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Plastic Bottle Recycling for 3D Printing Filament Production

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Abstract: *The rapid increase in plastic bottle consumption has created a major environmental challenge due to the accumulation of non-biodegradable waste. At the same time, the growing adoption of 3D printing technology has increased the demand for affordable and reliable filament materials. This project presents a sustainable solution by converting discarded PET plastic bottles into usable filament for Fused Deposition Modeling (FDM) 3D printing. The proposed system is designed to collect, clean, shred, dry, melt, and extrude waste plastic into uniform filament suitable for additive manufacturing applications. The main objective of this work is to develop a low-cost and eco-friendly recycling process that reduces plastic pollution while also lowering the production cost of 3D printing filament. The study focuses on the design and fabrication of a compact recycling and extrusion setup capable of producing filament with acceptable dimensional consistency and printability. Process parameters such as temperature control, extrusion speed, cooling rate, and filament winding are considered to improve output quality. The produced filament is expected to be evaluated based on diameter uniformity, mechanical behavior, and suitability for prototype printing.*

Keywords: PET bottle recycling, 3D printing filament, FDM, plastic waste management, sustainable manufacturing, filament extrusion, recycled PET, additive manufacturing, eco-friendly production, low-cost filament

I. INTRODUCTION

Plastic waste has become one of the most serious environmental concerns of the modern world due to the extensive use of non-biodegradable polymer-based materials in packaging, transportation, household goods, and consumer products. Among all plastic materials, polyethylene terephthalate (PET) is widely used for the manufacturing of water bottles, soft drink containers, food packaging, and other disposable products because of its lightweight nature, mechanical strength, transparency, and chemical resistance [1]. Although PET is technically recyclable, a considerable portion of used bottles still ends up in landfills, open dumping sites, and natural ecosystems, creating long-term ecological and waste management problems [2].

The rapid increase in plastic consumption has placed tremendous pressure on existing recycling systems. Global plastic production and waste generation continue to rise, while only a limited percentage of discarded plastic is effectively collected and reprocessed into secondary materials [1], [2]. As a result, PET bottle waste represents both an environmental burden and an underutilized resource that can be transformed into valuable engineering material through proper recycling methods [3].

At the same time, 3D printing, also known as additive manufacturing, has emerged as an important technology in product development, prototyping, customized fabrication, educational laboratories, and low-volume manufacturing applications. Among various additive manufacturing techniques, Fused Deposition Modeling (FDM) is one of the most widely adopted methods because of its affordability, ease of operation, and material accessibility [4]. In FDM printing, thermoplastic filament is melted and deposited layer by layer to create three-dimensional objects. The quality,

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consistency, and mechanical behavior of printed parts depend heavily on the characteristics of the filament used during the printing process [5].

Commercially available filaments such as PLA, ABS, PETG, and nylon are commonly used in FDM-based 3D printing systems. However, the cost of these materials can be a major barrier for students, educational institutions, hobbyists, researchers, and small-scale manufacturers who rely on frequent prototyping and low-cost experimentation [4], [6].

PET is a particularly suitable candidate for recycled filament production because of its favorable thermal and mechanical properties, recyclability, and compatibility with extrusion-based processing [3], [7]. When properly cleaned, shredded, dried, melted, and extruded, PET waste can be converted into filament form for use in FDM or FFF (Fused Filament Fabrication) systems. Several recent studies have shown that recycled PET can produce acceptable print quality and mechanical performance when the extrusion and printing conditions are carefully controlled [7], [8]. This demonstrates the practical feasibility of converting post- consumer plastic waste into a useful additive manufacturing feedstock. The concept of transforming waste PET bottles into 3D printing filament also strongly supports the principles of circular economy and sustainable manufacturing. Instead of treating plastic bottles as waste after a single use, this approach extends the material life cycle by converting discarded plastic into a value-added engineering product [9]. Such a system not only reduces the volume of waste entering the environment but also decreases dependence on virgin polymer feedstock. This contributes to reduced material cost, improved resource efficiency, and more responsible manufacturing practices in academic and industrial settings.

In addition to environmental benefits, this project has strong educational and economic relevance. It can also encourage students and young innovators to explore practical engineering solutions that combine waste management with manufacturing technology [10].

II. PROBLEM STATEMENT

The increasing use of single-use plastic bottles has created a major environmental challenge due to the large volume of PET waste generated every day and the limited efficiency of conventional recycling systems. Although PET bottles are recyclable, a significant portion of them is still discarded improperly, contributing to land pollution, drainage blockage, and long-term ecological damage. At the same time, the growing popularity of 3D printing technology has led to a rising demand for filament materials, which are often expensive and not easily affordable for students, small industries, research laboratories, and hobby users. Commercial 3D printing filaments available in the market are generally produced from virgin raw materials, increasing both production cost and environmental burden. This creates a dual problem: the accumulation of reusable plastic waste and the high cost of filament required for additive manufacturing. Therefore, there is a need to develop an efficient, low-cost, and sustainable system that can convert discarded PET plastic bottles into usable 3D printing filament with acceptable quality, dimensional consistency, and printability. Addressing this problem can help reduce plastic waste, lower filament production expenses, and support environmentally responsible manufacturing practices through material reuse and recycling.

III. OBJECTIVE

1. To design and develop an efficient system capable of converting waste PET plastic bottles into usable 3D printing filament.
2. To reduce plastic waste by promoting the reuse of discarded PET bottles through a sustainable recycling process.
3. To produce cost-effective filament that can serve as an alternative to commercially available 3D printing materials.
4. To ensure quality and consistency of the produced filament by optimizing parameters such as temperature, extrusion speed, and cooling conditions.
5. To evaluate the performance of recycled filament based on its strength, flexibility, and suitability for FDM 3D printing applications.

IV. LITERATURE SURVEY

Multiple Researchers (2023) conducted a study titled "Sustainable Fabrication of 3D Printing Filament from Recycled PET Plastic", published in the field of Materials Science / Additive Manufacturing. The research focused on developing a sustainable method for converting waste PET plastic into 3D printing filament through a controlled heating and extrusion process. The authors designed an experimental setup that ensured uniform filament diameter and emphasized the importance of maintaining temperature stability during extrusion to prevent polymer degradation. [1].

R. Aly et al. (2025) presented a research work titled "Recycling Plastic Water Bottles into High-Quality Filaments for Sustainable 3D Printing", published by Springer in an environmental and polymer engineering journal. This study investigated the conversion of PET water bottles into high-quality filament suitable for Fused Filament Fabrication (FFF) technology. The researchers proposed a systematic process involving shredding, sieving, drying, and extrusion. They emphasized drying at elevated temperatures as a necessary step to eliminate moisture and prevent hydrolytic degradation during the melting process. The study successfully produced filament with stable diameter and desirable mechanical properties. [2].

O. Rashwan et al. (2023) published a paper titled "Extrusion and Characterization of Recycled Polyethylene Terephthalate for Additive Manufacturing" in Nature Scientific Reports. This study explored the extrusion of recycled PET into filament and evaluated its suitability for additive manufacturing applications. The authors focused not only on the extrusion process but also on the characterization of the resulting material. To improve the mechanical and processing properties of recycled PET, additives were blended into the material before extrusion. [3].

L. Toth et al. (2024) authored the paper "Progress in 3D Printing of Recycled PET", published in Sustainable Materials and Technologies on ScienceDirect. This work provided a comprehensive overview of recent advancements in the use of recycled PET for 3D printing applications. Their findings indicated that modified recycled PET exhibited improved strength, flexibility, and printability, making it suitable for more demanding engineering and functional applications. [4].

Multiple Researchers (2024) published a review paper titled "Exploring the Potential of Recycled Polymers for 3D Printing Applications: A Review" in a Polymer Research / Sustainability Journal. This review examined the broader use of recycled polymers such as PET, PLA, and ABS in additive manufacturing. The authors analyzed various recycling methods, including mechanical recycling, extrusion, and material reprocessing, and discussed their influence on print quality, thermal stability, and mechanical performance. [5].

Multiple Researchers (2025) carried out a study titled "Conversion of Waste PET Bottles into 3D Printing Filament", published in the International Engineering Research Journal. This research presented an innovative and practical approach for converting waste PET bottles into usable filament for 3D printing. The study described the development of a complete prototype system consisting of a shredding unit, extrusion mechanism, and filament winding setup. [6].

V. PROPOSED SYSTEM

The proposed system is designed to convert discarded PET plastic bottles into usable 3D printing filament through a compact, cost-effective, and sustainable recycling process. The main purpose of this system is to reduce plastic waste while producing filament that can be used in Fused Deposition Modeling (FDM) 3D printing applications. The complete setup is developed as an integrated recycling and extrusion unit in which waste plastic bottles are collected, processed, melted, and converted into filament with a controlled diameter. The proposed model not only addresses environmental concerns related to single-use plastic waste but also provides an affordable alternative to commercially available 3D printing filament. The system begins with the collection and preparation of waste PET bottles, which forms the first stage of the proposed design. In this stage, used plastic water bottles are gathered from local sources such as households, colleges, workshops, and public places. Since post-consumer PET bottles often contain labels, caps, adhesives, dirt, and moisture, they cannot be directly used for extrusion. Therefore, the collected bottles are first sorted and cleaned to remove foreign materials that may affect the quality of the final filament. The labels and caps are removed manually, and the bottles are washed thoroughly to eliminate dust, liquid residue, and surface contamination.

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This preprocessing stage is very important because impurities in the raw material can cause irregular melting, poor extrusion flow, and weak filament quality.

After cleaning, the prepared PET bottles are cut and shredded into smaller pieces so that they can be fed easily into the extrusion unit. The shredding mechanism is one of the important subsystems in the proposed design because it reduces large plastic bottle surfaces into manageable flakes or strips. Smaller plastic particles help in achieving more uniform heating and melting during extrusion. The shredding process also improves feeding consistency, which is essential for maintaining a steady flow of molten plastic through the heating barrel. In the proposed system, the shredding unit is designed to operate with a simple blade- based mechanism capable of reducing plastic bottles into fine pieces suitable for thermal processing. This stage ensures that the plastic waste is transformed from irregular bottle form into processable feed material.

VI. DESIGN OF SYSTEM

Overview

The system is designed to convert waste PET plastic into 3D printing filament using a compact extrusion setup. It consists of mechanical, electrical, and thermal components integrated through a PCB-based control system. The design ensures proper heating, extrusion, temperature monitoring, and controlled motor operation for consistent filament production.

1) Stepper Motor (NEMA 17 – 4.5 kg•cm)

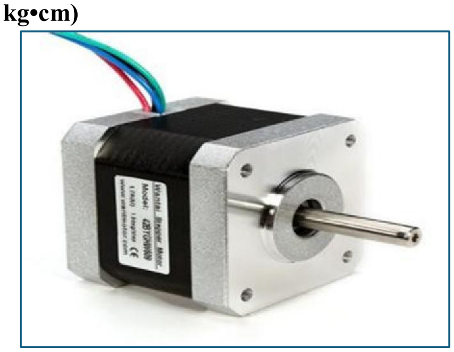

Fig.1. Stepper Motor

In Fig.1 the stepper motor is used to drive the extrusion mechanism and control the movement of plastic through the heating barrel. It provides precise speed and position control, which helps in maintaining a uniform filament diameter.

2) Power Supply (12V, 15A SMPS)

Fig. 2. Power Supply

In Fig.2 A 12V, 15A SMPS is used to provide stable power to the entire system. It supplies power to the heating element, stepper motor, and control circuitry. A voltage regulator is used to convert 12V to 5V for sensors and microcontroller operation.

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3) PCB Design for Hardware Implementation

a) Schematic of PCB Board

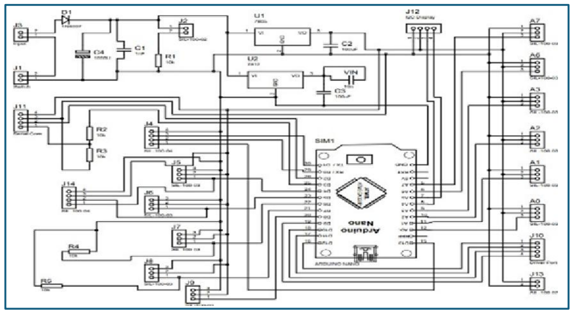

Fig.3.Schematic of PCB Board

In Fig.3 the PCB schematic is designed based on the input and output requirements of the system. Sensors like the thermocouple are connected to input ports, while actuators such as the stepper motor and heater are connected to output pins.

b) 3D View of PCB Board

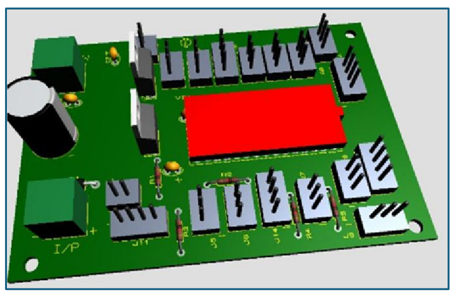

Fig.4. 3D View of PCB Board

In Fig.4 the PCB is designed in a compact layout showing component placement:

- With Components: Displays microcontroller, drivers, connectors, and modules mounted on the board.
- Without Components: Shows only the PCB layout for understanding routing and placement.

c) PCB Track Layout

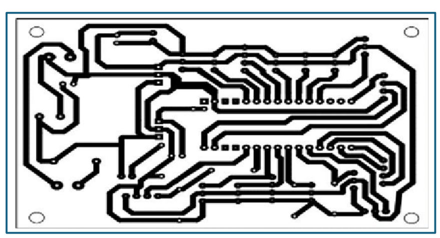

Fig.5. PCB Track Layout

In Fig.5 the track layout ensures proper routing of power and signal lines. High-current paths (heater and motor) are designed with thicker tracks, while signal lines are kept isolated to avoid noise interference.

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4) Temperature Measurement System (MAX6675 + K- Type Thermocouple)

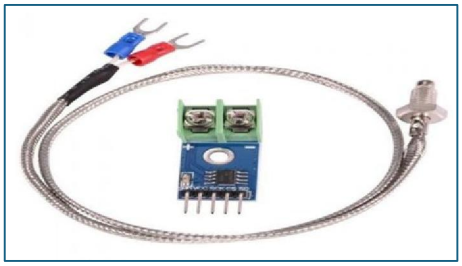

Fig.6. MAX6675 + K-Type Thermocouple

In Fig.6 the MAX6675 module is used along with a K-type thermocouple to measure high temperatures inside the heating barrel. It provides accurate temperature readings to the controller, ensuring proper melting of PET without degradation.

5) Heating System (Die Heater – Pin Type)

Fig.7.Die Heater – Pin Type

In Fig.7 the die heater is used to heat the extrusion barrel and melt the PET plastic. It operates on 12V power and maintains the required temperature for smooth extrusion.

6) Mechanical Structure (MS Square Channel)

Fig.8.MS Square Channel

In Fig.8 the frame of the system is built using MS square channels, providing strength and stability to support all components like motor, heater, and extrusion unit.

7) Insulation (Glass Wool)

Fig.9. Insulation (Glass Wool)

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In Fig.9 glass wool is used as an insulating material around the heating chamber. It helps in:

- Reducing heat loss
- Improving thermal efficiency
- Maintaining uniform temperature
- Providing fire resistance and safety

8) Display Unit (LCD with I2C Interface)

Fig.10. LCD with I2C Interface

In Fig.10 an LCD display (16x2) is used to show system parameters such as temperature and system status. It uses an I2C interface, reducing wiring complexity and operating at 5V supply.

9) Manufacturing Processes Used

The system components are fabricated using processes such as:

- Laser Cutting: For precise cutting of metal parts
- Lathe Machining: For shaping cylindrical components
- Drilling: For mounting holes and assembly
- Polishing: For improving surface finish and durability
- d = Diameter of filament (mm)

This equation is important for determining the volume and flow characteristics of the filament. It is also used in calculating extrusion rate and material usage.

VII. MATHEMATICAL EQUATIONS

The performance of the plastic bottle recycling and filament extrusion system can be analyzed using a set of mathematical relationships associated with material flow, filament formation, thermal processing, and production economics. These equations help in evaluating the dimensional consistency, efficiency, and practical performance of the developed system. The following equations are relevant to the proposed PET bottle recycling and 3D printing filament production process.

A. Filament Cross-Sectional Area

The filament produced by the extrusion system is generally circular in shape. Therefore, its cross-sectional area can be calculated using the equation for the area of a circle:

$$A = \frac{\pi d^2}{4}$$

Where:

A= Cross-sectional area of filament (mm2)

d = Diameter of filament (mm)

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This equation is important for determining the volume and flow characteristics of the filament. It is also used in calculating extrusion rate and material usage.

B. Volume of Extruded Filament

The total volume of filament produced can be calculated as:

$$V = A \times L$$

Where:

V = Volume of filament (mm^3)

A = Cross-sectional area of filament (mm^2)

L = Length of filament produced (mm)

This equation helps estimate how much filament can be generated from a given amount of recycled PET material.

C. Mass of Filament Produced

The mass of the produced filament can be determined using the density relation:

$$m = \rho \times V$$

Where:

m = Mass of filament (g or kg)

ρ= Density of PET material (g/mm^3 or kg/m^3)

V= Volume of filament

This equation is useful for comparing the quantity of input plastic waste with the output filament mass.

D. Mass Flow Rate

The mass flow rate during extrusion indicates how much material passes through the nozzle per unit time:

$$\dot{m} = \frac{m}{t}$$

Where:

- $\dot{m}$ = Mass flow rate (g (g/s or kg/s)
- m= Mass of extruded filament
- t = Time taken for extrusion

A higher and stable mass flow rate indicates better productivity and smoother extrusion performance.

F. Filament Diameter Error

To check the dimensional accuracy of the filament, the diameter deviation from the standard value can be calculated as:

$$\text{Diameter Error} = | \, da - ds \, |$$

Where:

- da = Actual measured diameter of filament (mm)
- ds = Standard desired diameter (mm)

For example, if the target filament diameter is 1.75 mm, this equation helps determine how far the produced filament differs from the desired value.

G. Force Calculation Equation

This equation is used to calculate the total force acting on the system:

$$F = m \times g$$

Where:

m = m1 + m2 + m3 (total mass)

g = 9.81m/s2

H. Load Torque Equation

This equation is used to calculate the load torque acting on the motor:

T = Fb × D/2

Where:

- Fb=F × Friction Factor
- D= Diameter of lead screw

G. Percentage Diameter Variation

The dimensional consistency of the filament can also be expressed in percentage form:

$$\%\text{Diameter Variation} = \frac{|\,da - ds\,|}{ds} \times 100$$

Where:

- da = Actual diameter
- ds = Standard diameter

This equation is very important because uniform diameter is essential for smooth feeding in FDM 3D printers

VIII. PROTOTYPE MODEL

The prototype model developed for the project "Plastic Bottle Recycling for 3D Printing Filament Production" represents a compact and functional system designed to convert waste PET plastic bottles into usable filament for 3D printing applications. The fabricated model demonstrates the practical implementation of the proposed concept by integrating mechanical, electrical, and thermal components into a single working setup. The prototype is designed to simulate the real-time conversion of plastic bottle material into a continuous filament form suitable for winding and later use in Fused Deposition Modeling (FDM) based 3D printers.

The model consists of multiple interconnected units mounted on a common base platform to ensure structural stability and ease of operation. From the observed arrangement, the prototype includes a filament winding mechanism, motor drive section, power supply unit, control circuit board, display module, heating/extrusion-related control components, and input bottle feeding section. Each of these components performs a specific function in the recycling and filament formation process. The overall prototype is developed to provide a clear demonstration of how waste PET bottle material can be processed through a controlled mechanical and electrical system.

At one end of the prototype, a spool winding mechanism is provided to collect the produced filament. This winding section appears to be driven by a stepper motor, which helps in rotating the spool at a controlled speed. The role of this section is to pull and wind the extruded filament uniformly so that it can be stored properly without tangling or irregular stretching. Controlled winding is an important part of filament production because it directly affects the diameter consistency and usability of the final filament. The inclusion of this unit in the prototype confirms that the system is not only designed for extrusion but also for practical filament handling.

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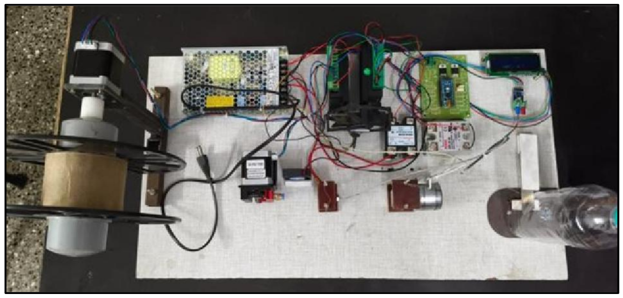

Fig. 11. Prototype model of plastic bottle recycling system for 3D printing filament production

The prototype also appears to include sensor-based or control-assisted modules, which may be used for process regulation and safety. Such components are important in a filament production system because they help maintain controlled operating conditions. In a practical PET recycling setup, variables such as feed rate, heating condition, filament movement, and spool rotation must remain stable to ensure good filament quality. Therefore, the inclusion of control electronics in the prototype improves the system's functionality and demonstrates an engineering-oriented approach toward automation and process management.

At the opposite end of the prototype, the input section for the PET bottle material is visible, where the plastic bottle is positioned for feeding or demonstration of the recycling process. This part represents the starting point of the material flow in the prototype. In the actual working system, PET bottles are first cut or processed into strips or flakes and then fed into the extrusion unit. The prototype model visually represents this concept by showing the bottle input arrangement as part of the overall recycling workflow. This helps in clearly explaining the material transformation path from waste plastic bottle to usable filament.

The mechanical arrangement of the prototype suggests that the model is designed not only as a concept display but also as a working demonstration unit. The structured layout of components on the mounting board indicates that the system has been developed with practical assembly in mind. The use of mounted modules, connected wiring, spool supports, and organized control hardware reflects a hands-on fabrication effort. This is important from an academic and engineering perspective because it proves the feasibility of the proposed idea beyond theoretical design. From an educational point of view, the prototype model plays a very important role in validating the project. It allows the user to demonstrate the sequence of operations involved in PET bottle recycling and filament production. It also helps in explaining the working principle of the system during presentations, project evaluations, and viva examinations. Since the project combines sustainability with manufacturing technology, the prototype acts as a visual and functional bridge between environmental problem-solving and engineering application.

IX. CONCLUSION

The project "Plastic Bottle Recycling for 3D Printing Filament Production" presents a practical and sustainable solution to two important modern challenges: the increasing accumulation of plastic bottle waste and the rising cost of 3D printing filament. The work demonstrates that discarded PET bottles can be treated not as waste, but as a useful raw material for engineering applications. By designing and developing a compact recycling and filament production system, the project establishes a meaningful connection between environmental protection and low-cost manufacturing.

The proposed system includes all essential stages required for converting waste PET bottles into usable filament, such as collection, cleaning, shredding, drying, extrusion, cooling, and winding. Each stage plays an important role in ensuring that the final filament is suitable for additive manufacturing applications. The overall study shows that with proper process control and system design, recycled PET can be transformed into filament with acceptable dimensional consistency and practical usability for FDM 3D printing. This makes the project highly relevant for educational institutions, innovation labs, small fabrication units, and sustainability-driven manufacturing environments.

One of the major strengths of this project is its ability to combine waste management, cost reduction, and engineering innovation into a single application. Instead of depending entirely on commercially available filament, users can produce their own filament from low-cost recycled plastic, thereby reducing material expenses and encouraging self-reliant production. At the same time, the project contributes to the reduction of plastic pollution by promoting the reuse of single-use bottles in a productive and value-added form.

X. FUTURE SCOPE

Although the developed system successfully demonstrates the conversion of waste PET bottles into 3D printing filament, there is significant scope for improvement. Future enhancements can focus on automation, higher production speed, and improved filament quality. The integration of automatic diameter monitoring with closed-loop control can ensure consistent filament thickness and better compatibility with commercial 3D printers. Further improvements can be made in the extrusion unit by enhancing thermal efficiency, insulation, and nozzle design to achieve smoother material flow and reduce degradation. Upgrading the shredding and drying processes can also improve the quality and consistency of the recycled material, resulting in stronger and more reliable filament. The system can be extended to process other thermoplastics such as PLA, HDPE, ABS, and PETG, increasing its versatility. Additionally, advanced testing methods like tensile testing and thermal analysis can be used to evaluate filament performance. This concept also has strong potential for commercial and community-level applications, including use in colleges, startups, and local recycling units. With further development, it can evolve into a low-cost, sustainable solution that supports both environmental protection and small-scale entrepreneurship.

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