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Design of an Extrudate Filament Machine for Recycling Waste Polyethylene Terephthalate Plastics into 3D Printing Filament

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ABSTRACT

This research paper presents the design of an extrudate filament machine tailored for recycling waste Polyethylene Terephthalate (PET) plastics into filament suitable for 3D printing. The exponential growth of plastic waste, particularly PET, poses significant environmental challenges. Recycling PET into usable filament for 3D printers not only addresses environmental concerns but also promotes sustainable manufacturing practices. The design process encompasses a thorough analysis of requirements, considering factors such as input material variability, filament diameter consistency, and production throughput. Through conceptual and detailed design phases, the machine is optimized to effectively shred, melt, extrude, cool, and wind the recycled PET material into uniform filament spools. Material selection is carefully curated to ensure durability, thermal stability, and compatibility with PET recycling processes. The machine integrates various components such as shredders, extruders, cooling systems, and filament winding mechanisms to efficiently process waste PET plastics. Furthermore, the paper explores the economic feasibility and environmental benefits of implementing such a system for local plastic recycling initiatives
Keywords: *Extrudate filament machine, Polyethylene Terephthalate, 3D printing, Plastic recycling, Sustainable manufacturing)*

I. INTRODUCTION

The emergence of 3D printing technology has hada significant impact on various industries, particularly in terms of economics. 3D printing is highly favoured for its ability to create prototypes in a shorter time frame, compared to traditional methods which often take much longer [1]. This has a significant effect on the expenditure involved in producing high-quality products. In recent years,3D printing technology has seen a significant advancement in rapid prototyping procedures. Rapid prototyping, such as 3D printing, is an effective tool in product development [2].

The Extrudate Filament Machine is an innovativesolution that addresses two important issues in the modern world: plastic waste and filament costs. With the increasing number of plastic bottles in our daily lives, finding ways to recycle them and reduce the environmental impact of plastic wastehas become increasingly important. At the same time, 3D printing enthusiasts often face high costswhen purchasing filament, which limits their ability to experiment with the technology [3].

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One of the advantages of using a plastic bottle filament converter for 3D printing is the reduced filament production costs. Plastic bottles are readily available and inexpensive compared to traditional filament materials such as ABS, PLA or PETG [4]. This makes it a cost-effective option for individuals who want to experiment with 3D printing but may not have thebudget for expensive filament. Additionally, this technology provides an environmentally friendly alternative to traditional filament production, which involves the use of non-degradable materials [5].

Polyethylene Terephthalate (PET) is a commonly used thermoplastic polymer in the production of beverage bottles, food containers, and packagingmaterials. PET is highly recyclable and versatile,making it an attractive material for recycling andrepurposing into new products. For 3D printing, PETG is one of the best filament options. PETG is PET with added glycol to make it less brittle and improve impact resistance and durability [5].

The use of plastic filament extruder machines is consistent with several Sustainable Development Goals (SDGs) of the United Nations [6]. Firstly, SDG 12: Responsible Consumption and Production, as recycling plastic through extruders encourages responsible consumption and production by reducing the demand for new polymers and resource usage [7]. Secondly, by preventing plastic waste from entering oceans and water bodies, extruders help preserve marine habitats and reduce plastic pollution. Thirdly, SDG 15: Life on Land, as extruders reduce plastic waste and promote recycling, they help maintain terrestrial ecosystems, wildlife habitats, and biodiversity. Lastly, SDG 9: Industry, Innovation and Infrastructure, as plastic filament extruders are innovative technologies that promote sustainable practices in various industries and help establish robust recycling infrastructure [6].

II. METHODOLOGY

A plastic recycling filament extrusion machine is a device that converts recycled plasticmaterials into reusable plastic filaments. These plastic filaments are then used in 3D printing to create objects using 3D printing technology. Themain components of a plastic recycling filamentextrusion machine include shredder strip: to cutplastic bottle into long and narrow strip, an extruder: which heats and extrudes the plastic material, a filament guide: to ensure the smoothand consistent feeding of melted filamentthrough the extrusion process, and a coolingsystem: to rapidly cool down the newly extruded plastic filament to a temperature where it solidifies and maintains its desired shape and dimensions [8]. A light sensor is also added to measure filament diameter precisely. The extruder functions to melt the plastic material and extrude it into filament form[9].

The process begins by cutting the recycled plastic material and feeding it into the machine. Then, the plastic material is heated and melted by the extruder. The formed filament is then cooled and wound onto spools for further use [8].

2.1 Mechanical Parts

Mechanical parts for an extrudate filament machine design typically include extruder, filament guide, cooling system, winding mechanism, spool holder, motor, and drive system and also bearings and bushings [3].

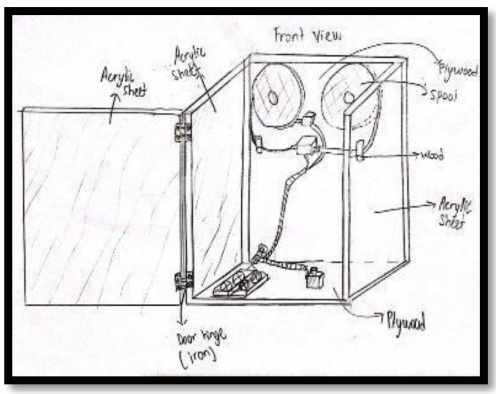

Figure 1: Design 1 (Mechanical parts) for filament extrusion machine

Figure 1 illustrates the design of a plastic recycling filament extrusion machine using perspex and wood for the machine body and base. This design is box-shaped to indicate that the machine is compact. The machine's design combines Perspex and wood, which makes it lightweight and portable.

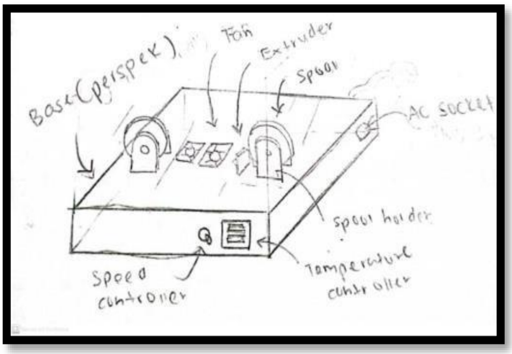

Figure 2: Design 2 (Mechanical parts) for filament extrusion machine

Design 2 has a footprint that is almost the same asdesign 1, but it is modified by making it lower, smaller, and without obstacles. This is intended to demonstrate that the machine is environmentally friendly, compact, and at the same time easy to move. Additionally, in design 2, the electrical components are housed in an enclosure made ofPerspex at the bottom. This is intended for user safety to prevent contact with the electrical components.

Design 3 shown in Figure 3 has the same components as designs 1 and 2, but this design is elongated in shape. Additionally, this design does not have a cover surrounding it like designs1 and 2. This is intended to cool the extruded filament quickly. This design also has housing for electronic components like design 2, which is located beside the machine.

Pugh analysis, also known as the Pugh method or decision matrix method, is a technique used for evaluating and comparing multiple alternatives against a set of criteria (Hachimi et al., 2021). It helps in selecting the most suitable solution or design from a range of options. The design, size, safety, wholeness, and flexibility have been determined to be the five primary criteria.

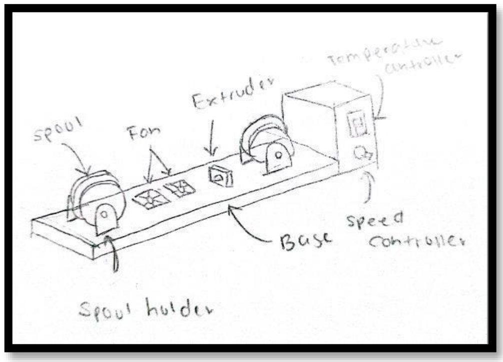

Figure 3: Design 3 (Mechanical parts) for filament extrusionmachine

Table 1: Pugh Analysis for Mechanical Parts

Criteria	Design 1	Design 2	Design 3
Design	4	3	1
Size	2	4	3
Safety	2	5	4
Wholeness	4	4	2
Flexible	3	5	1
Total	15	21	11

Design proposal 2 has been selected for development after thorough review in considering the predetermined criteria. CAD Design for Mechanical Part

The Extrudate Filament Machine developmentprocess starts with a design phase in which computer-aided design (CAD) software is used to meticulously outline the machine's dimensions and cutting processes [10]. With computer technology, drafts (technical and engineering drawings) for a part or product, including the overall design of a project, can be designed, processed, optimised, and primarily produced. This process is known as computer-aided design (CAD) or computer-aided

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manufacturing (CAM). In this research, CATIA software is used to design every part and components.

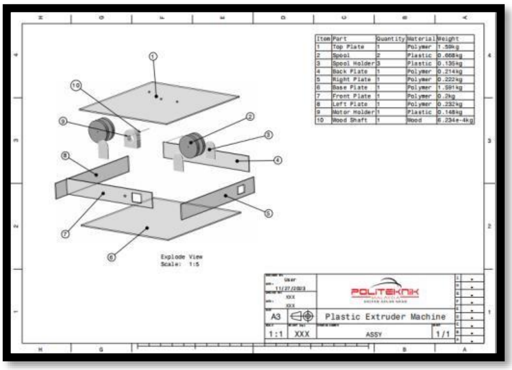

Figure 4: Assembly drawing for mechanical parts

Figure 4 depicts an assembly drawing along with a bill of materials that outlines each component. The first section comprises the structural parts at the top of the project, utilizing Perspex as the enclosure for electronic components. As seen in number 1, there are three holes for wires of electronic components to pass from the top to thebottom.

Then, numbers 4, 5, 6, 7, and 8 represent the walls and base for the electronic component enclosure.It can be observed that numbers 5 and 7 have holes and square spaces; these are for placing electronic components such as temperature controllers, speed controllers, and power sockets.

Number 2 represents the Spool; on the right is thespool for holding bottle threads, and on the left isthe spool for holding the extruded plastic filament. Numbers 3 and 9 are the Spool holders and motor holders respectively.

Figure 5 shows an isometric drawing, which provides a top, front, and side view of the project.

Through the top view of the project, the dimensions for the thickness and length of each material can be observed. The overall height and length of the project can also be determined through the side view and front view. From what can be seen in the top view, the length and width of this machine are 510mm x 480mm, and the height is 70mm, as seen in the front view. It can also be observed through this isometric drawing that all the holes used are 5mm in diameter.

Bill of Materials (BOM) provides a detailed list of all the components required to manufacture aproduct, including their quantities, descriptions,weight, and material type. Table 2 shows the BOM for mechanical parts. Here, the total weight of the mechanical components is 5 kg

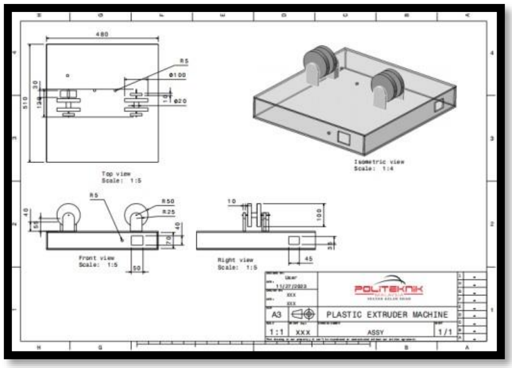

Figure 5: Assembly drawing for mechanical parts (top, frontand side view)

Table 2 : Bill of Materials for Mechanical Parts

Item	Part	Quantity	Material	Weight
1	Top Plate	1	Polymer	1.59kg
2	Spool	2	Plastic	0.668kg
3	Spool Holder	3	Plastic	0.135kg
4	Back Plate	1	Polymer	0.214kg
5	Right Plate	1	Polymer	0.222kg
6	Base Plate	1	Polymer	1.591kg
7	Front Plate	1	Polymer	0.2kg
8	Left Plate	1	Polymer	0.232kg
9	Motor Holder	1	Plastic	0.148kg
10	Wood Shaft	1	Wood	6.234e-kg

2.2 Sheredder Strips.

Shredder strips are a type of cut that is commonly used in paper shredders and certain industrial shredding applications. This cutting method involves slicing the material into long, narrow strips. These strips are typically uniform in width but can vary in length depending on the shredder's settings [6].

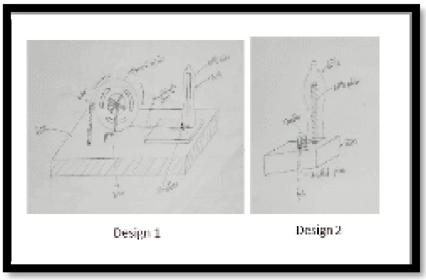

Figure 6 : Sketch of a shredder design

Based on Figure 6, there are two proposed designs and Pugh analysis has been conducted to determine the suitable design to be used in this project. Pugh analysis in Table 3 shows that Design 2 is the most suitable solution for selection of a shredder design because it has a high rating scale for its user-friendliness, high stability, and ease of development

Table 3: Selection of Shredder Design

Criteria	Design 1	Design 2
Design	3	3
Product Stability	3	2
Cost	2	3
Easy of Development	2	3
Total	10	11

CAD Design for Shredder

Using computer-aided design (CAD) software (Figure 7 & Figure 8), the process for shredder machine starts with a design phase when precise data regarding the machine's size and cutting processes are described [6].

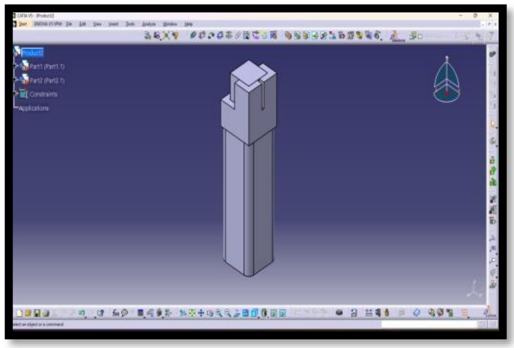

Figure 7: Sketch of a shredder design using CATIA software

After the design is complete, the following stage is to use the 3D printing technology by creating specifications that include the materials needed

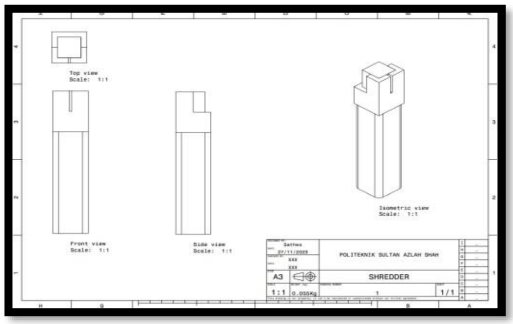

Figure 8: Drafting of a shredder design

2.2 Electrical parts

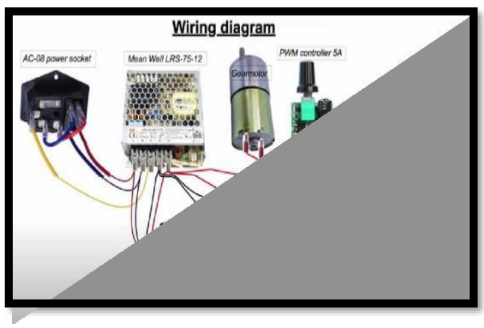

Figure 9: Schematic wiring diagram for electrical parts

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Electrical parts for an extrudate filament machine design typically include hot end kit aluminum heat block with heater thermistor, temperature sensors, temperature control system using Rex C-100, motor controller using Motor DC 12V, power supply AC-08 power socket, PLC to control speed of DC motor rotation, user interface using Mean well LRS- 75-12, safety components, wiring and connectors and also relays and contactors [1].

The wiring diagram illustrates in Figure 9, the layout and connections of a circuit in its actual or nearly equivalent position and wiring involving specific components, accessories, and units. This diagram includes the physical positions of components, wiring, and accessories.

Based on Figure 10 and Figure 11, all the electronic controls are located on the control panel. Once everything is completed, it fits everything nicely but has a lot of cables. To ensure that the connections remain secure for the duration of the machine, hot glue should be applied to each terminal. The rocker switches were meant to fit snugly, therefore some filing on the switch holes could be necessary to fit in them. Attached to the control box is an LCD panel display with 4 mounting bolts M3X 16mm.

Figure 10: Sketch of an electrical controls box design

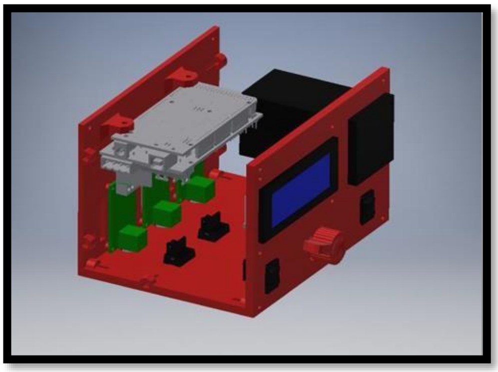

Figure 11: Sketch of all electronic components

The controller unit is the most crucial part and entirely responsible for programming and load. The extruders and motors are controlled by certain pins on the controller.

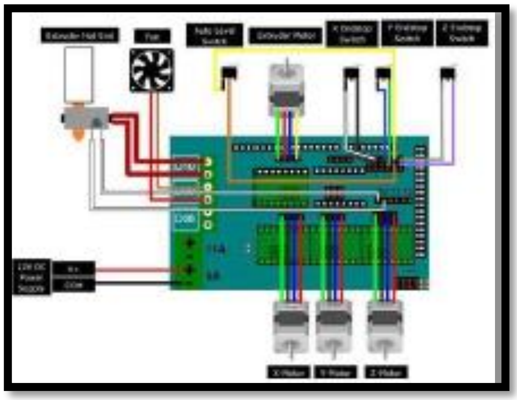

Figure 12: Sketch of a wiring diagram for electrical and electronics parts

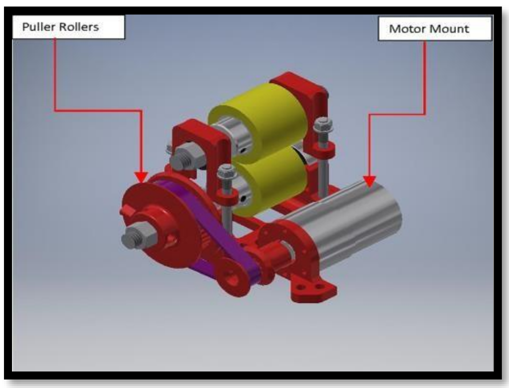

Figure 13 : Sketch of a puller design

2.4 Puller

The puller design show in Figure 13, which controls the filament's diameter, is an essential component of the Extrudate Filament Machine. The diameter will decrease with rapid pulling and increase with slower pulling (Cardona et al., n.d.). To acquire the right diameter for manufacturing filament, users must manually adjust the motor speed. Users may want to keep an eye on the diameter when making the filament, since it may vary due to external factors like temperature swings or hopper misfeeding. This should only be done once per material. This has greater significance when dealing with composites and non-uniform feedstocks.

III. RESULTS AND DISCUSSION

The design specifications for the extrudate filament machine were based on industry standards and requirements for 3D printing filament production. The design specifications were carefully selected to ensure compatibility with existing 3D printing systems and to meet the quality standards expected of commercial filament products. These included parameters such as filament diameter (1.75 mm), extrusion temperature range (240°C to 260°C), and throughput capacity (minimum 1 kg/hour).

The selection and arrangement of machine components were critical considerations in the design process to ensure efficient filament production and user-friendly operation. Emphasis was placed on durability, accessibility, and safety in the layout design. The extrudate filament machine was designed to incorporate key components such as an extruder, heating elements, temperature sensors, cooling system, filament guide, winding mechanism, and control panel. The layout was optimized to minimize footprint and facilitate ease of operation and maintenance.

The integration of mechanical and electrical systems was carefully planned to achieve seamless operation and control of the extrudate filament machine. Close attention was paid to interface compatibility, wiring routing, and system alignment to prevent conflicts and ensure smooth functionality. The successful integration of mechanical and electrical systems was a key milestone in the design process, enabling precise temperature control, motorized operation, and safety features implementation. Collaboration between mechanical and electrical engineers was essential to address interface challenges and optimize system performance.

Safety considerations were paramount in the design of the extrudate filament machine to mitigate risks associated with high temperatures, moving parts, and electrical hazards. Adherence to applicable safety standards helped instill confidence in the reliability and safety of the machine for operators and end-users. Compliance with industry regulations and standards was verified throughout the design process.

IV. CONCLUSION AND RECOMMENDATION

The design of the extrudate filament machine for recycling waste PET plastics into 3D printing filament has been successfully completed, meeting the specified design requirements and objectives.

Through careful consideration of design specifications, selection of appropriate materials, integration of mechanical and electrical systems, and implementation of safety features, a robust and reliable machine has been developed.

The extrudate filament machine demonstrates the feasibility and effectiveness of recycling waste PET plastics into high-quality 3D printing filament, contributing to sustainability efforts in the additive manufacturing industry.

The successful design and development of the extrudate filament machine lay the foundation for further advancements in sustainable 3D printing filament production.

Continued innovation and collaboration across academia, industry, and government sectors will drive the adoption of recycling technologies and contribute to the transition towards a circular economy.

The extrudate filament machine represents a significant step forward in addressing environmental challenges associated with plastic waste while supporting the growth of the additive manufacturing industry**.**

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