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EXTRUSION OF 3D PRINTING FILAMENT FROM WASTE PLASTIC

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Abstract -*:* In recent times, the issue of plastic recycling has become one of the leading issues of environmental protection and waste management. Polymer materials have been found an application in many areas of daily life and industry. Along with their extended use, the problem of plastic waste appeared because, after withdrawal from use, they became persistent and noxious wastes. The possibility of reusing polymeric materials gives the possibility of valorization a second life and enables effective waste utilization to obtain consumable products. The 3D printing market is a well-growing sector. Printable filaments can be made from a variety of thermoplastic materials, including those from recycling. The production of filaments for 3D printers from recycled polymers is the alternative present approach. The possibility of recycling basic thermoplastic materials.

***Key Words**: 3D Printing, Filament, Recycling, Polymer, Plastic, Waste Management, Extruder.*

I. INTRODUCTION

Technology for 3D printing is now being developed by industrial businesses. 3D printing is a method of additive manufacturing that may be used to create items out of plastic. Plastics come in a variety of densities, including Polyethylene Terephthalate, Polypropylene, High-Density Polyethylene, Low-Density Polyethylene, and Polystyrene. Efforts to employ 3D printing technology to transform waste plastic into usable components aid in the reduction of plastic waste. Machines that employ 3D printing to manufacture complicated components are incredibly useful for research and development in the field of mechanical engineering applications. Also, since 3D printing simply utilizes drawings and so-called computer-aided design, it is simple to create and produces goods with high levels of precision (CAD).

NEED TO STUDY

Plastic pollution is one of the environmental challenges that affect all countries nowadays. The detrimental consequences of plastic are caused by its inherent toxicity. This influence will undoubtedly affect how the environment, humans, and marine life are doing. Research by the College of Engineering at the University of Georgia in the United States found that between 4.8 and 12.7 million tons of plastic garbage were created by 192 coastal nations in 2010, with 275 million of those tons ending up in the seas. This study indicates that Indonesia is, behind China, the second-largest producer of plastic garbage. In the Netherlands, between 1.15 and 2.41 million tons of plastic garbage are dumped into rivers and the ocean annually, according to data compiled by The Ocean Cleanup Foundation. Water contamination has become a significant issue because of inadequate sanitation, which could put people at risk for health issues.

FUSED DEPOSITION MODELLING /FUSED FILAMENT FABRICATION:

The fused filament fabrication (FFF), fused deposition modeling (FDM), and filament freeform fabrication (3D printing) methods all make use of a continuous thermoplastic filament. It is inserted into an extruder head of a spinning, heated printer, where it is extruded onto an expanding product. The print head is manipulated by the computer to specify the printed form. To stop and start deposition and create an interrupted plane without stringing or dribbling between portions, the speed of the extruder head can be adjusted as shown in fig-1.

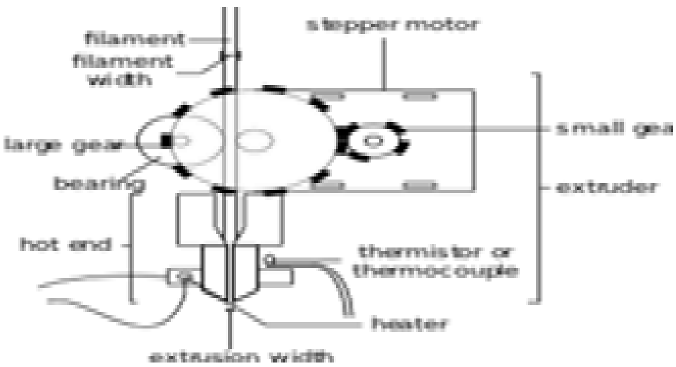

Fig-1: Illustration of a direct drive extrude

II. LITERATURE REVIEW:

The literature review says about earlier researchers, analyses, and studies on 3D printing filament extruder machines, their construction, design, methodology, and work done by different people. We studied some of those papers and those papers are mentioned as follows.

Muyiwa Oyinlola et.al., [1]: Proposed Additive manufacturing (3D printing) can transform low-income societies with underdeveloped infrastructure and inadequate manufacturing capabilities. This study adopted a transdisciplinary approach which included a critical synthesis of the extant literature, laboratory experiment and cross-sectionalal engagement with stakeholders, to examine the potential of converting plastic waste to 3D printed products. The study showed that while several extruders have been developed in the last decade, there are still many challenges some of which include difficulty to produce filaments with consistent diameter, degraded mechanical properties, and health hazards from emissions during extrusion. The study highlights the need for building local capacity to develop, operate and maintain technologies associated with 3D printing. **Muhammad Luthfi Sonjaya et.al., [2]:** Says the motivation of this research is to create a 3D printer filament from plastic waste using simple machine components. In addition, another goal is to redesign an autonomous-extruding machine to manufacture 3D printing filament. The research process begins with design, needs analysis, machine rebuilding and electrical assembly, machine function testing, analysis of filament, and filament testing in a 3D printing machine. The categories of shredded plastic material were plastic cups (polypropylene, PP) and a mixture of plastic bottles (polyethylene terephthalate, PET) and plastic cups (polypropylene, PP). The analysis of the research was the capacity of the extrusion machine, the best temperature in producing filaments based on shapes and sizes, and testing of 3D printing filaments of plastic waste which was applied to the 3D printing machine. The result showed that 190°C was the greater temperature to heat the barrel, the machine capacity of each plastic waste category, and the characteristic plastic waste was almost similar compared to the market filament of polylactic acid (PLA) in terms of filament size and 3D printing machine parameter. **Pouyan Ghabezi et.al., [3]:** Proposed Additive Manufacturing (3D Printing, and specifically Material Extrusion) is a rapid and convenient manufacturing method using raw material in filament form and is a potential candidate process for the use of recycled plastics and fibres gathered from industrial waste and domestic recycling. In this research, off-cuts of basalt fibre and recycled mushroom trays made of Polypropylene (PP) have been collected, recycled and combined in an extruder to make short fibber-reinforced filaments as material extrusion feedstock filament material. The extruding parameters including motor speed, heating temperatures, cooling fan status, and extrusion tension have been optimized to produce a filament made from these waste materials with the desired surface quality, void content, and profile. Differential scanning calorimetry has been done to measure the melting and crystallization temperatures of collected polypropylene and recycled filaments, and the tensile strength and elastic modulus of the reinforced recycled polypropylene have been measured in presence of different percentages of short basalt fibber with 4.5 mm length. The produced filaments with 5% wt. of basalt are a good candidate for use as feedstock in manufacturing using 3D printing.**Miriam Benitez et.al., [4]:** Discussed In this work different ways to valorise discarded ear tags made of TPU from the livestock sector were stud- died. This singular residue does not require separation from other plastics like other industrial and urbane wastes, which could contribute to simplifying its management. Firstly, mechanical processing was carried out by several cycles of consecutive extrusion and injection processes. The material obtained in each pro- cess was characterized using different physical, chemical, and mechanical characterization techniques in order to study the degradation as a consequence of processing cycles. Thereafter, suitable filaments for 3D printing were obtained and the effect of infill pattern in the mechanical properties of the printed pieces was investigated. Results showed that these applications were suitable options to valorise TPU waste consisting of discarded ear tags. **Maurine N. Andanje et.al., [5]:** Discuss Plastic solid waste continues to present opportunities. The use of recycled plastic material in additive manufacturing, also known as 3D printing, is expected to make the process more sustainable and help to address the global problem of plastic waste. There is growing interest among researchers on the development of filaments from recycled plastics towards the realization of a circular economy in the additive manufacturing technology. In this paper, we present outcomes about filaments fabricated from recycled high-density polyethylene and recycled polypropylene using the extrusion method. The extrusion process parameters considered in the fabrication of the filaments included extrusion temperature, screw speed and fan cooling. These parameters were analysed and optimized using the Taguchi design of experiments technique. The response variable was the filament diameter which was desired to be 2.85 ± 0.05 mm with a circular cross section. **Goutam Prasanna Kar et.al., [6]:** Says a massive carbon footprint is associated with the ubiquitous use of plastics and their afterlife. Greenhouse gas (GHG) emissions from plastics are rising and increasingly consuming the global "carbon budget". Here, we demonstrate that by dynamically crosslinking thermoplastic polyolefins, commodity plastics can be upcycled into technically superior and economically competitive materials. A broadly applicable crosslinking strategy has been applied to polymers containing solely carbon−carbon and carbon−hydrogen bonds, initially by maleic anhydride functionalization, followed by epoxy−anhydride curing. These dynamic networks show a distinct rubber modulus above the melting transition. We demonstrate that sustainability and performance do not have to be mutually exclusive. The dynamic network can be extruded into a continuous filament to be in three-dimensional (3D) printing of complex objects, which retain the mechanical integrity of vitrines. Being covalently crosslinked, these networks show a thermally triggered shape-memory response, with 90% recovery of a programmed shape. This study opens up the possibility of reclaiming recycled thermoplastics by imparting performance, sustainability, and technological advances to the reprocessed plastic. **Luca Fontana et.al., [7]:** Discussed Fused Granular Fabrication (FGF) or screw-extrusion based 3D printing for polymers isa less diffused alternative to filament-based Additive Manufacturing (AM). Its greatest advantage lies in superior sustainability; in fact, polymer granules can be used to directly feed an FGF printer, reducing the time, cost and energy of producing a part. Moreover, with this technology, a circular economy approach involving the use of pellets made from plastic waste can be easily implemented. Polylactic Acid (PLA) pellets were processed at different printing speeds and with different infill percentages on a customized version of a commercial Purse i3 Plus 3D printer modified with a Maho screw extruder. For the characterization of the 3D printed samples, rheological, thermal, mechanical and porosity analyses were carried out. In addition, the energy consumption of the 3D printer was monitored during the production of the specimens. The results showed that a higher printing speed leads to lower energy consumption, without compromising material strength, whereas a slower printing speed is preferable to increase material stiffness. **Daniela Fico et.al., [8]:** Says in the last years, the excessive use of plastic and other synthetic materials, that are generally difficult to dispose of, has caused growing ecological worries. These are contributing to redirecting the world's attention to sustainable materials and a circular economy (CE) approach using recycling routes. In this work, bio-filaments for the Fused Filament Fabrication (FFF) 3D printing technique were produced from recycled polylactic acid (PLA) and artisanal ceramic waste by an extrusion process and fully characterized from a physical, thermal, and mechanical point of view. The data showed different morphological, thermal, rheological, and mechanical properties of the two produced filaments. Furthermore, the 3D objects produced from the 100% recycled PLA filament showed lower mechanical performance. However, the results have demonstrated that all the produced filaments can be used in a low-cost FFF commercial printer that has been modified with simple hand-made operations in order to produce 3D-printed models. The main objective of this work is to propose an example of easy and low-cost application of 3D printing that involves operations such as the reprocessing and the recyclability of materials, that are also not perfectly mechanically performing but can still provide environmental and economic benefits. **Herianto et.al., [9]:** Proposed the presence of recycled plastic materials for the 3D printing process expects that the production process will be more environmentally friendly and solve the problem of plastic waste globally. One of the ways to make recycled plastic filaments is by extrusion. This research aims to optimize the extrusion process parameters in the manufacture of recycled plastic filaments (Polypropylene) that have never been conducted before. The extrusion process was analysed using the Taguchi and ANOVA methods. The results of this study indicate that the spooler speed of 4 rpm, extrusion speed of 40 rpm, and extrusion temperature of 200oC in the parameter setting produce an average filament diameter of 1.6 mm. However, filaments made from Recycled Plastic (Polypropylene) have a rough and easily curved surface, so further research is needed. **Nithar Ranjan Madhu et.al., [10]:** Says According to research findings of many peer-reviewed studies, up to 90% of household items may be made of plastic. But nowadays, just a small portion of plastic waste is recycled. Plastic pyrolysis and polymer breakdown are environmentally hazardous. Processing is, therefore, necessary for recycling. Fused deposition modelling, or FDM, is one of the most popular types of additive manufacturing. It uses the melt extrusion process to deposit filaments of thermal polymers in a predetermined pattern. Using a computer-generated design, 3D printing, sometimes referred to as additive manufacturing, is a technique for building three-dimensional objects layer by layer. A 3D item is produced by the additive method of 3D printing, which involves building up layers of material. To make a three-dimensional object, FDM printers eject a thermoplastic filament that has been heated to its melting point layer by layer. 3D printing is a rapidly expanding industry and the market in this field has grown up to 23% by 2021. The most frequent type of fibre found in that is thermoplastic fibre. In this instance, waste ABS (acrylonitrile butadiene styrene) plastic from industrial FDM printers was gathered and examined in a bustling open shop.

III. METHODOLOGY:

The filament's size, structure, and outcome are its three most critical components. Heating the aluminum block and nozzle, in which the plastic bottle strips were fused, was the extruding machine's primary procedure. Based on the average diameter and surface roughness tests, 85°C was shown to be the ideal temperature for producing filament. The size was chosen since those were the diameters of the first filaments manufactured in the sector.

The components of the previous extruding machine were (1) dc power supply, (2) W1209 thermostat, (3) dc motor speed regulator, (4) Aluminum heating block, (5) nozzle, (6) 12V dc motor, (7) Ceramic heating rod, (8) spool, (9) Thermocouple. The nozzle is a component that molds the extruded plastic after the plastic has been heated. The nozzle circle is 4 mm in diameter, which means the solid filament result should be about 4 mm in diameter. It is different from the filament used in the 3D printing machine. The innovation has been applied to mold filaments for 3D printing machines.

Spooler speed, extrusion speed, and extrusion temperature are the variables in the extrusion process. Extrusion speed has two levels, 40 and 50 rpm, while spooler speed has two levels, 2 and 4. The aluminum heating block's temperature is managed by the W1209 thermostat. To power other components, a dc power supply is employed. One of your 3D printer's most important components is the extruder.

Layers of filament are deposited by FDM printers to create models. Compounding is the term used to describe the creation of filament for 3D printing. To get the appropriate mechanical qualities, a raw plastic resin is first generated in the form of plastic bottle strips and then pushed through a heated nozzle. After drying, the filament is extruded to create the desired width and wound on a spool.

WORKING PRINCIPLE:

By forcing material through a die with the desired cross-section, the extrusion process produces objects with set cross-sectional profiles. Its capacity to work with brittle materials and produce intricate cross-sections, as well as its superior surface polish, set it apart from other manufacturing methods. Extrusion can be done with hot or cold material and can be continuous or semicontinuous. Metals, polymers, ceramics, concrete, modeling clay, and edibles are among the items that are frequently extruded. Extrudates are the broad term for the products of extrusion. This process is shown in fig-2

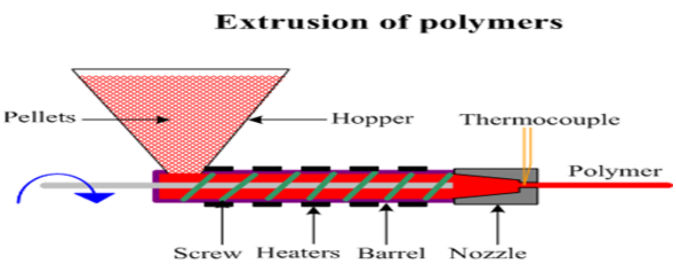

Fig -2: Working principle of Extrusion of Polymers

IV. FABRICATION:

This fabrication discusses about the components used and the fabrication of a 3D printing filament extruder.

MAIN COMPONENTS

I. DC POWER SUPPLY:

Direct current (DC) voltage is supplied by a DC power supply to a test instrument. Constant Voltage (CV) and Constant Current are its two modes of operation (CC). Although CC mode governs the current, CV mode controls the output voltage in fig -3

Fig- 3: Dc power supply

2. W1209 TEMPERATURE CONTROLLER:

Temperature control is a process in which the change of temperature of a space (and objects collectively there within), or of a substance, is measured or otherwise detected, and the passage of heat energy into or out of the space or substance is adjusted to achieve a desired temperature as shown in fig-4

Fig -4: W1209 temperature controller

3. DC MOTOR SPEED REGULATOR:

A motor controller is a device or group of devices that can coordinate in a predetermined manner the performance of an electric motor. A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and electrical faults. Motor controllers may use electromechanical switching, or may use power electronic devices to regulate the speed and direction of a motor as shown in fig-5

Fig- 5: Dc motor speed regulator

4. ALUMINUM HEAT BLOCK:

An aluminum block is used to supply the heat to the Nozzle. Electric heat is supplied to an aluminum block with the ceramic heating rod heater as shown in fig-6.

Fig- 6: Aluminum heat block

5. NOZZLE:

A nozzle is a device designed to control the direction or characteristics of a fluid flow as it exits an enclosed chamber or pipe. A nozzle is often a pipe or tube of varying cross-sectional area, and it can be used to direct or modify the flow of a fluid. Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. In a nozzle, the velocity of fluid increases at the expense of its pressure energy as shown in fig-7.

Fig – 7: Nozzle

6. CERAMIC HEATING ROD:

A cartridge heater is a tube-shaped, heavy-duty, industrial Joule heating element used in the process heating industry, usually custom manufactured to a specific watt density, based on its intended application. Compact designs can reach a watt density of up to 50W/cm² while some specialty high-temperature designs can reach 100w/cm² as shown in fig-8

Fig- 8: Cartridge heating rod

7. SPOOL:

Spool is also known as Bobbins. Bobbins are usually made of plastic, steel, wood, plywood, or cardboard. Plastic Bobbins are characterized by lightweight and durability and are used for lighter-weight cables such as automotive wires and a wide variety of other purposes.

8. DC MOTOR:

A DC motor is any of a class of rotary electrical motors that converts direct current (DC) electrical energy into mechanical energy. The most common types rely on the forces produced by induced magnetic fields due to flowing current in the coil. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current in a part of the motor as shown in fig 9.

Fig -9: 12V Dc motor

CONSTRUCTION:

1. To prepare a 3D printing filament extruder with a W1209 thermostat and Dc power supply.

2. Connect the Thermostat to the 12v 20amp dc power supply in the above manner. The Ground terminal of W1209 is connected. The negative terminal of the dc power supply. +12v terminal of the thermostat is connected to the positive terminal of the dc power supply.

3. K1 terminal of the thermostat is connected to the positive terminal of the dc power supply.

4. Connect one end of the ceramic heating rod to the K0 terminal of the thermostat and another end of the ceramic heating rod to the negative terminal of the dc power supply is shown in fig-4.8.

5. Connect the dc motor speed regulator to the dc power supply. Connect the positive power terminal of the dc motor speed regulator to the positive terminal of the dc power supply and connect the negative power terminal of the dc motor speed regulator to the negative terminal of the dc power supply.

6. Connect the ceramic heating rod to the aluminum heating block and a nozzle is connected to the aluminum heating block.

7. Connect the positive motor terminal of the dc motor speed regulator to the positive terminal of the 12v dc motor and connect the negative motor terminal of the dc motor speed regulator to the negative terminal of the 12v dc motor.

Fig -10: Wiring of W1209, Ceramic heating rod, and Dc power supply.

V. EXPERIMENTATION:

1. First, the most ordinary empty water or another drink bottle is needed. It should be cleaned from dust, labels, and glue. A long 0.3-0.5 mm width strip is made by using the specially designed cutter.
2. The next step is to wind the plastic string on the bobbin. The loose end of the strip should be stenosed, making it easier to insert it into the heating block channel.
3. The operator panel consists of a W1209 temperature controller powered by 240v, that is controlling the temperature of the head. Temperature data is provided by thermocouple K placed in the head.
4. The main setting of the experiment is the setting of the W1209 thermostat. By long pressing the set button in the thermostat we can set the following setting.
Setting for W1209 thermostat

I. P0 cool or heat: heat
II. P1 Hysteresis: 0.1
III. P2 Highest temperature: 89
IV. P3 Lowest temperature: -50
V. P4 Probe correction: 0
VI. P5 Delay 0-10: 0
VII. P6 Key tone: off

5. Press the set button to fix the value, add the (+) button to increase the value and forward to the following term, and subtract the (-) button to decrease the value and backward to the following term.
6. The bobbin is set in motion by a 12v dc motor, and the speed is increased are decreased with help of a dc motor speed regulator. The motor has 12V and a torque of 2Nm. The speed of the dc motor is increased or decreased by varying the voltage supply to the dc motor speed regulator.

7. At the beginning, a narrowed plastic string should be inserted through the cold nozzle power supply, which will greatly facilitate the initial extrusion of the filament through the nozzle, the next step is connecting the power supply. Activated W1209 temperature. The controller is now heating the block to a set temperature 89°C and this temperature was chosen experimentally.
8. When the heating block reaches the set temperature, the plastic string should be drawn manually until you can attach it to the bobbin. Now by switching on and regulating the rotation of the bobbin, the molten plastic is forced through the hothead, then cooled and hardened, and then wound on a bobbin as shown in fig-4.9.
9. The W1209 temperature controller displays “LLL” which means the sensor is not connected to the controller and the controller displays “HHH” which means the aluminum heating block reaches the set temperature and goes below the alarm set point.

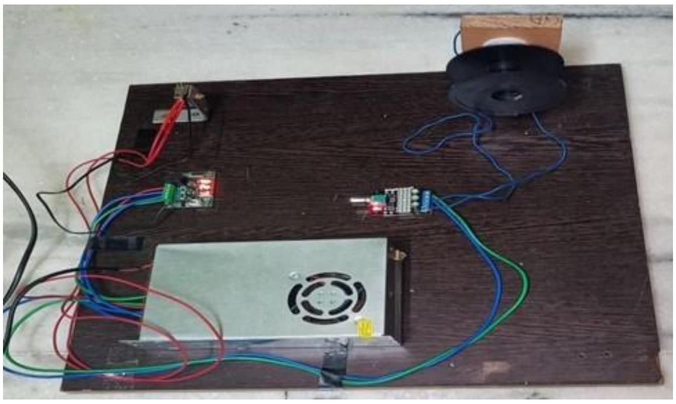

Fig -2.9: 3D printing filament extruder

VI.RESULTS AND DISCUSSION:

CALCULATION:

To calculate the time required to extrude a particular amount of filament from the nozzle, we will need to know the following information:

- Volumetric flow rate (mm^3/s): This will determine the speed of flow of filament through the top end of the nozzle.
- The desired layer height of filament (mm): This will determine the layer height of filament after filament through the hot end of the nozzle.
- The desired line width of filament (mm): This will determine the line width of filament after filament through the hot end of the nozzle.
- The desired speed of the spool (mm/s): This will determine the speed of the spool which was controlled by the dc motor speed regulator.
- Weight of the filament (g/mm^3): This will determine the weight of the plastic used for filament production.
- Volumetric flow rate (mm^3/s): layer height (mm)* line width (mm)* speed(mm/s).
- Let’s assume that the layer height is 0.5mm, the line width is 0.45mm, and the speed is 70mm/s.
- Volumetric flow rate (mm^3/s): 0.5*0.45*70
: 15.75mm^3/s
- To calculate the time taken to extrude 1kg of filament: 1000/(filament weight*volumetric flow rate)
- PET-G filament weight = 3.05g/m^3 = 3.05/1000 = 0.00305g/mm^3
- Time is taken to extrude 1kg of filament: 1000/(0.00305*15.75) = 5.7hr

OBSERVATION TABLE:

Table -1: Time required for filament extrusion.

Sl.no	Mass (kg)	Volumetric flow rate (mm^3/s)	Weight (g/mm^3)	Time taken (hrs.)
1	1	15.75	0.00305	5.7
2	2	15.75	0.00305	11.5
3	3	15.75	0.00305	17.34
4	4	15.75	0.00305	23.12
5	5	15.75	0.00305	28.91

RESULTS:

The components are fixed to a wooden board with the help of screws. The first component to be assembled is the dc power supply which is fixed on a wooden board. The next component to be assembled is the W1209 Temperature controller beside the dc power supply and fixed it. Then a nozzle is fixed to the aluminum heating block and the aluminum heating block is fixed to a clamp to hold it at a particular height. A dc motor speed controller is fixed on a wooden block in front of the dc power supply. A bobbin connected with a dc motor is paced in front of the aluminum heating block. Wiring is supplied to all the components as shown

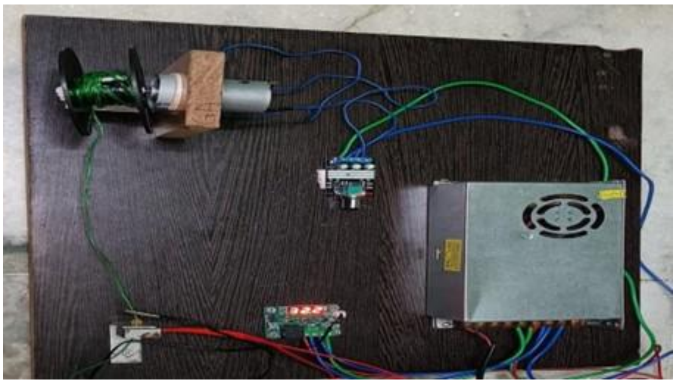

Fig- 11: Working of 3D printing filament extruder

Extrusion and filament handling were the two categories into which the automation system in this study was separated. The dc motor speed regulator, dc motor, and ceramic heating rod were the components that could be regulated during the extrusion process. The thermocouple served as the input and the W1209 temperature controller served as the primary control in the management of the filament process. Testing was done on plastic as a material to determine the ideal temperature for extruding waste plastic in a plastic bottle. The different kinds of plastic were kept in bobbin reels individually.

The tools used in data collection included an extrusion machine with a 3 mm nozzle, stopwatch, and digital vernier caliper. Extruders allow extruding of the filament used by 3D printers, starting from some plastic material. An extruder is part of the 3D printer that is responsible for pushing the filament along, melting it, and placing it on the bed to build the model. It is made up of many different tools that do a combination of different jobs.

The process of extrusion started with the preparation of plastic bottle strips of width 0.3-0.5mm. The filament was formed by the nozzle and frozen by air, resulting in a speed of 72 RPM and a speed of 54 RPM. There are two types of 3D printing filament sizes, 3 mm and 1.75 mm, and the extrusion temperature in the machine for producing filaments was 85°C.

Fig -12: PET-G filament

DISCUSSION:

This study examined the mechanical properties of samples fabricated through 3D printing with recycled filaments. The results were encouraging for the field of recycling technology linked to 3D printing, as the properties did not vary greatly from the material. The generated samples were highly usable, but slight complications were present when working with the recycled filament. Future studies should add to and streamline the data on elastic modulus through the use of extensometers. This demonstrates that used 3D printer components can be generated that have comparable properties to that of original components.

VII. CONCLUSIONS

The plastic waste extruding machine creates 3D printing filaments from polyethylene terephthalate glycol plastic bottles. The availability of raw materials for the 3D printer is one of the biggest challenges for using additive manufacturing for production and commercialization. The requirements option of good mechanical properties as well. In this order, we made a plan to produce the filament extruder, starting with conception and ending with the realization. finally, a filament extrusion parameter has been studied. Also, filament material has been mechanically characterized. The mechanical properties of filament obtained in our manufacturing will be considered satisfactory. The Time and cost have been reduced. A workflow manufacturing filament extrusion system has been developed. We have demonstrated a low-cost and efficient system with the ability to take waste plastic bottle strips these down stock into feedstock with which to form 3D printer filament, and then to use this filament to print parts of a similar quality to commercial polymer filaments. Plastics are not susceptible to biodegradation and their decomposition causes additional contamination of the environment. Desktop 3D printing makes it possible to produce complicated plastic products at home instead of in a factory. It is estimated that the value of this sector will increase intensively in the next years. The temperature suitable for PET-G plastic bottles is 85°c.

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