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Fabrication of a 3D Printer Filamnet Extruder

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Abstract:- 3D printing, an additive manufacturing process, transforms digital designs into physical objects by layering material. This mechanization adds consecutive layers to build up the complete entity, resulting in a 3D object. It develops objects progressively to formulate the preferred look. Filaments are the main component in a die cast model (FDM) 3D printer, these are thermoplastic substances that are injected through a hot die to form the object. These filaments are available in different types such as PLA, ABS, PETG, HDPE each of which has specific characteristics that offer different applications and material options in 3D printing. This paper depicts about fabricating and developing a design of a 3D filament extruder that can produce 1.75 mm diameter filaments from recycled HDPE material. The extruder consists of a motor, a speed controller, a cylinder, a hopper, band heaters, a thermocouple, a temperature controller, a fan, a nozzle and a winder. This system works in the correct temperature range of 350-370 degrees Celsius for melting thermoplastic materials (recycled HDPE). Extruder function is to feed the material from the nozzle into the hot cylinder. A motor screw pushes the metal into the nozzle, where it becomes the filament. This filament is then injected onto a substrate for later use in 3D printing. The temperature is determined using thermocouples and a temperature controller, which ensures optimal extraction conditions. A fan is designed to quickly cool the removed filament.

The objective of this research is to create an economical as well as efficient filament to produce high quality filaments. Extruder performance is evaluated based on filament diameter consistency, material penetration and energy efficiency.

Keywords:- *3D Printer, Filament Extruder, Thermoplastic, Temperature Control, Filament Diameter.*

I. INTRODUCTION

3D printers use the filament as a thermal source for modeling their waste into 3d printing. There are many types of filaments with different characteristics and different temperature ranges to print the desired product on the market. Currently, filaments are accessible in many various diameters such as 1.75mm, 2.85mm and 3mm. The fabrication of 3D filament usually involves processes such as heating, drawing and cooling down to change the crystals into the final output. During this process, the filament is drawn out instead of being pushed into the die to create the filament. However, the diameter of that filament is indirectly proportional to the outlet diameter of the nozzle. The dimensions of the filament are determined by the sequence of events that occurs after the plastic is subjected to heat. Under the influence of an external force the filament is extruded to determine the width. The most frequently used filament sizes are 1.75mm or 3mm in diameter. Plastic pellets are either white or transparent in appearance. The hue of the filament can be altered by adding the appropriate additive before heating.

A prime example of the rapidly growing technology is 3D printing, which is as well the fastest growing field of engineering technology. Three Dimensional printing is considered cheaper in markets that produce low volume, customization and high value for the manufacturing team, such as aerospace and medical devices. 3D printing is a mechanism in which products, as in plastic or metal, are layered on top of each other to create a desired 3D object, such as glasses, or in some 3D form. The low cost of 3D printers allows the user to create useful objects even at home. Low cost 3D printers include Fuse Deposition Modeling (FDM), Stereo-lithography (SLA) and Digital Light Processing (DLP). In 3D printing, there are 2 popular types of filaments that are popularly used: Poly-lactic acid (PLA) and Acrylonitrile Butadiene styrene (ABS). Both The mentioned areas have their own mechanical and physical characteristics. However, before a flawless 3D printed product is successfully produced, final products are rejected due to human error and technical errors. The more features 3D printed products have, the greater the 3D performance. The arrival of desktop 3D printers to reduce the cost of distribution is creating demand for recycled 3D filaments. The recycling of 3D printed waste and 3D parts is an important issue to consider at the end of life. Therefore, the purpose of this project is to fabricate a filament extruder with low recycling costs that can produce ABS filament and investigate its mechanical properties.

The use of Poly-lactic acid (PLA) and Acrylonitrile butadiene and selenium is common in the making of composite materials (polymer) in form of granules and pellets. The materials being used are melted by means of ceramic group heaters. Materials are melted under controlled temperatures using sensors and controllers. The tail of the barrel is used to feed the feed material along the shaft. There are three areas of feeding area, melting area, measuring area. The quality concerning the filament is influenced by the rotational speed relative to the pressure and temperature conditions. The process of extruding plastic filament results in filaments of different diameters (1.75mm) using the same machines. Various types are used for different diameters, but our team revised the current convection extruder with alterations that allow us to produce different diameters at the same time using the same process-or step of the extruder. The expenditure of fiber is increasing day by day. So as to solve this problem faced by manufacturers, owners of small workshops, the filament manufacturing machine was created.

To prevent environmental pollution and Preserve natural resources for our descendants, plastic recycling is the most effective way to handle post-consumer plastics in the circular economy. The utilization of distributed recycling for plastic by consumers saves energy for transportation and reduces power usage compared to manual recycling. A recyclebot, an open-source waste plastic extruder, has been identified as a promising approach for upcycling waste thermoplastic into 3D printing feedstock. The filament extrusion involves heating, melting, and extruding thermoplastic materials into a continuous filament. Among the primary parts of an extruder are the extrusion screw, barrel, hopper, die. By using an electric motor, a rotation is utilized to move the raw material (in pellet form) from the container to the hot tub. The melt is fed through the mold and formed into the desired shape and size. As the string cools and hardens, the string retains its shape, making it ideal for 3D printing. The extraction process takes place by a combination of thermal energy and mechanical energy that ensures the stability of the dimensions and quality of the filament. In this process, proper control of temperature, pressure and speed of extraction is indispensable for producing a premium fiber that meets the required requirements. Research on recyclebot and distributed post-consumer plastic recycling has shown that the embodied energy of filament is 90% less during mining, processing or synthesis than in conventional production, to save money on purchasing filament, the recyclebot enables consumers to recycle plastic at home. HDPE, a thermoplastic with excellent strength-to-density ratio and high strength properties, is widely used due to its wide range of applications as recyclable. The use of this substance is widespread for items like milk and yogurt bottles, jerry cans or pipes, shampoo bottles , chemical drums, children's toys/bags packaging, cable insulation, household goods, and kitchen equipment. Millions of tons of post-consumer HDPE waste are produced due to the wide range of applications in consumer goods, and pipes The RecycleBot can produce HDPE fibers and establish a proof-of concept for recycling plastic waste with excellent quality. In a life cycle analysis of HDPE recycling using RecycleBot for 3D printing filament showed that distributed recycling uses 80% less energy than conventional recycling because the physical effort required for collection and transport is significantly reduced.

Various materials, including thermoplastics, composites and metals are being produced using additive manufacturing technologies such as 3D Printer Technology The utilization of this technology in industries as diverse as aerospace and automotive has facilitated manufacture intricate components without the use of costly tooling. Although these thermoplastics are widely available and possess advantageous mechanical, chemical, and physical characteristics, they are frequently expensive and primarily imported. This process involves the use of waste plastics to both reduce costs and help preserve the environment. At different transfer speeds, the MTS test machine is utilized for mechanical tests in accordance with test standards.

The layout for the plastic extrusion is as shown below

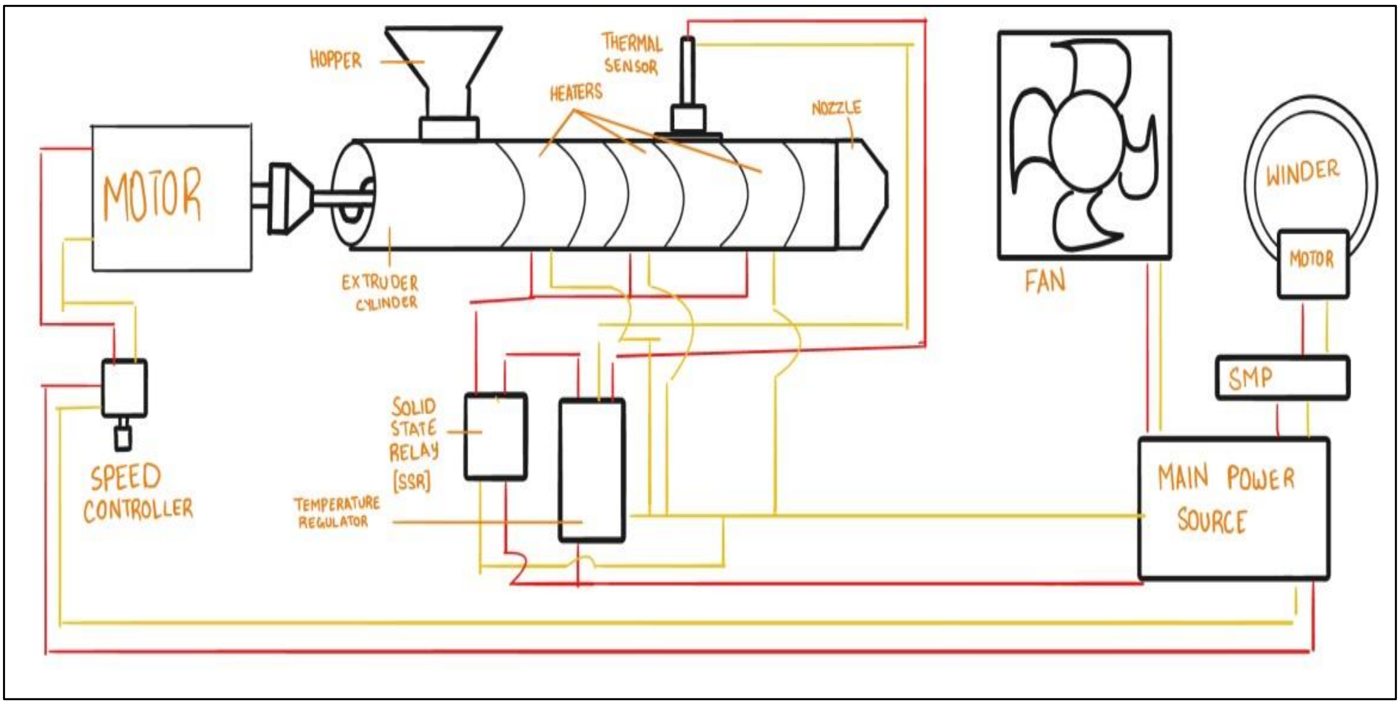

Fig 1 Schematic Diagram/Layout of the Extruder

➢ *Objectives of Work:*

- Developing and producing plastic filaments for 3D printing.
- It is mainly focused on producing filament of 1.75 mm diameter from plastic pellets.
- Constructing an extruder usable for manufacturing 3D filaments by small manufacturing units, companies, and colleges that have access to a portable 3d machine.
- Reducing the price of the filament used in 3D printer.
- To prevent environmental pollution and conserve natural resources by plastic recycling.

➢ *Problem Definition:*

Plastic recycling is the most desirable way in a sustainable economy to deal with non-recyclable plastics to reduce environmental pollution and ensure the well-being and safeguarding natural resources for the benefit of those to come. The best way to recycle recycled plastics is to repurpose the waste into a 3D printed filament using a plastic extruder.

II. LITERATURE SURVEY

P. Ravichandran et al [1] in 2020, authored "Design and Developmnt of 3D Printer Filament Extruder for Material Reuse" published in the International Journel of Scientific & Technology Research Volume 9, Issue 01 stated that the growth of 3D printers is a great way to reduce waste and save resources. The device is compact enough to be carried around and can be utilized by both small enterprises and universities. This advanced product reduces maintenance. The operation of this device does not necessitate specialized personnel and minimizes the unit's running costs and initial investment. It can achieve fairness and management of the workflow. The implementation of this system might need design changes to meet the customer's specific requirements.

Menberu Zeleke Shiferaw et al [2] in 2023 authored "Developing Filament Extruder and Characterization of Recycled High-Density Polyethylne for 3D Printing Filament Material" published in Engineering Open Access, 1(1) 5-20, stated that the environmental pollution caused by plastic waste and the demand for polymer materials in FDM 3D printing by creating affordable, user-friendly recycled HDPE filaments. A filament mill was developed to produce smooth, round recycled HDPE filament with a diameter of 1.75±0.01 mm at 220 °C, 20 rpm shaking speed, and 5 rpm drawing speed using a 2 mm die. The physical, mechanical, chemical, and thermal characteristics of the recycled HDPE were validated against original samples. Results showed the filament's tensile strength at 19.02±0.35MPa, marginally lower than that of HDPE, indicating comparable strength. The spectrum revealed slight impurities, while thermogravimetric analysis exhibited thermal stability with degradation temperatures similar to HDPE. Additionally, the filament showed high water resistance, with only a 0.12% weight increase after six days in distilled water.

Mamta H. Wankhade el at [3] in 2018, authored "Design and Development of Plastic Filament Extruder for 3D Printing" published in the International Journal of Technology & Engineering (ISSN 2455-4480) stated that the 3D printing technology has enabled the production of objects from a variety of materials, including plastic, metals, paper, and food.Users are able to explore their creativity. Universities, manufacturing companies, and everyday users rely on 3D printing as a speedy means of developing prototypes, exploring the technology's potential, or discovering ways to enhance it. Because of the rapid growth of this technology, it has been leapt to improve performance. The development of vibration abstraction is expected to open the doors to new ideas for 3D printing. Users can access a wide range of high resolution materials for 3D printed parts.

Prof.Mona A. Nassar, el at [4] in 2019, authored "Design Of 3D Filament Extruder for Fused Deposition Modeling" published under a Creative Commons Attribution 4.0 International License which stated that to produce filament of high quality, the temperature and extraction speed must be adjusted in a suitable manner. If the extraction speed is too fast, the raw plastic will not melt completely, the solid pieces will be small and the strand will become rough and bubble. This condition can be prevented by reducing the motor speed for the correct temperature. Heating up will cause the plastic pellets to melt completely, resulting in a smooth plastic strand. The test section showed that the model can produce good quality filament at 18 motor speeds (RPM) and temperatures above 200°C, melting HDPE pellets and was used for testing. The diameter of the final filament was influenced by the nozzle size and the speed of the hot filament from the outlet.

Ahmed Abid Malpura, el at [5] in 2024, authored "3D Printer Filament Extruder" published in International Research Journal of Engineering and Technology Volume: 11 Issue: 04 stated that the manufacturing and commercial applications of additive manufacturing face significant obstacles in procuring raw materials for 3D printing. Hence, this issue is reinforced by the requirement for good quality materials and properties of mechanical parts. We resolved the issue by devising a comprehensive design and production plan for the extruder. A systematic approach was taken to examine the parameters related to fiber extraction in this work. The produced fiber's mechanical characteristics were analyzed and favorable outcomes were achieved. The simplified workflow not only reduced time and costs, but also helped to develop an efficient system for the production of governors.

Bharat M Kambalur, el at [6] in 2016, authored "3D Printer Filament Extruder for Plastic Recycling" published by department of ECE B.M.S College of Engineering Bangalore stated that a successful filament extruder involves a structured process of planning, building, testing, and refining. To produce high-quality filament, it's essential to overcome challenges in mechanical design, electronic control, and process settings.

Alvaro Goyanes [7] in 2014, designed and build An extrusion machine was developed that produces 3D printer filament using polyethylene terephthalate (PET) water bottles as its raw material.

Rina Abdullah el at [8] in 2017 a temperature control system using an Arduino board. This project gave us insight into the process of interfacing the microcontroller with temperature sensors.

Ruben Foresti el at in 2019 presented their work on "Nano-Functionalization of 3D Bio-Engineered Scaffold in Bio-Composite Materials" at the IEEE International Conference on BioPhotonics (BioPhotonics), pages 100–101.

Samuel H. Huang el at [10] in 2013 conducted a "Comprehensive Literature Review on Additive Manufacturing and Its Societal Impact," published in the International Journal of Advanced Manufacturing Technology, 67(5–8).

Juan Wang el at [11] examined the impact on the mechanical properties and water absorption of Polycaprolactam (PA6) and Polyhexamethylene Adipamide (PA66) in their 2020 publication in RSC Advances, 10(36), pages 21491–86.

Shan Zhong el at [12] in 2018, explored "Coupled Distributed Recycling and Manufacturing with Recyclebot and RepRap 3-D Printing" in Resources, Conservation and Recycling.

T. Letcher [13] in 2014, conducted a study titled "Material Property Testing of 3D-Printed Specimens in PLA on an Entry-Level 3D Printer," and the findings were published in Volume 2A of the Advanced Manufacturing journal.

Xinran Xiao's [14] publication, in 2008 published “Dynamic Tensile Testing of Plastic Materials," in Polymer Testing, 27(2), explored the mechanical properties of plastic materials under dynamic tensile conditions.

Arup Dey, el at [15] in 2021 authored "A Comprehensive Review on Filament Materials for Fused Filament Fabrication," published in the Journal of Manufacturing and Materials Processing.

➢ *Summary:*

The reviewed studies (2016-2024) focus on developing filament extruders for 3D printing. Here are the key findings:

- **Reduced Waste and Increased Accessibility:** Extruders can create filament from recycled materials, reducing waste and production costs (1, 2). Compact designs make them appropriate for small businesses and educational institutions (1).
- **High-Quality Filament Production:** Successful extruders require a systematic approach involving design, prototyping, testing, and optimization (6). Challenges include mechanical design, electronic control, and process parameters like temperature and speed (4, 6).
- **Material Exploration:** Studies explored using recycled HDPE and other materials for filament production (2, 4).
- **Future Advancements:** Research suggests focusing on advanced control algorithms, exploring new materials, and improving efficiency and sustainability (6).

III. METHODOLOGY

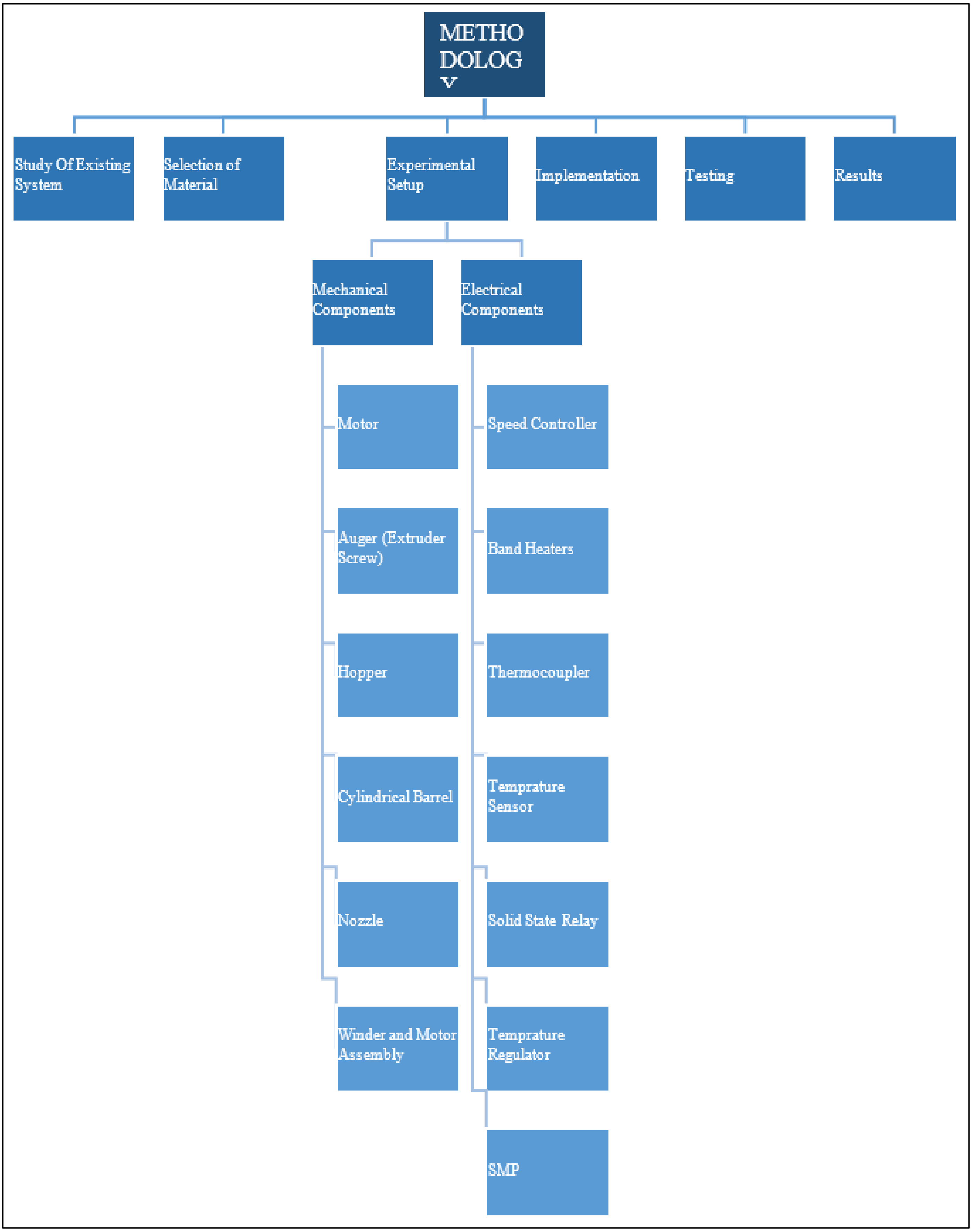

Fig 2 Methodology

A. *Selection of Material:*

- *Plastics and Recycling:*

Despite the fact that various materials are being researched for 3D printing, ABS and PLA are the most popular ones. In other words, it heats, softens, cools, and returns to a solid state. This process can be done over and over again. They are popular in the community because of their potential to melt and process, majority of the polymers you encounter with on a daily basis are thermoplastics.

HDPE exhibits a density ranging from 930 to 970 kg/m³, slightly denser than low-density polyethylene (LDPE). Its impressive tensile strength of 38 MPa surpasses that of LDPE (21 MPa), making it suitable for demanding structural applications. Additionally, HDPE demonstrates excellent temperature resistance, withstanding up to 120°C (248°F) for short periods. One of HDPE's standout features is its remarkable chemical resistance. It resists many solvents, ideally suited for applications where exposure is necessary towards aggressive substances is common. However, bonding HDPE can be challenging; welding is often necessary for secure joints. Furthermore, HDPE contributes to environmental sustainability. It is commonly recycled and bears the resin identification code "2." This recyclability aligns with global efforts to reduce plastic waste and promote circular economies.

For this research, a diverse range of post-consumer HDPE plastic products such as water bottles, shampoo bottles, detergent bottles and household containers were collected based on resin identification numbers to separate them from other plastics. Stickers and adhesives are removed by manual peeling with a wire brush, and then the plastic is rinsed with water to prevent contamination. A rotary mill is intended to crush purified HDPE plastic into strips, followed by slicing them into rectangular pieces using tin shears. To achieve an even size, the shells are filtered through a 5 mm sieve. The shredded HDPE plastic pieces are collected using a machine at a local recycling company to produce recycled HDPE pellets. The recycled HDPE the pellets underwent a drying process in an oven at 60 °C, lower than the glass transition temperature of the HDPE polymer (110 °C) to be extracted.

Fig 3 HDPE Pellets

B. *Experimental Setup:*

The figure below shows the experimental setup to produce 3D printer filament.

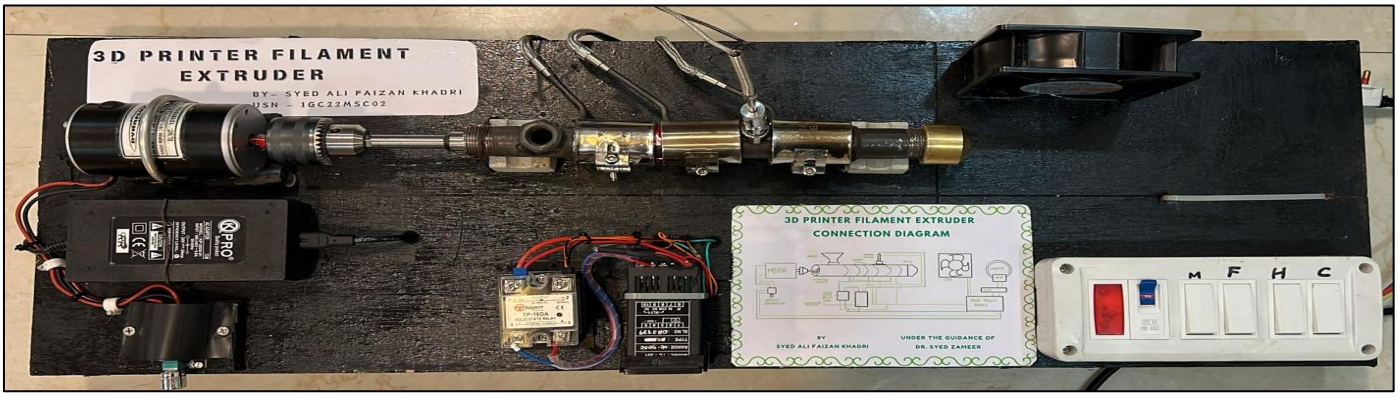

Fig 4 Extruder Setup

- *The Setup of this Extruder Machine was done using Components Listed below:*

Table 1 Extruder Machine

Component	Quantity
Turning screw	1
Steel Tube	1
Hopper	1
Heaters	3
Nozzle	1
Motor	2
Fan	1
Spool	1

➢ *Motor:*

A DC motor, with a voltage of 24V DC, with a current of 1.3A and an output power of 25W, is used in the 3D printing process to advance the feed material. This motor is coupled to a rotor rotating at a speed of 1500 revolutions per minute (RPM). A speed controller has the ability to modify the motor's speed, thereby altering the rate at which the feed material is pushed. The 24V Direct-Current motor is the main drive in this application and transforms electrical power into mechanical energy to move the feed material. The electrical characteristics of the motor, including voltage class, current consumption and power, determine its suitability to move the vibration and achieve the required feed rate. The motor's power consumption is indicated by its current rating of 1.3A. This current is conducted through the motor windings and produces a magnetic field that engages with the permanent magnets or electromagnets in the motor, causing a rotating motion. The power of 25 watts indicates the motors power, which is the rate of speed at which the motor can operate. In this context, the output power is important to overcome the friction and resistance forces that occur when feeding the material. The motor rotation speed of 1500 rpm determines the rotation frequency of the grinder. This rotational speed along the pitch of the screw represents the linear feed rate of the material. A speed controller can directly control the RPM of the motor and change the feed rate as needed. The rotary converter (turning screw) acts as a mechanical translator and converts the rotary motion from the motor into the linear movement of the feed material. The pitch of the screw thread and the speed of the motor determine the rate at which the feed material is pushed forward. By changing the RPM of the motor, it is possible to change the rate of feeding materials according to the speed essential for the removal of the 3D process. The speed controller plays vital role in setting the motor speed and feed rate. This electronic device can directly control the voltage supplied to the motor and change the rotational speed. By adjusting the speed controller settings, the operator can adjust the feed speed to achieve optimal results. As a result, the DC motor, working together with the spindle and the speed controller, is a fundamental part of the 3D printing process.

The electrical properties of the motor, the speed of rotation and the mechanical properties of the auger work hand-in-hand to advance the feed material at the operating speed. The ability to accurately adjust the feed rate with a speed controller is essential to producing high quality 3D objects with consistent dimensions and material properties.

Fig 5a Motor

During the process of 3D filament manufacturing, it is mandatory to use a speed controller to regulate the speed of DC motor. This speed controller is designed to work on 24V DC power, to be compatible with the operating voltage of the motor. Its ability to handle currents of up to 3 amps ensures that it can handle the current of the motor without overheating or breaking. A speed controller works by adjusting the voltage supplied to the motor. This voltage change can be reached in several ways such as pulse width modulation (PWM) and voltage controlled oscillator (VCO). PWM rapidly switches the DC voltage on and off at high frequencies, creating an average voltage that can be controlled to regulate the speed of the motor. Simultaneously, a VCO produces a variable frequency signal that is employed to regulate the speed of the motor. By altering the voltage supplied to the motor, the speed controller effectively controls the speed of rotation. This control is important in 3D printing, as the filament feed rate must match the extraction speed in order to produce high quality parts. The speed controller can accurately adjust the feed rate, and the operators can achieve the best results. In addition to regulating the motor speed, the speed controller can provide other functions such as protection against overcurrent, overheating and voltage fluctuations. These features improve the motor's reliability and durability, thereby improving the 3D printer's overall performance.

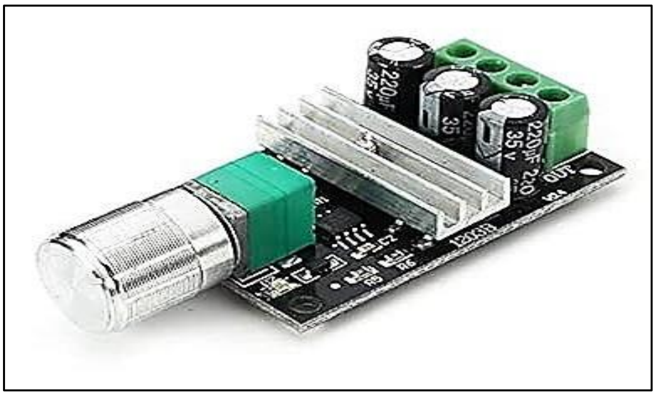

Fig 5b Speed Controller

- *Turning Screw:*

The crucial steps in the extraction process of 3D printing filaments are the turning screw. This machine tool, made of hardened steel alloy, is designed to transform circular movement into straight-line movement. The feed material, such as plastic pellets or filament, is conveyed through the extraction nozzle of an extruder in which the screw functioned to expulse. The dia. of the screw is 18 mm, while its length is 400mm. These dimensions have been chosen for strength, stiffness and compatibility with the extruder design. The screw is housed in a steel tube for support, reducing friction and preventing bending or twisting during operation. The rotational motion required to drive the screw is provided by a DC motor. The output shaft of the motor is connected to the head of the rotating shaft and turns. As the mill rotates, its threads engage the feed material and push it forward along the turning screw. The feed speed can be controlled by adjusting the speed of the DC motor. The strength and performance of the screw is affected by a number of factors, including the pitch of the threads, the characteristics of the feed material, and the frictional force between the mill and the pipe. A well-designed screw with an appropriate thread base and material can be produced smooth, until the fiber is removed. Thus, the turning screw is pivotal in the extraction process for 3D printing filaments. By converting the rotary motion into a linear motion, the feed material is forced through the extruder nozzle. The dimensions, materials and design of the screw, along with the DC motor drive, determine the strength and performance of the extraction process.

Fig 6 Turning Screw (Auger)

- *Steel Tube:*

The steel tube is an essential component of the 3D printer's extraction mechanism, as a feed material channel and structural support. This tube has a length of 300 mm, an outer diameter of 30 mm and an inner diameter of 20 mm. Its open design allows feed materials to be transferred, while its solid construction ensures durability and stability. One end of the steel tube features a hole or opening where the hopper is attached. The hopper is a container that holds the feed material, such as plastic pellets or filaments. When the hopper is filled, the material can be poured into the tube, where it is then transported to the extrusion nozzle. Inside the tube is a rotating screw. Near the end of the steel tube is a nozzle. The die is a machined orifice that controls the diameter of the wire that comes out. The food, now melted, passes through the nozzle, forming a continuous stream. The diameter of the nozzle determines the thickness of the filament, which is crucial to the integrity and durability of 3D printed object. A coupler is affixed to the far end of the steel tube, which is adjoined to a DC motor. This connection ensures reliable and efficient transmission of rotary motion from the motor to the auger allowing for movement and feed governance of the material.

In short, steel tube plays an important role in the extrusion process. It provides a path for the feed material, supports the rotating wheel and nozzle. The dimensions, design and material of the tube are carefully selected to optimize the extraction process and ensure the production of high quality 3D printed objects.

Fig 7 Steel Tube

- *Hopper:*

The hopper is a vital part of the 3D printing process that acts as a source of feed material. It is usually a container with a wide base and a narrow opening at the top. Feed material, such as plastic pellets or fibers, is poured into a container and preserved there until necessary. The hopper design allows for easy filling and prevents spillage or contamination. The narrow opening at the top helps the material flow into the extrusion tube and ensures uniform feeding. The throat of the hopper is usually connected to a steel tube to house the rotating shaft. When the extruder is activated, the feed material flows from the container into the tube and is then moved by the rotating screw to the extraction die. The capacity and design of the container may vary depending on the specific needs of the 3D printer and the type of feed material being used.

Fig 8 Hopper

- *Nozzle:*

In 3D printer filament extruder machines, the nozzle attached to the end of a steel tube is an essential component that extrudes the filament material in precise, controlled layers to create the desired 3d object. This type of nozzle is usually made of bronze, which is a heat-resistant and long-lasting material that can endure the high temperatures at which it will be heated to melt and extrude the filament material. This device has a nozzle that is 35mm outside diameter, which makes it easy to fit through the steel tube and its thread is 30mm in size for quick installation. The most critical aspect of the nozzle is its output diameter, which in this specific context is 1.75mm.The thickness of the extruded filament, which is determined by the carefully calibrated diameter, has a direct impact on the quality and resolution of any 3D printed item. The steel tube is used to feed the filament into the heated nozzle, where it melts into a viscous liquid. As the liquid filament emerges from the nozzle, it cools and solidifies, forming the filament. The aperture dimension of the nozzle orifice is important to maintain the thickness of the filament during the extraction process, and to avoid defects such as holes, overlaps or changes in the layer contact.

Therefore, the nozzle plays a significant role in the 3D printing process by controlling the extrusion of the filament material and determining the quality of the final product. Nozzle dimensions and outlet diameters are carefully designed to ensure performance and reliability in filament extruders.

Fig 9 Nozzle

- *Heaters:*

Band heaters are essential part of 3D filament extruder that is liable for providing the necessary heat to melt and produce filament. These heaters are cylindrical in shape and are designed to surround a steel tube that holds the filament. With an internal diameter of 30 mm, the heaters snugly wraps around the steel tube. This facilitates effective heat transfer and prevents heat loss. This heater works with 24 volts and an output of 350 watts, which is hot enough to melt a variety of filament materials. This heater can reach a temperature of 600 ° C, which is sufficient for most common filaments such as PLA, ABS and PETG. To maintain temperature control, heaters are often used in conjunction with a temperature controller. This unit monitors the temperature of the heater and adjusts the output power accordingly to ensure that the desired temperature is maintained. By adjusting the temperature, it is possible to improve the extrusion process, and it is possible to avoid the degradation of the material or the failure of the printed object. Band heaters are well-suited for filament extrusion due to their ability to provide consistent and uniform heating over the length of the steel tube. This prevents unnecessary heating of the filament, which can cause warping, twisting, and other defects. In addition, the cylindrical shape of the heater ensures that the heat is evenly distributed around the pipe, reducing the risk of hot or cold spots.

Hence, heaters are fundamental part of 3D printing machines that provide the heat necessary to melt and produce filament materials. Their internal diameter, power and temperature range are carefully designed to meet the specific needs of fiber extraction. By using a temperature controller, precise temperature control can be accomplished and ensure the fabrication of high quality 3D printed objects.

Fig 10a Band Heaters

In filament extruding machines, thermocouple sensors are placed near the band heaters to monitor the temperature. The generated voltage is transferred to the temperature converter, which uses it to adjust the output power of the heater and maintain a constant temperature. This precise temperature control is essential to ensure optimal filament extrusion and prevent material degradation or imperfections in the printed material. Thermocouple sensors possess several benefits compared to other temperature measurement methods. It is very accurate and has a extensive temperature ranges suitable for measuring the maximum temperature produced by group heaters. In addition, thermocouple sensors are inexpensive and require little maintenance. These provide accurate and reliable temperature measurement for heat sinks that melt filament materials. These sensors are typically made from two different metals joined at one end to form a joint. When the junction is subjected to a temperature difference, it produces a voltage proportional to the temperature.

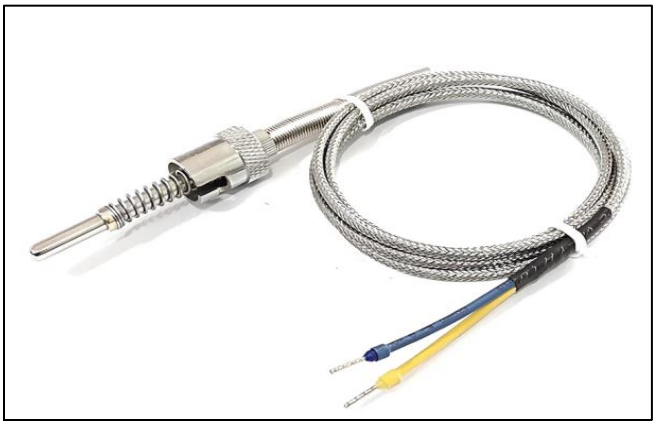
Fig 10b Thermocouple

Solid state relays (SSRs) have become increasingly popular in a multitude of industrial applications. Unlike traditional relays, these electronic devices possess numerous advantages that make them ideal for electrical control of band heaters used in extrusion. SSRs are basically semiconductor switches that can handle large currents with a low power signal. Unlike electronic relays that rely on mechanical connections to change the current, SSRs use electronic components to accomplish the same function. This eliminates the need for mechanical connections that can consume time and lead to noise in the electrical circuit. In filament extruders, SSRs are used to control the current applied to the band heaters. By changing the control signal to the SSR, the output power of the heater can be changed and the temperature can be changed. This precise temperature control is essential to ensure optimal filament extraction and prevent material degradation or fracture of the printed material. SSRs have several benefits over electronic relays in filament extruders. It is more reliable and has a longer service life due to the absence of mechanical joints. In addition, SSRs are faster and exhibits higher switching frequency, which can improve the response of the temperature control system. It is less susceptible to noise and interference, which may intervene with electronic relays. Additionally, SSRs are more streamlined, compatible and easier to integrate into electronic control systems. This makes it more suitable for use in applications where space is limited such as 3D filaments.

As a result, solid-state relays are an important component in filament extruders and are superior to traditional electronic coils. Their reliability, speed and accurate control functions are required for controlling the power supply of filter heaters and ensuring optimal filament extraction. As the technology continues to advance, SSRs will play an increasingly important role in 3D printing and other industrial applications.

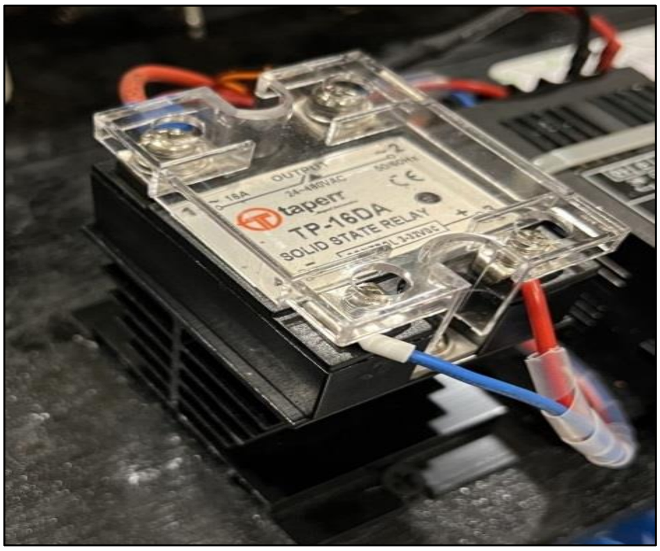

Fig 10c Solid State Relay (SSR)

Temperature regulators are essential components responsible for maintaining accurate temperature control of the band heaters that melt and extrude the filament material. These devices play a critical role in ensuring optimal extrusion, preventing material degradation, and producing high-quality printed objects. A typical temperature regulator for filament extrusion applications can regulate temperatures up to 900 degrees Celsius, which is sufficient for most common filament materials. These devices utilize a combination of sensors, control algorithms, and power output mechanisms to achieve accurate temperature control. The regulator typically incorporates a thermocouple sensor to measure the temperature of the band heater. The sensor's output is then processed by a control algorithm, which compares the measured temperature to the desired setpoint. If there is a discrepancy, the algorithm adjusts the power output to the heater accordingly. This process is repeated continuously to maintain the desired temperature. Temperature regulators for filament extruders often feature advanced features such as PID (Proportional-Integral-Derivative) control, which provides precise temperature control and minimizes overshoot and undershoot. Additionally, many regulators offer a user-friendly interface with adjustable settings, allowing for customization to meet specific application requirements.

The precision and reliability of the temperature regulator are critical for the success of the filament extrusion process. A malfunctioning or inaccurate regulator can lead to inconsistent filament flow, material degradation, or even damage to the extruder. Therefore, it is essential to select a high-quality temperature regulator that is specifically designed for filament extrusion applications.

In conclusion, temperature regulators are indispensable components in 3D printer filament extruder machines, providing precise temperature control for the band heaters that melt and extrude the filament material. By ensuring accurate temperature regulation, these devices contribute to the production of high-quality printed objects and enhance the comprehensive performance of the extrusion process.

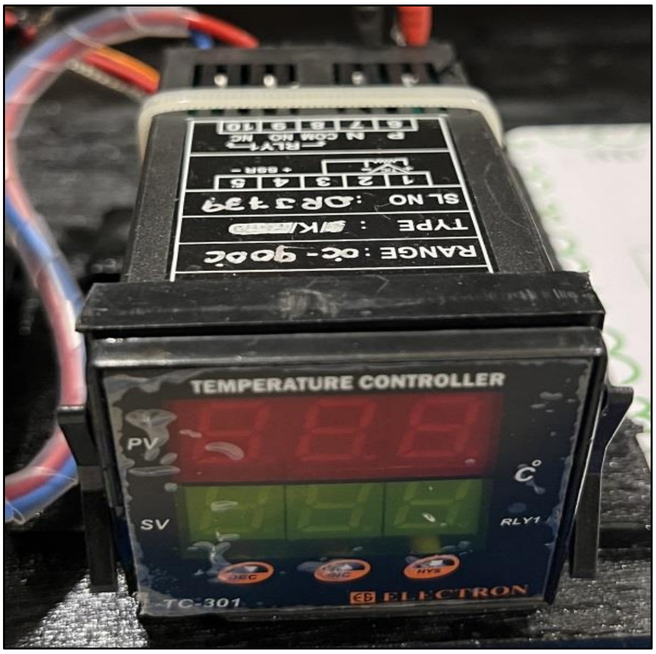

Fig 10d Temperature Controller

- *Fan:*

Fan is an important part of 3D filament extrusion machine, providing the necessary cooling to ensure that the filament hardens quickly and maintains the desired shape. The fan used in this project works on 220/240VAC, runs on 0.18A current and 33watts.

Fig 11 Fan

- *Winder:*

The spool is typically a cylindrical object with grooves or ridges that allow the filament to wind around it. As the filament is extruded and cooled, it is guided onto the spool, where it is stored for future use. The spool is essential for maintaining the filament's integrity and preventing it from becoming tangled or damaged. It also facilitates for easy storage and transportation of the filament material. The spool is attached to a motor which rotates to support ease in collection and storage of the filament produced.

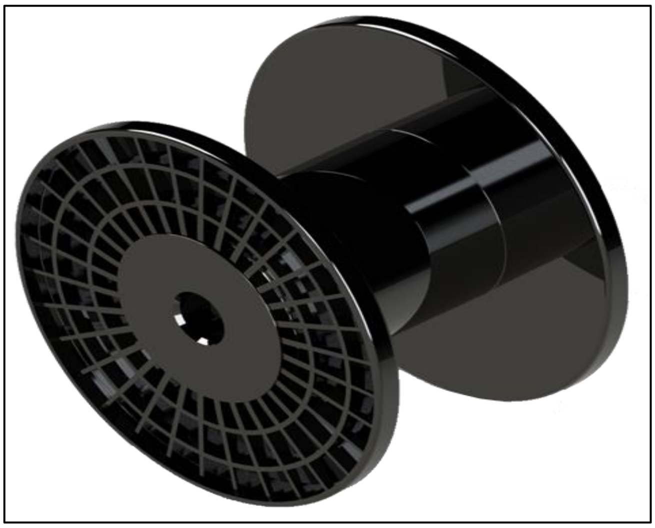

Fig 12a Spool

To drive the spool and collect the extruded filament in a 3D printer, a low-speed DC motor is typically used. This motor operates on 12 volts and has a rotational speed of 10 revolutions per minute (RPM). The motor is connected to a gearbox or pulley system that reduces its speed to a suitable level for winding the filament onto the spool. This reduction in speed ensures that the filament is wound evenly and without excessive tension. The motor's performance is critical for the smooth operation of the filament extruder. A dependable and efficient motor will help to prevent filament jams, tangles, and other problems that can interrupt the process.

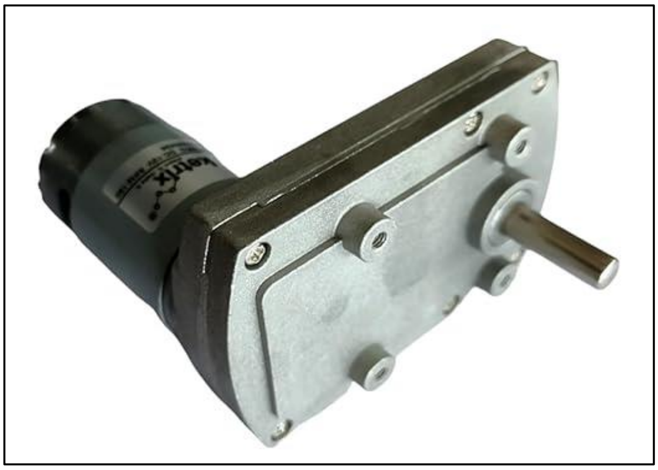

Fig 12b Gear Motor

A Switching Mode Power Supply (SMPS) is a highly efficient electronic circuit used to convert DC voltage from one level to another. According to a 3D printer filament extruder, an SMPS can be used to supply the 12V DC current required to power the motor that drives the filament spool. In a filament extruder, an SMPS can be used to convert the input voltage (e.g., from a 24V power supply) to the required 12V DC voltage for the motor. The SMPS will regulate the output voltage to ensure that the motor receives a stable and reliable power supply, even if the input voltage fluctuates. By using an SMPS, it is possible to achieve a more efficient and reliable power supply for the filament extruder motor, ultimately improving the overall performance and reliability of the 3D printer.

➢ *SMPSs offer some Advantages over Linear Power Supplies, Including:*

- High efficiency: SMPSs can be significantly obtaining much greater efficiency than linear power supplies, reducing electrical loss and generating less heat.
- Smaller size: SMPSs are typically smaller and lighter than linear power supplies, making them ideal for space-constrained applications like 3D printers.
- Lower cost: SMPSs are generally more cost-effective than linear power supplies, especially for higher power outputs.
- Wide input voltage range: SMPSs can often operate with a wide range of input voltages, making them adaptable to different power sources.

Fig 12c SMPS

C. Implementation:

A filament extruder, a fundamental component of 3D printers, is a sophisticated assembly of interconnected components, each playing a vital role in the extrusion process.

The foundation of the extruder is a wooden plank that provides a stable base for the various components. Clamped securely to this plank is the motor, the driving force behind the extrusion process.

A speed controller, connected to the motor via an adapter, allows for precise adjustments to the extrusion rate. Both the speed controller and motor are then connected to the main power supply switch, enabling the operator to govern the extruder's operation.

At the heart of the extruder is a hollow steel tube. Inside this tube, a turning screw is coupled to the motor's shaft. As the motor rotates, the screw turns, pushing the filament material through the tube. At one end of the tube, a nozzle is attached, regulating the diameter of the extruded filament. At the other end, a hopper is positioned to feed the filament material into the tube. To ensure optimal heating of the filament, heaters are wrapped around the steel tube. A thermocouple is also placed near the tube to monitor the temperature. A temperature controller allows the operator to adjust the temperature as needed, ensuring that the filament is heated to the appropriate melting point. The heaters, thermocouple, and temperature controller are connected to a solid-state relay, which then connects to the main power supply. This setup provides precise control over the heating process.

To cool the extruded filament, a fan is positioned besides the nozzle. Directly plugged to the main power supply, the fan blows air onto the filament, accelerating its cooling process. This is essential for preventing the filament from warping or curling as it solidifies.

Finally, a winder assembly is placed near the fan to collect the extruded filament. This assembly comprises of a spool adjoined to a motor that runs at 10 RPM. To reduce the voltage to 12V, an SMPS (Switching Mode Power Supply) is used. The SMPS is then connected to the main power supply, providing the necessary power for the spool motor.

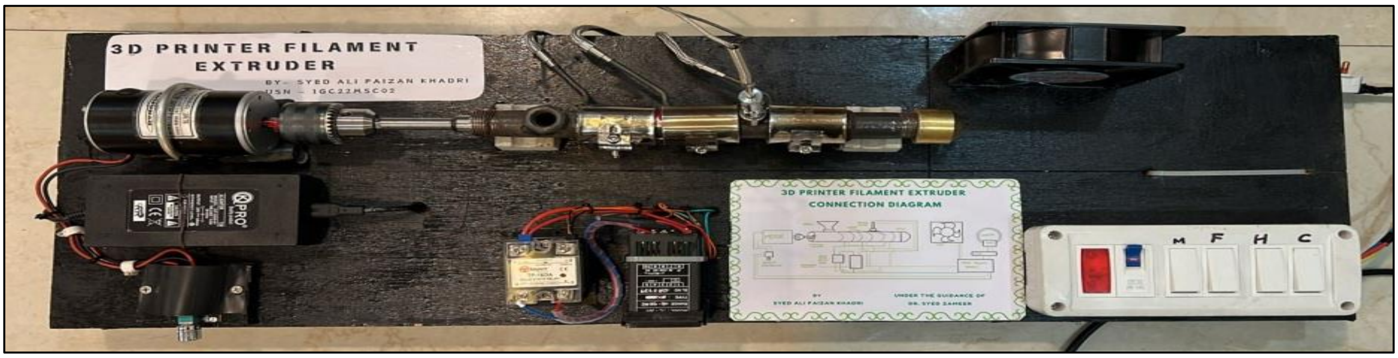

Fig 13 Extruder Assembly

IV. RESULTS AND DISCUSSION

The filament extruder is first connected to a power source and the push button switch was turned on. The temperature of the heater is adjusted using a PID temperature controller. The heating element begins to heat the barrel, while the K-type thermocouple begins to measure the temperature and feed it back to the PID temperature controller. The solid-state relay turns off when the temperature exceeds the desired heating value and turns on when the temperature drops. The switch of the extrusion motor turns on when the required amount of heat is maintained and the rotation of the extrusion motor starts. HDPE is into the funnel and transferred to the heating section of the barrel by rotating the turning screw. The metal material is forced into the nozzle. The extrudate is cooled and solidified by a cooling system. Finally, the filament is pulled and wound around the spool.

- *Test 1:*

HDPE pellets are fed into the extruder and exposed to over 400°C. This high temperature caused the HDPE to turn from a solid to a liquid. As the molten HDPE was pressed through the steel pipe, the combination of low rotational speed and sustained high temperatures caused the material to burn and crystallize. The filament is not formed because the material is trapped and burnt.


Fig 14 Burnt HDPE

- *Test 2:*

During the second test, the RPM of the motor driving the extrusion process was set at 50 RPM, while the temperature was reduced to the range of 300-350 °C. The motor caused the rotating turning screw to move faster in the steel tube. This screw acts as a piston and pushes the HDPE material forward into the nozzle. High temperature is an important factor in converting HDPE from a solid state to a liquid state. This phase change was necessary for the extraction process because it made it easier to form metal objects and push them out through the nozzle. When the molten HDPE reaches the nozzle, the pressure inside the steel tube pushes it through the narrow opening. The resulting filament is a continuous strand, characterized by its white color. The dia of the extruded filament was 1.75mm which was as desired.

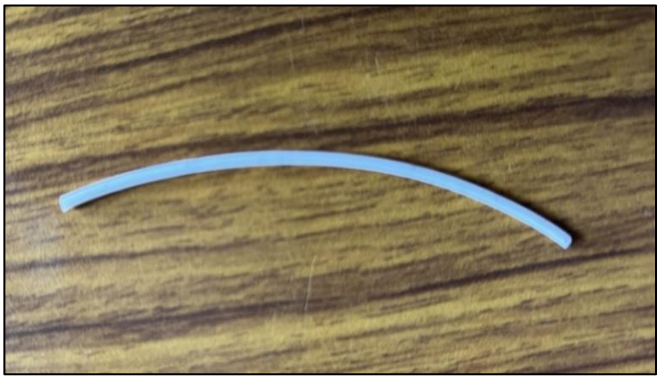
Fig 15 Extruded Filament

Once the HDPE filament was successfully extruded, it was subjected to rigorous testing to evaluate its mechanical properties.

To test their mechanical properties bending and tension elements were printed using the extruded filament in a 3D printer. Approximately 40mis were taken by the printer to print one element.

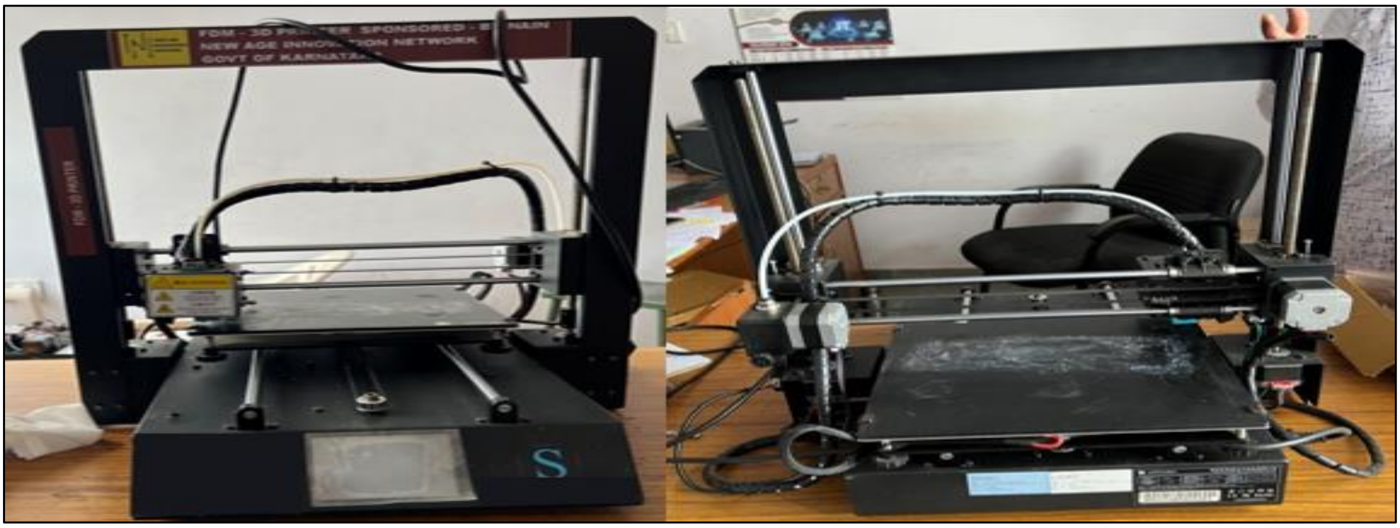
Fig 16 3D Printer

Once both the elements were printed. Two key tests were conducted: bending and tension.

Bending tests were performed to assess the filament's ability to withstand deformation without breaking. Sample elements, such as beams or plates, were printed using the extruded HDPE filament. These elements were then exposed to a gradually increasing bending load until they failed. By measuring the maximum load before failure, it was possible to determine the filament's flexural strength.

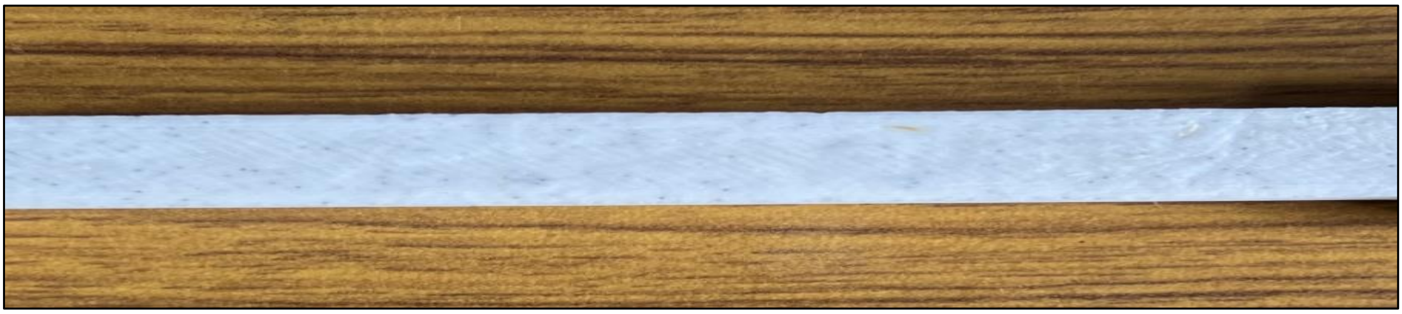

Fig 17 Bending Element

- *The following Graph shows the Result of the bending Test:*

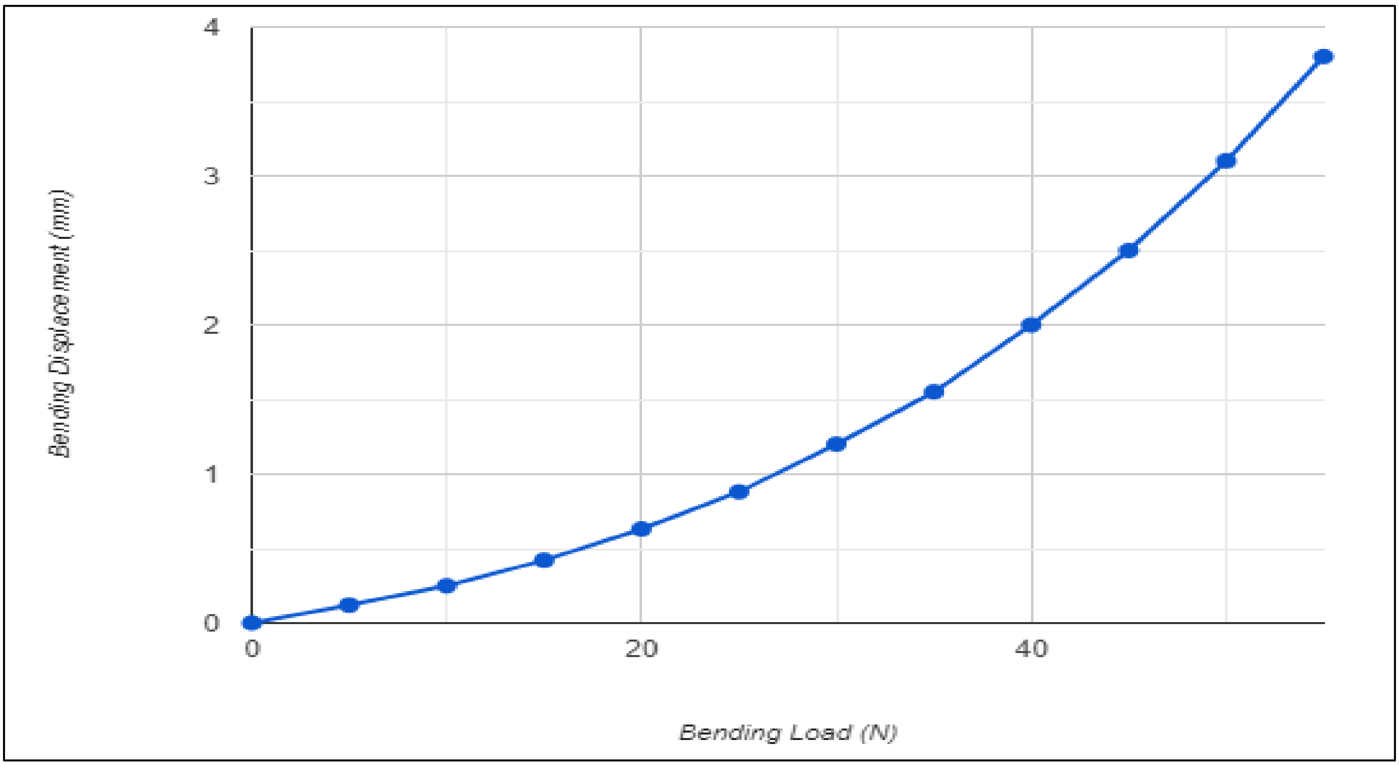

Fig 18 Bending Load vs. Displacement Graph

The provided graph illustrates the relationship between bending load and displacement for a 3D-printed HDPE (High-Density Polyethylene) sample tested at 300°C.

- **X-axis:** Bending Load (N) represents the applied force causing the sample to bend.
- **Y-axis:** Bending Displacement (mm) measures the deflection of the sample under the applied load.

The graph shows a typical nonlinear relationship between bending load and displacement. The majority of materials are capable demonstrate both elastic and plastic deformation.

Tension tests were carried-out to determine the filament's resistance to stretching. Samples were stretched until they broke, facilitates for the measurement of tensile strength. This test offers valuable insight about the filament's ability to withstand pulling forces without yielding or fracturing.

Fig 19 Tension Element

➢ *The following Graph shows the Result of the Tension/Tensile Test:*

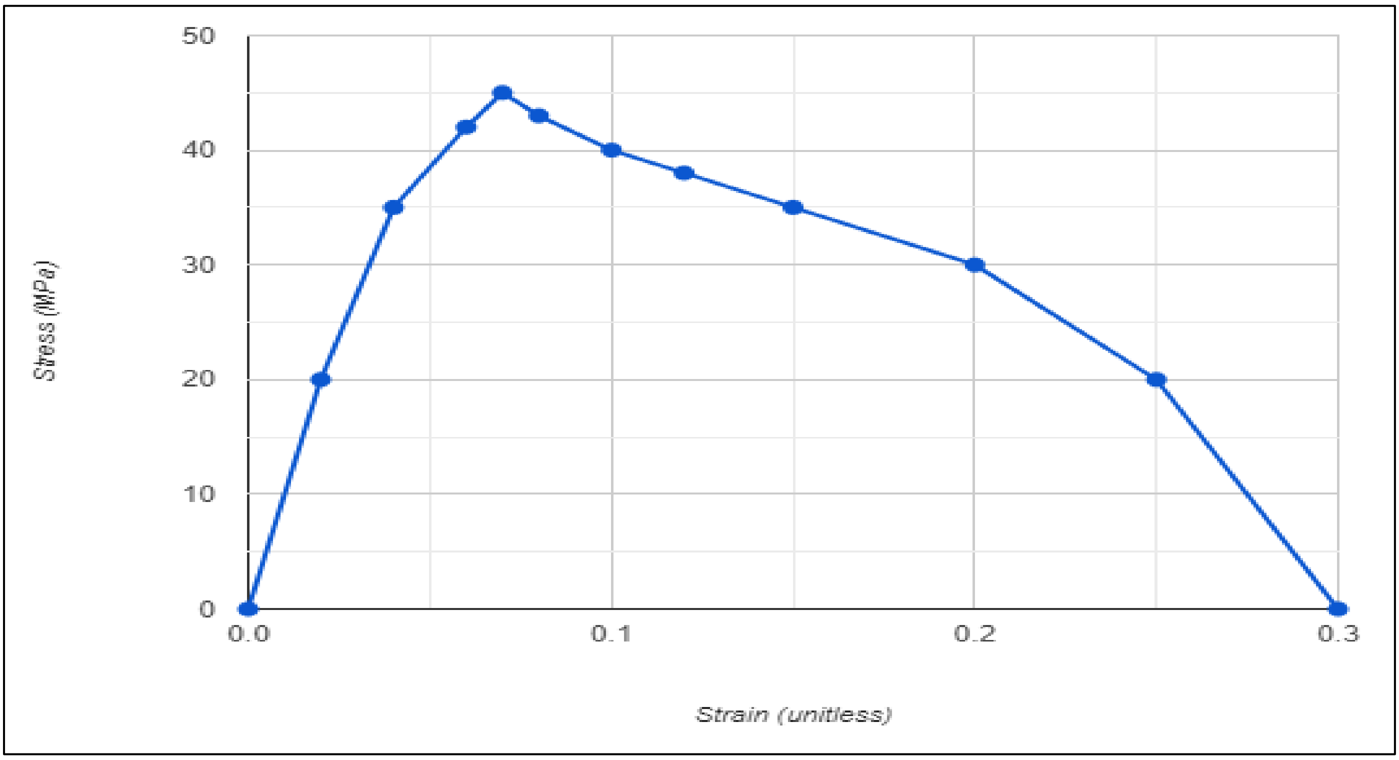

Fig 20 Tensile Stress-Strain Curve

The provided graph illustrates the relationship between tensile stress and strain for a 3D-printed HDPE (High-Density Polyethylene) sample tested at 300°C.

- **X-axis:** Strain (unit less) represents the deformation of the material relative to its original length.
- **Y-axis:** Stress (MPa) represents the deformation force applied per unit area of the material.

The curve starts with a linear portion, indicating elastic deformation. The curve then is non-linear, indicating the yield point. This is the point where the material begins to deform plastically, and it will not return to its original shape. As the strain increases further, the material undergoes necking, where a localized reduction in cross-sectional area occurs. Eventually, the material fractures at the point of necking.

➢ *From the above Tests*

- **Strength and Stiffness:**The analysis of both the tensile stress-strain curve and the bending load vs. displacement curve indicates that the 3D-printed HDPE possesses adequate strength and stiffness. This makes it fitting for needs where structural integrity is a primary concern. The material's ability to withstand both tensile and bending loads without excessive deformation is a positive attribute.

- **Ductility:** The moderate ductility exhibited by the HDPE suggests that it can undergo a certain amount of plastic deformation without fracturing. This is beneficial in applications where the material may be subjected to impact or shock loads. While the ductility may not be as high as some other materials, it is sufficient for many practical purposes.

While the overall mechanical features of the 3D-printed HDPE are promising, it's important to consider other variables that may influence its performance:

- **Printing Parameters:** The specific printing parameters, such as temperature, infill density, and layer height, can significantly impact the material's properties.
- **Post-Processing:** Post-processing techniques like annealing or heat treatment can further enhance the mechanical properties of HDPE.
- **Environmental Factors:** Exposure to UV radiation, chemicals, or extreme temperatures can affect the long-term performance of the material.

By carefully considering these factors, engineeirs and designers can optimize the use of 3D-printed HDPE to meet the specific requirements of their applications.

V. CONCLUSION

The advent of 3D printing has changed various industries, from manufacturing to prototyping and design. As the need for 3D-printed products continues to grow, so too does the requirement for high-quality filaments. Given the increasing market prices of commercially available filaments, there is a compelling need for efficient and cost-effective methods of filament production. This paper presents the design and development of a portable filament extruder, specifically tailored for small-scale industries and educational institutions. The primary objective was to fabricate a machine that not only works but also easy to operate and maintain. By minimizing the size and difficulty of the setup, we aimed to fabricate the extruder accessible to a large range of users. One of the main benefits of this design is its portability. The compact and lightweight-ness of the extruder allows for easy transportation and setup in various locations. This flexibility makes it ideal for educational institutions, hobbyists, and small-scale manufacturers who do not have easy accessibility to a dedicated production facility. Another significant benefit of this extruder is its user-friendliness. The control panel is made to be intuitive and ease to operate, requiring minimal training. This minimizes the need for specialized labour, making the machine available to a wider number of users. Regarding cost-effectiveness, the extruder is designed to minimize both initial investment and ongoing operating costs. By using affordable components and materials, we have been able to reduce the overall price of the machine. Additionally, the streamlined workflow and efficient design contribute to decreased energy usage and reduced maintenance requirements.The extruder successfully produced recycled filament with a diameter of 1.75±0.01mm, which falls within the standard range of 1.75(±0.05) mm. This demonstrates the accuracy and precision of the extrusion process. The heating temperature of 350°C, screw speed of 40rpm, and pulling speed of 10rpm were carefully selected to optimize filament quality and consistency. The development of this portable filament extruder represents a significant step forward in the field of 3D printing. By providing a cost-effective and user-friendly solution for filament production, we aim to empower individuals and organizations to explore the possibilities of this innovative technology. While further refinements may be necessary for large-scale production, this design offers a priceless tool for those looking to manufacture their own filaments.

SCOPE OF FUTURE WORK

The development of a portable filament extruder for 3D printing represents a significant step forward, but there is potential for further study and improvement. Here are some potential areas for future work:

- **Material Versatility:** Experiment with different materials: Explore the extrusion of a wider range of materials, including biodegradable plastics, conductive filaments, and flexible materials. Optimize extrusion parameters: Fine-tune the extrusion mechanism for every material to achieve optimal results.
- **Precision and Control:** Implement advanced control systems: Explore the need of advanced control algorithms to better the precision and consistency of the extrusion process. Incorporate sensors: Integrate sensors to monitor temperature, pressure, and filament diameter in real-time, allowing for more precise adjustments.
- **Efficiency and Cost Reduction:** Optimize energy consumption: Explore ways to reduce the energy consumption of the extruder, such as improving the heating efficiency or using more energy-efficient components. Reduce material waste: Investigate methods to minimize material waste during the extrusion process, such as improving the accuracy of the filament diameter control.
- **Scalability:** Design larger-scale extruders: Develop larger extruders capable of producing higher volumes of filament for industrial applications. Integrate with 3D printing systems: Explore the integration of the filament extruder with 3D printing machines for a seamless workflow.
- **Sustainability:** Utilize recycled materials: Focus on developing processes for extruding recycled plastics and other sustainable materials. Reduce environmental impact: Explore ways to minimize the extruder's environmental footprint, such as reducing energy consumption and waste.

By addressing these areas of future work, the filament extruder can be further refined and improved, making it a more versatile and sustainable tool for 3D printing applications.

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