DESIGN AND FABRICATION OF A PLASTIC BOTTLE RECYCLING SYSTEM FOR 3D PRINTING FILAMENT PRODUCTION

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ABSTRACT:

The rapid growth of 3D printing technology has increased the demand for filament, a material used to create three-dimensional objects. This research presents the design and fabrication of a machine that recycles used PET plastic bottles into 3D printing filament. The machine features a cutting mechanism for shaping the bottles, a heating unit to melt the plastic, and an extrusion mechanism to form the filament. The study aimed to assess the performance of the recycled filament, focusing on its quality, consistency, and suitability for 3D printing applications. Experimental results demonstrate that the recycled filament, produced from PET plastic bottles, exhibits the required characteristics for use in 3D printing, although challenges with filament uniformity and strength persist. This solution offers a sustainable approach to plastic waste management while meeting the growing demand for 3D printing materials.

Keywords: 3D printing technology, filament uniformity, plastic waste.

1. Introduction

Plastic waste has become one of the most pressing environmental challenges of the 21st century, with millions of tons of plastic bottles, particularly those made from Polyethylene Terephthalate (PET), being discarded every year. These bottles, which are used for packaging beverages like Pepsi, 7Up, and Mirinda, take hundreds of years to decompose in landfills, contributing to significant environmental pollution (Nayanathara & Amila, 2024). PET plastic is highly durable and resistant to degradation, making it one of the most difficult materials to recycle effectively. Despite efforts to reduce plastic waste, a large portion of PET bottles still end up in the environment, posing a threat to ecosystems and wildlife. As the volume of plastic waste continues to grow, there is an urgent need to develop sustainable methods for repurposing this material into valuable products, reducing its impact on the planet.

In recent years, 3D printing technology has gained significant traction across a variety of industries, including automotive, aerospace, healthcare, and education. 3D printing, also known as additive manufacturing, allows for the creation of three-dimensional objects by depositing material layer by layer (Chao et al., 2024). This technology offers several advantages, such as the ability to create complex shapes, reduce material waste, and enable rapid prototyping. As 3D printing continues to evolve, the demand for filament used as the raw material for these printers has surged.

Currently, most commercial 3D printing filament is made from plastics like PLA and ABS, but these materials can be expensive and are often not environmentally friendly. The possibility of using recycled materials, especially from plastic waste, presents a unique opportunity to address both the growing demand for 3D printing materials and the need to tackle plastic waste.

Several studies have explored the design and development of machines that recycle waste PET bottles into 3D printing filament, addressing both environmental and economic concerns. Dhopte et al. (2022) designed a portable filament-making machine using simple mechanical components that converts PET bottles into filament for 3D printing. Their machine extrudes PET strips into filaments of varying diameters, offering a solution to reduce filament costs for small-scale manufacturers. However, this study does not delve into the long-term stability of filament quality or the optimization of extrusion parameters.

Similarly, Tylman and Dzierżek (2020) developed a machine that cuts PET bottles into strips, melts them, and extrudes them into filament, with an emphasis on controlling extrusion temperature and filament winding speed. While their work emphasizes temperature control, it does not examine the mechanical properties of the recycled filament or the impact of different types of PET bottles on filament quality. Meraj et al. (2024) conducted experiments to study the effects of varying PET strip widths and extrusion temperatures on the quality of the extruded filament. They found that specific settings produced optimal mechanical properties, such as tensile strength.

However, their study focused solely on PET strips, overlooking the potential integration of other plastic materials into the filament-making process. Bustos et al. (2022) explored the extrusion of recycled PET, comparing it to virgin PETG, and highlighted the importance of adequate drying to avoid material degradation during processing. While their work contributes valuable insights into the material's behavior, it does not focus on optimizing machine design for small-scale operations. Agrawal & Joshi (2024) further investigated the design of a filament-making machine, examining different polymer materials like PLA, ABS, and nylon, with a focus on filament quality for various diameters.

However, their study primarily focuses on other polymers, not PET, and overlooks the potential challenges in processing recycled PET. In addition, Vikram et al. (2020) designed a filament-making device capable of producing 1.75mm and 3mm filaments from ABS and PLA materials, focusing on improving cost-efficiency for small-scale operations. Although their work highlights a more cost-effective solution for filament production, it does not address the recycling of PET bottles, which is crucial for reducing plastic waste in 3D printing.

A key research gap exists in the ability to use recycled PET filament in a way that is accessible to individual users who wish to explore and materialize their ideas through 3D printing prototypes. For 3D printing technology to be more widely applicable, it must be accessible not only to large industries but also to individuals, hobbyists, and researchers. The concept of transforming PET plastic bottles into filament presents an exciting opportunity to make 3D printing more sustainable and cost-effective for anyone who wants to develop and prototype their ideas. By enabling individuals to recycle plastic waste into usable filament, this approach has the potential to democratize 3D printing and foster innovation in various fields.

The primary objective of this study is to design and fabricate a machine capable of recycling PET plastic bottles into filament for 3D printing. This machine aims to provide a sustainable, cost-effective solution to the growing issue of plastic waste while meeting the demands of the 3D printing industry. The study will focus on optimizing the recycling process to ensure the production of high-quality filament, assess its performance in 3D printing applications, and explore the potential for scaling this process to meet industrial needs.

2. Design and fabrication

The proposed recycling machine consists of three primary stages: (1) cutting the plastic bottles into strips, (2) heating the strips to a molten state, and (3) extruding the molten plastic into filament. The cutter mechanism is designed to handle various bottle shapes and sizes and produce consistent strips that can be fed into the heating and extrusion units. The heating unit uses a controlled temperature to melt the PET plastic without degrading its properties, while the extrusion die shapes the molten plastic into filament. The schematic diagram of the plastic bottle recycling machine for 3D printing filament is illustrated in Figure 1.

Based on the mechanical schematic of the plastic bottle recycling machine, the 3D design diagram depicts the components of the system as illustrated in Figure 2. Key parts include the plastic bottle holder, cutting blade, and blade fixer for cutting the bottles. The motor drives the take-up roller, ensuring smooth operation. The heater and nozzle provide heat for processing the plastic, and the guider ensures proper alignment during the recycling process. The machine's base and motor cover stabilize the system, ensuring efficient and safe operation. All components are mounted on the fixing frame.

The required power on the motor shaft (Pyc) can be calculated as:

$$P_{yc} = \frac{P_{ct}}{\eta} \qquad (1)$$

Where: P_{yc} is required power on the motor shaft, P_{ct} is calculated power on the working shaft, η is overall efficiency.

The overall power is calculated using the formula:

$$P_{ct} = \frac{F * v}{1000} \qquad (2)$$

Where F is the pulling force of the plastic filament during cutting and heating (N), v is the speed of the plastic winding (m/s).

To select the force F for the calculation, I used a force measuring device during the plastic bottle cutting process and through the heating unit. The measured result is 21.08 N, as shown in Figure 3.

Substituting the values:

$$P_{ct} = \frac{21.08 * 0.2}{1000} = 4.216 \times 10^{-3}\ \text{kW}$$

The overall efficiency is: $\eta = \eta_{kn} = 1$

Thus, the required power on the motor shaft is:

$$P_{ct} = \frac{4.216 \times 10^{-3}}{1} = 4.216 \times 10^{-3}\ kW = 4.216\ W$$

Figure 1. Mechanical schematic of plastic bottle recycling machine

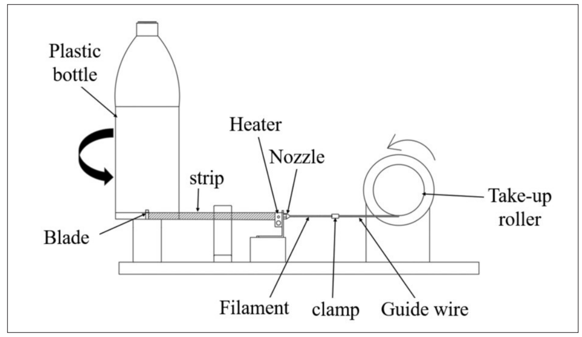


Figure 2. 3D design of the plastic bottle recycling machine

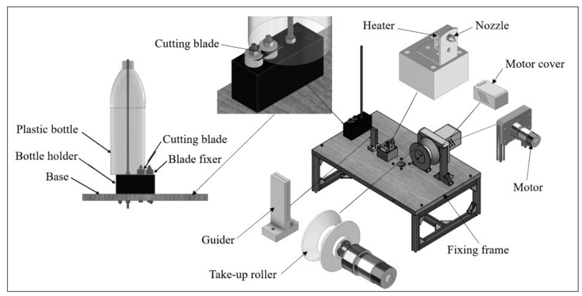
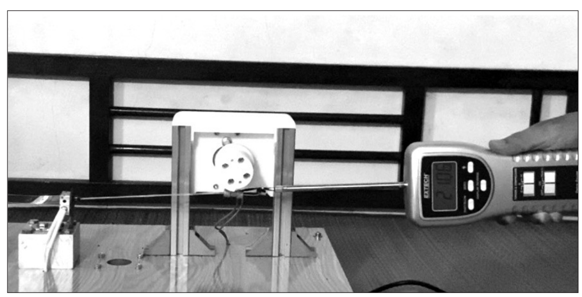


Figure 3. Pulling force measurement during bottle cutting and heating using the force gauge



Based on the power requirements, the DCM50-555 464K 24VDC motor was selected, offering a rated speed of 4500 RPM and an output power of 17 W. Through a gear reduction system with a 464:1 ratio, the output speed is reduced to approximately 9.7 RPM, while the torque is increased to 60 kgf·cm (6 N·m). This configuration ensures sufficient torque for the intended application while maintaining precise speed control.

Figure 4 represents the system of a plastic bottle recycling machine. It includes a 12V DC power supply (20A) plugged into the grid, which powers a boost converter to step up the voltage. A temperature controller (W3230) regulates the heater and nozzle temperature. The speed control circuit adjusts the speed of a 24V DC motor (DCM50-555 46K), which drives the take-up roller. A cooling fan is also integrated into the system to maintain optimal temperature during operation. Connections for VCC, GND, and motor control are illustrated throughout the diagram. The plastic bottle recycling machine has been fully constructed according to the design specifications. The image shown in Figure 5 illustrates the real machine after its fabrication, featuring the complete setup with the motor, transmission system, and control panel, all functioning as intended for efficient recycling.

Figure 4. Circuit Diagram of the plastic bottle recycling machine

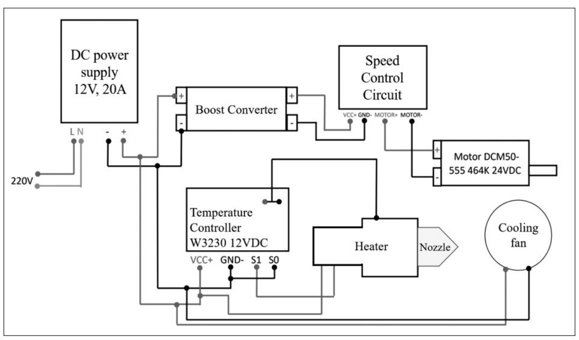
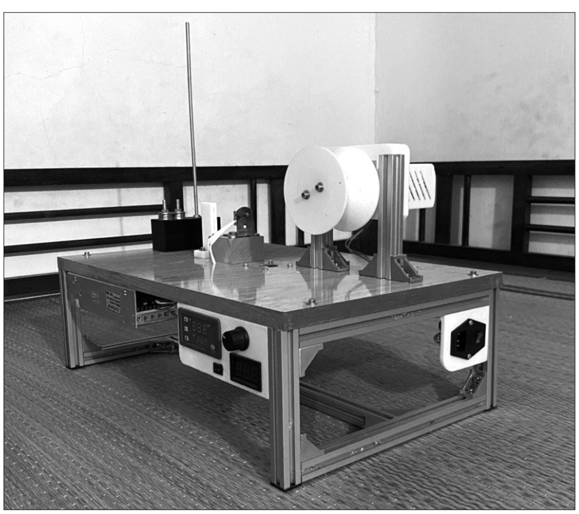


Figure 5. The picture of the plastic bottle recycling machine after complete fabrication



3. Experimental setup and results

3.1 Experimental setup

The preparation of a 1.5L plastic Pepsi bottle for the plastic bottle recycling machine experiment begins by removing the label and heating the bottle with a flame. This process allows the air inside the bottle to expand, ensuring an even deformation of the bottle's shape. Once the shape has been sufficiently expanded, a knife is used to carefully cut off the bottom of the bottle. This method helps to create a modified bottle that can be used effectively in the recycling process. The prepared bottle, ready for filament production by the plastic bottle recycling machine, is shown in Figure 6. The experimental setup for a plastic bottle recycling machine is presented in Figure 7. After preparing the plastic, it is placed in position. The operator pulls to create the initial strip and pushes it into the heater and nozzle, forming a short segment of filament. The operator then connects the filament to the guide wire using a clamp. The machine continues working automatically, completing the production of the plastic bottle. Once finished, the process repeats for the next plastic bottle, ensuring continuous operation for recycling.

Figure 6. Preparation of a 1.5L plastic bottle

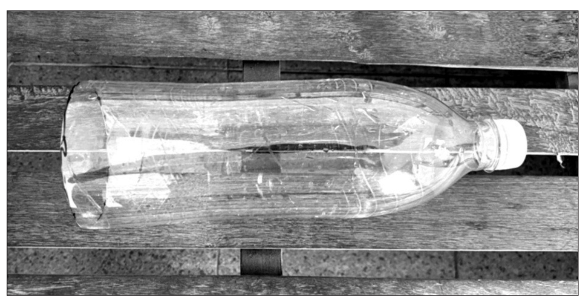
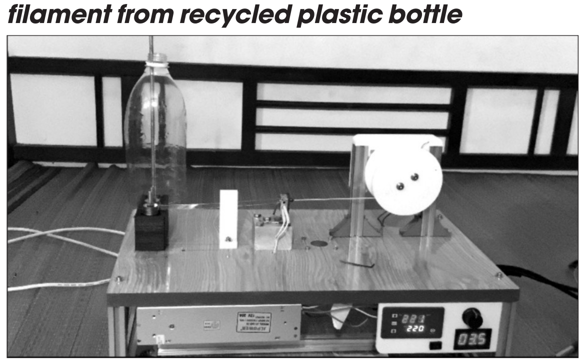


Figure 7. Experimental setup for making PET filament from recycled plastic bottle



3.2. Experimental results

The filament's diameter was measured at 10 different positions using a 1/20 caliper, with a 10 mm distance between each measurement. The average diameter was calculated from these measurements. The results, shown in Table 2, indicate that the diameter variation across the measured positions is minimal. The average diameter is suitable for 3D printing applications. Both the Pepsi and 7Up plastic bottles exhibited similar results.

The 3D printing test was conducted using the filament shown in Figure 9, utilizing a Snapmaker 3D printer. The experiment involved printing parts with varying levels of complexity, ranging from simple to more intricate shapes. The results of the 3D printed products are shown in Figure 10. The printed samples demonstrated that the filament provides satisfactory printing quality for basic applications, ensuring proper extrusion and layer adhesion. Additionally, the printer successfully produced parts with relatively complex geometries, indicating the filament's versatility and suitability for more detailed 3D printing tasks. The accuracy and stability of the printed shapes suggested that the filament is reliable for both simple and moderately complex designs. Overall, the results indicated that the filament works effectively with the Snapmaker 3D printer, offering a consistent performance across different print designs.

Figure 8. Mass of filament and the completion time for one Pepsi plastic bottle and one 7Up bottle

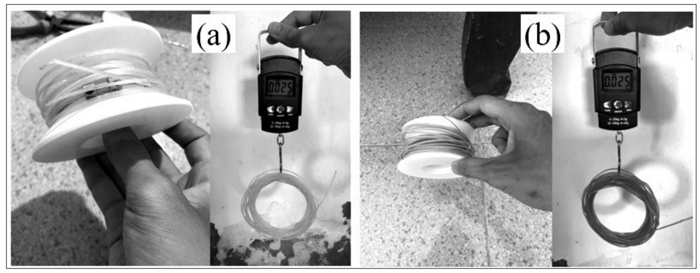


Table 1. Experimental results

Type of plastic bottle	Time to complete one bottle (sec)	Obtained weight (gam)
Pepsi	2407	25
7Up	2420	25

Figure 9. Filament diameter measurement

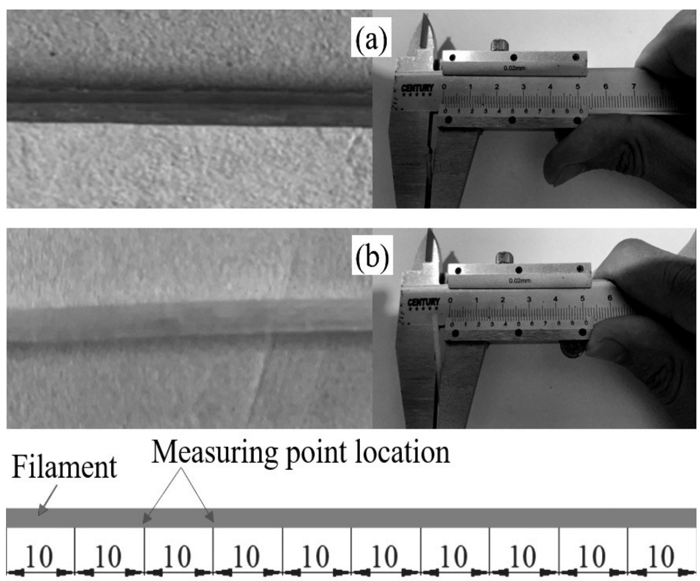


Table 2. Results of measured filament diameter

Location	1	2	3	4	5	6	7	8	9	10	Aver
Pepsi	1.76	1.74	1.80	1.78	1.78	1.82	1.78	1.74	1.76	1.78	1.774
7Up	1.74	1.76	1.80	1.78	1.80	1.82	1.80	1.78	1.78	1.76	1.782

Figure 10. 3D Printing setup with produced filament

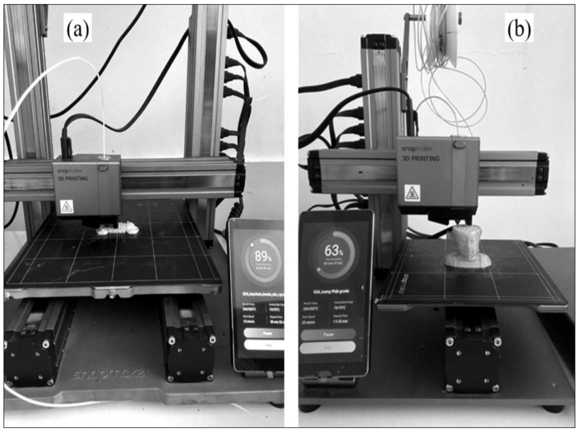
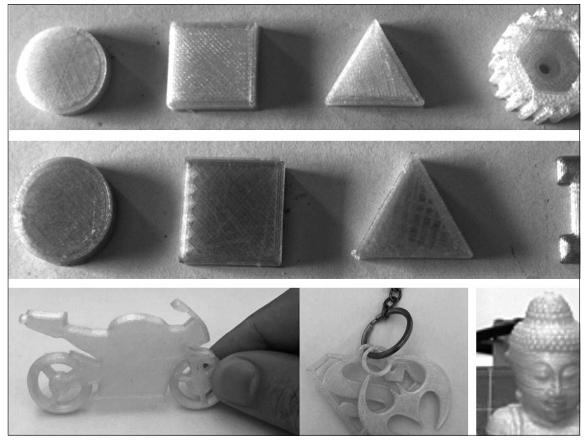


Figure 11. 3D printed samples made from PET filament derived from Pepsi and 7Up bottles



4. Conclusion

This study successfully demonstrates a feasible method for recycling PET plastic bottles into 3D printing filament. The developed machine produces filament with consistent quality suitable for 3D printing, showing minimal diameter variation and reliable performance in printed products. The results indicate that the recycled filament can support both simple and moderately complex 3D printed shapes. However, there are opportunities for improvement in the process, such as refining the extrusion temperature and feed rate for better filament consistency.

Future work could also explore the integration of automatic feeding systems and enhancements to the heating system to further improve filament quality and production efficiency. The research presents an environmentally sustainable solution for recycling plastic waste and addressing the filament demands of 3D printing ■

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THIẾT KẾ VÀ CHẾ TẠO HỆ THỐNG TÁI CHẾ CHAI NHỰA PHỤC VỤ SẢN XUẤT SỢI IN 3D

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TÓM TẮT:

Sự phát triển nhanh chóng của công nghệ in 3D đã làm gia tăng nhu cầu đối với vật liệu sợi in (filament). Nghiên cứu này trình bày việc thiết kế và chế tạo một thiết bị có khả năng tái chế chai nhựa PET đã qua sử dụng thành sợi in 3D. Hệ thống tích hợp cơ chế cắt để tiền xử lý chai nhựa, bộ gia nhiệt để làm nóng chảy vật liệu, và cụm đùn để tạo hình sợi filament. Nghiên cứu đánh giá hiệu suất của sợi tái chế dựa trên các tiêu chí về chất lượng, độ đồng nhất kích thước và khả năng ứng dụng trong in 3D. Kết quả thực nghiệm cho thấy sợi PET tái chế đáp ứng các yêu cầu chức năng cơ bản cho in 3D; tuy nhiên, vẫn tồn tại những thách thức liên quan đến độ đồng đều của sợi và độ bền cơ học. Các phát hiện này cho thấy tiềm năng của giải pháp như một hướng tiếp cận bền vững trong xử lý và tái sử dụng rác thải nhựa, đồng thời đáp ứng nhu cầu ngày càng tăng đối với vật liệu trong công nghệ sản xuất bồi đắp.

Từ khóa: công nghệ in 3D, độ đồng nhất của sợi in, chất thải nhựa.