# PRODUCTION OF FILAMENT FROM (PLA OR ABS) WASTE USING CUSTOM MADE MINI EXTRUSION MACHINE

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**THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE IN BACHELOR OF MECHANICAL ENGINEERING**

**FACULTY OF ENGINEERING**
**UNIVERSITY MALAYSIA SABAH**
**2022**

## DECLARATION

This thesis has been submitted to Universiti Malaysia Sabah in partial fulfilment of the Bachelor of Mechanical Engineering degree. This work has never been submitted for a university degree or diploma before. I also certify that the work described above is entirely my own, with the exception of quotations and summaries, which have been properly acknowledged.

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1 JULY 2022

Bryan Noel Sabinus

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**ACKNOWLEGMENT**

I would like to express my gratitude to my supervisor, Dr Melvin Gan Jet Hong, for his invaluable guidance and insight throughout the completion of this project. His constant participation in assisting and giving kind support and advice has been a great help to me in solving all the problems that I faced. Not to forget, Dr Nancy Julius Siambun, my previous supervisor during FYP 1 that always giving me an endless helped in this writing. Having the chance to complete this project under their guidance was a worthwhile experience.

Secondly, I also want to thank my examiner Ir. Mohd. Adzrie Radzali and Dr. Mohd. Kamal Mohd. Shah for their useful feedback of my work, the lab assistant for assisting me in handling equipment, and University Malaysia Sabah for their financial support.

Thirdly, I also want to thank my family, my friends and my senior for all of their encouragement and moral support. Their unwavering support has given me the willpower to remain motivated anytime I was going through a difficult time.

Last but not least, I would want to express my gratitude to all of my outstanding lecturers who helped me during my time studying at University Malaysia Sabah by sharing their knowledge and expertise, both theoretically and practically.



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# ABSTRACT

A 3D printer is the 21st-century technology that is widely utilized across a wide range of sectors. It creates a three-dimensional desired object from a model created with Computer Aided Design (CAD). Acrylonitrile Butadiene Styrene (ABS) and Poly-Lactic Acid (PLA) is a common type of plastic polymer that is used in the 3D printing. This study is regarding recycling waste produced from the mentioned material to identify the possibility to re-extrude it back become reusable filament. Modification of extrusion machine from previous study is done to make it functions in producing filament from waste material. For the result of the experiment, producing filament using waste from ABS is consider the most successful, the diameter ranging between 4.3mm to 2.5mm, hence tolerance is ±0.13mm. The hardness of ABS ranged from 48 to 66.5, the value decreases from its standard hardness value. As for the surface roughness, the filament produced is mostly smooth but still has other part that is rough. Morphological porosity showing high porosity content on ABS filament, and low porosity content on PLA filament. In addition, test for PLA is limited due to its brittle characteristic. Overall, the study of re-extruding waste material into ABS and PLA filament was a success, however it still needs a lot of work and further research to produce good filament.



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**ABSTRAK**

*PENGELUARAN FILAMEN DARI SISA (PLA ATAU ABS) MENGGUNAKKAN MESIN PEYEMPERITAN YANG DIUBAH SUAI*

Pencetak 3D ialah teknologi abad ke-21 yang digunakan secara meluas merentasi pelbagai sektor. Ia mencipta objek tiga dimensi yang dikehendaki daripada model yang dicipta dengan Reka Bentuk Bantuan Komputer (CAD). *Acrylonitrile Butadiene Styrene* (ABS) dan *Poly-Lactic Acid* (PLA/0 ialah sejenis polimer plastik biasa yang digunakan dalam percetakan 3D. Kajian ini adalah mengenai kitar semula sisa yang dihasilkan daripada bahan tersebut untuk mengenal pasti kemungkinan untuk menyemperit semula menjadi filamen yang boleh digunakan semula. Pengubahsuaian mesin penyemperitan daripada kajian lepas dilakukan untuk menjadikannya berfungsi dalam menghasilkan filamen daripada bahan buangan. Untuk hasil eksperimen, menghasilkan filamen menggunakan sisa daripada ABS dianggap paling berjaya, diameter antara 4.3mm hingga 2.5mm, maka toleransi ialah ±0.13mm. Kekerasan ABS adalah antara 48 hingga 66.5, nilainya berkurangan daripada nilai kekerasan standardnya. Bagi kekasaran permukaan, filamen yang dihasilkan kebanyakannya licin tetapi masih mempunyai bahagian lain yang kasar. Keliangan morfologi menunjukkan kandungan keliangan yang tinggi pada filamen ABS, dan kandungan keliangan rendah pada filamen PLA. Di samping itu, ujian untuk PLA adalah terhad kerana ciri rapuhnya. Secara keseluruhannya, kajian menyemperit semula bahan buangan ke dalam filamen ABS dan PLA telah berjaya, namun ia masih memerlukan banyak kerja dan kajian lanjut untuk menghasilkan filamen yang baik.



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**LIST OF ABBREVIATION**

| | |
|---|---|
| 3D | 3 Dimensional |
| ABS | Acrylonitrile Butadiene Styrene |
| AC | Alternating Current |
| DC | Direct Current |
| PID | Proportional Integral Derivative |
| PLA | Poly Lactic Acid |
| PVA | Polyvinyl Alcohol |
| PET | Polyethylene Terephthalate |
| HIPS | High Impact Polystyrene |
| HDPE | High-Density Polyethylene |
| LDPE | Low-Density Polyethylene |
| PC | Polycarbonate |
| PS | Polystyrene |
| PP | Polypropene |
| FDM | Fused Deposition Modelling |
| SPI | Society of Plastic Industry |
| MFI | Melt Flow Index |
| MFR | Melt Flow Rate |
| ASTM | American Society for Testing and Materials |
| ISO | International Organization for Standardization |
| SAN | Styrene-Acrylonitrile |
| TGA | Thermal Gravimetric Analysis |
| DTG | Differential Thermogravimetric Analysis |
| DTA | Differential Thermal Analysis |
| UMS | Universiti Malaysia Sabah |
| FKJ | Fakulti Kejuruteraan |



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## CHAPTER 1

## INTRODUCTION

### 1.1 Overview

Additive manufacturing, also known as 3D printing, is the technique of creating a three-dimensional solid object of nearly any shape from a digital model. 3D printing, also known as "additive manufacturing" or "stereolithography," is sometimes depicted as a mysterious, almost magical process. 3D printing transforms computer models into tangible objects. It melts various materials, such as biodegradable plastic filament Polylactide or poly-lactic acid (PLA), Acrylonitrile Butadiene Styrene (ABS) plastic, and Nylon, into thin layers on a surface, then moves up and prints another layer. After layer upon layer, a physical item is created (Panchenko & Gumennyy, 2014). Fused Deposition Modelling (FDM) 3D printers frequently use these two types of material, PLA and ABS. These materials, however, are classed as Type 7 or "other" by International Resin Identifier Codes, and so cannot be recycled as typical thermoplastic materials since they would remain solid during the recycling process, causing complications for the recycling facility (Griffin, 2020).

The melting temperature of PLA is 155°C (Laureto *et al.*, 2017) while for ABS is around 180°C (Kumar *et al.*, 2017). Because of its excellent dimensional stability and ease of production, joining, and painting, it is frequently used for prototype preparation. Although it is recyclable, it takes a long time to disintegrate because of its weak resistance to organic solvents. Using an extrusion machine to melt and reshape the PLA or ABS material back to filament is one approach to recycle the filament. After being loaded into the hopper, the material is fed through a spinning screw within a heated barrel. By decreasing the depth of the screw channel along the barrel, the material is compressed. According to Lafleur, P, & Vergnes, B (eds) (2014), the screw barrel system comprises of three parts: feed, where raw material in pellet form is packed together; compression, where melted material is sheared by the screw flights and the screw channel depth gradually decreases; and metering, where all of the polymer is molten, and the screw channel depth remains unchanged.



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The existing extrusion equipment for melting thermoplastics, on the other hand, is only available on a large or industrial scale. This has some drawbacks, such as the expensive cost of the machine and the need for skilled labor to operate the technical equipment. The machine's size is likewise enormous, making it difficult to deploy in small businesses or for laboratory use at educational institutions. Not only that, but the expense of upkeep is relatively significant. Figure 1.1 shows an example of an existing extruder machine in the market.


**Figure 1.1: Tabletop Plastic Extruder**

Source: (Thang Huynh *et al.*, 2021)

## 1.2 Problem Statement

Researchers have been exploring ways to recycle the 3D printing filament waste. This is a potential study field that should be investigated further. However, in Sabah, it is presently not possible to convert the 3D printing filament waste into filament for use in 3D printing. Furthermore, the equipment required to make filament is only available on a large or industrial scale, which demands a considerable amount of waste material. The Mechanical Engineering in the Faculty of Engineering has custom-made a table-top mini extrusion machine as shown in Figure 1.2. Initial tests revealed that the machine was capable of producing filament. However, to assure



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the machine's efficacy and workability in producing decent filament, it will need to be modified and improved. The screw is one of the extrusion machine components that needs to be improved. A concrete hammer-drill bit is used in the initial design as the extrusion screw; however, the screw depth (internal screw diameter) is insufficient, resulting in insufficient stress to enable plastic melting. As a result, an external heater must be installed on the exterior part of the barrel. To achieve consistent melting of waste thermoplastic inside the barrel and throughout the extrusion process, the proper positioning of heaters along the screw-barrel must be researched methodically. Aside from that, the effect of extrusion-rate, which is influenced by the screw's speed rate, needs to be investigated in order to produce the best filament quality. To be used in a 3D printer, the filament produced should have a uniform diameter, as well as appropriate porosity, thermal, and mechanical properties.

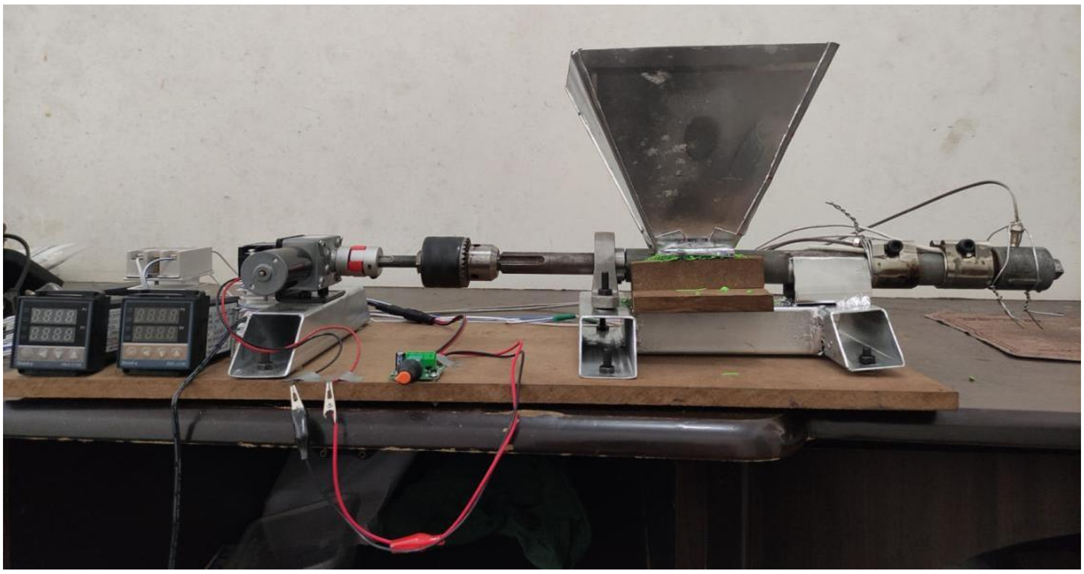

**Figure 1.2: Custom made tabletop plastic extruder available in FKJ**

Source: Extrusion machine at Mechanical Engineering Lab, in the FKJ.

**1.3 Research Objective**

In this project, filament from PLA or ABS waste will be produced using a tabletop extrusion machine that priorly custom-made in the Mechanical Engineering Lab, in the FKJ. To successfully achieved a usable 3-D printing filament, the following objectives need to be studies:



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(i) The physical properties of produced PLA or ABS filament.

(ii) The produced PLA or ABS filament's hardness and roughness.

## 1.4 Scope of Work

The scope of this study is reviewing prior research on related topics and fields, such as the materials used in Fused Deposition Modelling (FDM) 3D printing. In addition, modify the existing design of an extrusion machine to produce (PLA) or (ABS) filament. Only (PLA) and (ABS) waste properties for 3D printing filament are the focus of this project. A suitable extrusion speed for the diameter consistency, porosity, thermal, and mechanical properties of the produced filament, as well as a heat profile on the extrusion barrel for the diameter consistency, porosity, thermal, and mechanical properties of the produced filament will be taken into account in order to produce a high-quality 3D printing filament.



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### 1.5 Research Methodology

The project shall be carried out accordingly to a set of methodology that had been planned, as following:

i. Literature review / Research Study

The idea and guideline of the design project will be obtained from reviewing the available articles, journals, websites, books, interviews, and online references.

ii. Identifying Problem

The project is started by obtaining the topic from the supervisor and identifying the issue, which is to make filament from (PLA) and (ABS) wastes by using the custom-made mini extrusion machine. The primary objectives are to create a high-quality filament from (PLA) and (ABS) waste that can be used for 3D printing.

iii. Material Selection and Fabrication Process

Material selection for this project is only one which is (PLA) and (ABS) waste. To produce the 3D printing filament from (PLA) and (ABS) waste.

iv. Prototype testing

After the prototype has been modified and all of the (PLA) and (ABS) waste characteristics have been identified, the prototype will be tested. This stage is critical for determining whether the project is successful by analysing whether the prototype is functional and verifying that the design details have satisfied the technical requirements. The diameter consistency, porosity, thermal, and mechanical properties of the filament will be tested in general. The purpose of this test is to ensure that the filament created by the prototype can be used in a 3D printer.

v. Data Collection and Performance Evaluation

To examine the performance of the extrusion machine, the data acquired during prototype testing will be analysed further. It will then be saved for mathematical modelling purposes, such as determining the melt flow rate of the FDM filaments produced by this extrusion machine.



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## 1.6 Research Contribution

The project is about the study of 3D printing waste that can be recycled as a filament to be used again as new material, (PLA) and (ABS). Most recycling companies will collect (PLA) and (ABS) materials and transport them to major processing plants. Furthermore, using (PLA) and (ABS) in the FDM 3D printer as the reusable filament throughout the country may lessen waste management difficulties and therefore preserve human lives as well as animal life.



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**CHAPTER 2**

**LITERATURE REVIEW**

## 2.1 Introduction

This chapter goes through the history of the 3D printer and the extrusion machine used to make the filament for the printer. To have a better grasp of this project, related journals, thesis, articles, books, and research papers were examined in order to determine the critical variables that should be taken into account for the design in order to offer a better understanding of the extrusion machine.

## 2.1 Extrusion Machine

Since Joseph Brammah patented his invention in 1797, the extrusion method has been around for a long time. Extrusion is a process in which granulates or shredded raw material are fed into an extruder and heated using numerous heaters until a plasticized material is pushed out of the extruder in the form of wires of the appropriate shape (Raza & Singh, 2020). Figure 2.1 is an example of a schematic diagram of standard single screw extrusion machine, with major components has been indicated. The essential components of an extrusion machine are a hopper (A) at one end from which plastic resin is fed, a barrel (D) that is generally electrically heated, a rotating screw (E), and a nozzle (I) at the other end of the hopper that is used to shape the extruded material (Njobet, 2012).



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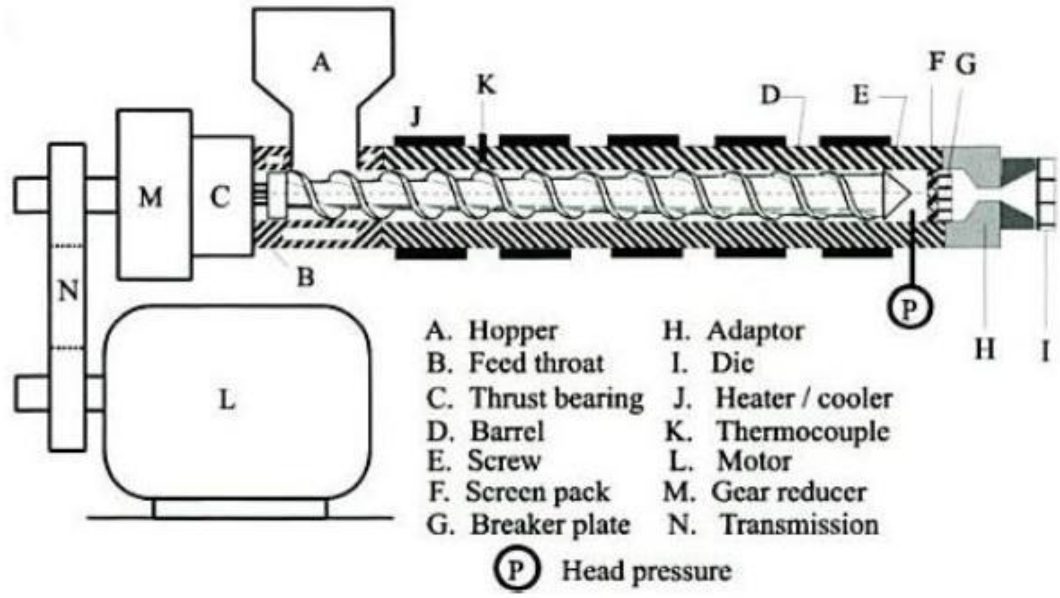


**Figure 2.1: Component of typical single screw extruder**

Source: (Njobet, 2012)

### 2.1.2 Component & Design of Plastic Extrusion Machine

This subchapter explains about the component and the design of the plastic extrusion machine.

#### 2.1.2.1 Screw

During extrusion, the screw has a significant impact. Its job is to push grains into the barrel and transfer material from the hopper to the system (Poudel, 2015). The screw is operated by an AC motor and housed in a screw barrel (Muruganr, 2016). However, if the screw is unable to create adequate pressure due to flow limits, or if it generates more pressure than is required, filament quality will be harmed, resulting in waste and reduced productivity (Garca-León *et al.,* 2019).

#### 2.1.2.2 Barrel

The barrel is a component that keeps the material inside the extrusion screw as it travels through it (Tare *et al.*, 2020). Aside from that, a heating system will be mounted on the barrel, which will use the concept of inductive heating to melt the



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raw material inside it (Reddy *et al.*, 2020). The extrudates' form and size are determined by the shape and size of the molten material that passes through the barrel owing to the pressure exerted by the screw (Poudel, 2015). Energy connected with extrudate enthalpy change is associated with convective heat transfer between barrel and polymer, and viscous dissipation owing to mechanical energy into heat inside the material in a typical extrusion process (Paul *et al.*, 2019). The contact area between the barrel and the flowing substance within determines the rate of heat convection.

#### 2.1.2.3 Feed Hopper

Gravity feed hoppers are commonly employed in extrusion machines, which implies that gravity forces the material from the hopper down to the screw. The hopper is generally in the shape of a funnel and is well-designed to allow the grains to glide through the sloped surface within the hopper (Poudel, 2015). The volume of the hopper is a common problem when building a hopper since it determines how much material can be fed into it.

#### 2.1.2.4 Nozzle or Die

The nozzle, also known as the die, is located at the front of the barrel. The material inside the barrel, which is mostly molten, is forced out of the barrel and goes via the nozzle (small opening). As a result, the form and profile of the finished product will be determined by the nozzle (Paul *et al.*, 2019).

#### 2.1.2.5 Band Heater

Due to their effectiveness and inexpensive cost, electrical heaters or band heaters are often employed in extruder machines (Poudel, 2015). The size of the heater is dependent to the size of the extrusion machine. Extruders of smaller sizes have fewer melting zones, whereas larger or longer extruders have more melting zones, necessitating the use of a larger heater. A specific number of current passes through a conductor with a specific resistance, which functions as a flow barrier and causes heat to be generated. The following equation can be used to compute the quantity of heat created (Chris Rauwendaal, 2013).

$$QC = I^2R = VI = V^2/R$$



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Where, $C$ is Capacitance, $R$ is Resistance, $Q$ is Charge flow, $V$ is Voltage, and $I$ is Current

Meanwhile, another equation was devised that is employed in both AC and DC currents and is stated in RMS (root mean square). The quantity of heat created in a three-phase circuit may be computed using the equation below (Chris Rauwendaal, 2013).

$$QC = 3VI$$

**2.1.2.6 Motor**

Since AC motors are brushless and digital, most extruder machines utilise DC motors instead of AC motors (Poudel, 2015). The primary purpose of a DC motor is to rotate the screw within the pipe, and it may be controlled using a 12V DC motor controller or a PID controller (Ravichandran *et al.*, 2020). The needed power to pick an appropriate motor may be calculated as follows: (Fadeyibi *et al.*, 2016):

$P_{sc} = 0.7355CLQ$

$P_{sc}$ = Power required by the screw conveyor (kW)

$C$ = Constant coefficient for conveyed material, usually taken as 0.3.

$L$ = Length of the screw conveyor

Next, the pressure in the extrusion barrel can be calculated as follow:

$P = Psc / Qf$

$P$ = Pressure inside the extrusion barrel

$P_{sc}$ = Power available to the screw conveyor (kW)

$Q_f$ = flow rate of material (kg/s)



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### 2.1.3 Extrusion Screw and Barrel

One of the most important components to consider when achieving good extrusion performance is the extrusion screw. The geometrical arrangement of the screw is essentially dependent on the material to be treated, according to Garca-León *et al.*, (2019) research. The feeding zone, compression zone, and metering zone are the three zones that make up the screw. Figure 2.2 shows a schematic representation of the screw.


**Figure 2.2: Extrusion Screw Zone**

Source: (García-León *et al.*, 2019)

The feed zone, also known as the conveying zone, is responsible for transporting materials to the compression zone, as shown in Figure 2.2. The materials are sheared at the compression zone, and a part of the material is melted owing to heat generated by friction between the screw, barrel, and the material. Meanwhile, the heating element will be positioned in the metering zone. This zone contains molten material that is ready to be extruded via the nozzle.

The calculation corresponds to length value for each zone over the *L* length of the screw are listed as below:

i. Feeding zone = *L*/2

ii. Compression zone = *L*/4

iii. Metering Zone = *L*/4



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### 2.1.4 Basic Operation of Screw Extruder

It is critical to comprehend the screw extruder's basic operation. The material is gravity-fed down the barrel of the extruder from the supplied hopper. Frictional forces act on the material, as well as the barrel and the screw surface, while the screw rotates. While the material is still in the solid state, these frictional forces will propel it ahead. The friction and the heating element provided to the barrel will gradually heat the material as it travels ahead. When a material's temperature rises over its melting point, the amount of solid material in the substance decreases as a result of melting. When the molten state material reaches the barrel's end, it is simply pumped through. As the molten state material approaches the barrel's end, it will simply be pushed through the nozzle and conform to the shape of the nozzle's flow channel. Because the nozzle creates flow resistance, nozzle head pressure is required to drive the material out. The flow channel of the nozzle, the temperature of the polymer melt, the flow velocity of the nozzle, and the rheological qualities of the polymer melt all influence the nozzle head pressure (Rauwendaal, 2014). It is crucial to remember, however, that the nozzle, not the extruder, causes the nozzle head pressure.

## 2.2 Plastic and Filament material for 3D-Printing

As previously said, 3D printing techniques now have a wide range of materials accessible, including plastics, metals, resins, composites, and many more, all of which may be utilised in various stages (filament, powder, pellets). However, from the beginning, the most common materials for AM processing have been plastics or polymers, which have long since become practically vital to modern life due to the wide range of applications they serve (Barnatt,2016). PLA and ABS filament are the two most common polymer materials used in the FDM printing technique. Biodegradable Polyvinyl Alcohol (PVA) and High Impact Polystyrene (HIPS), robust and flexible Polyethylene Terephthalate (PET), and nylon are all common forms of commercial 3D printer filament (PA) (Strong, 2005).

Thermoplastics and thermosets are the two types of plastics that may be found. Thermoplastics are solids at room temperature that may be heated to become soft and flexible, then placed in a mould or other shaping device and shaped after cooling. The ability to reheat a thermoplastic item and reshape it numerous times is a distinguishing feature of all thermoplastics. This distinguishes thermoplastics from thermosets, which cannot be remoulded once they have cooled. This can be



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