poly(lactic acid)”, Prog. Polym. Sci.*, 33, pp 820–852.

[13] W.H. Carothers, J.W. Hill (1932) “*Studies of polymerization and ring formation. XII. Linear superpolyesters", J. Am. Chem. Soc.*, 54, pp 1559–1566.

[14] Dana da Silvaa, Maya Kaduria, Maria Poleya, Omer Adira, Nitzan Krinskya, Janna Shainsky-Roitmana, Avi Schroeder (2018) *“Biocompatibility, biodegradation and excretion of polylactic acid (PLA) in medical implants and theranostic systems” Chemical Engineering Journal*

[15] Y. Cheng, S. Deng, P. Chen, and R. Ruan (2009) *“Polylactic acid (PLA) synthesis and modifications: a review,” Front. Chem. China,* 4(3), pp. 259–264

[16] "PLA vs ABS: Filaments for 3D Printing Explained & Compared | All3DP." (2017) [Online]. Available: https://all3dp.com/pla-abs-3d-printer-filaments-compared/. [Accessed: 30-Aug2017].

[17] L. Chilson (2017) "The Difference Between ABS and PLA for 3D Printing - ProtoParadigm." [Online]. Available: https://www.protoparadigm.com/news-updates/the-difference-between-abs-andpla-for-3d-printing/. [Accessed: 30-Jul-2017].

[18] Z. Tadmor and C. G. Gogos, (2006) *Principles of Polymer Processing (Google eBook).*

[19] M. Rides, C. Allen, H. Omloo, K. Nakayama, and G. Cancelli (2009) *"Interlaboratory comparison of melt flow rate testing of moisture sensitive plastics," Polym. Test.,* 28 (6), pp. 572–591

[20] K.S. Boparai, R. Singh, H. Singh (2016) *"Development of rapid tooling using fused deposition modeling: a review" Rapid Prototyping Journal*, 22 (2), pp 281-299.

[21] Available online: https://www.phaserfpv.com.au/products/prusaprusamentpla3dprintingfilament

[22] M. Jones (2019) "*PETG/PLA Recycling: How to Recycle 3D Printer Waste*" [Online]. Available: https://all3dp.com/2/3d-printer-recycled-plastic-tips-for-your-waste-plastic/

[23] I. Anderson (2017) "*Mechanical Properties of Specimens 3D Printed with Virgin and Recycled Polylactic Acid" 3D Printing and Additive Manufacturing*, 4 (2)

Syed Muhammad Raza, Contact#
+92316-6140909,+92334-6140909

Dilawar Singh, contact#
+46764524438, email:
dilawar2017singh@gmail.com

HALMSTAD
UNIVERSITY

PO Box 823, SE-301 18 Halmstad
Phone: +35 46 16 71 00
E-mail: registrator@hh.se
www.hh.se