Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 31s (2025)
https://www.jneonatalsurg.com

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Conversion of Waste PET Bottles into 3D Printing Filament: A Sustainable Approach

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Cite this paper as: Sandeep Chopade, Swati Chopade, Sushopti Gawade, Kavita Shirsat, Darshit Ajmera, Yash Bharambe, (2025) Conversion of Waste PET Bottles into 3D Printing Filament: A Sustainable Approach. *Journal of Neonatal Surgery*, 14 (31s), 732-741.

ABSTRACT

This study explores an innovative approach to repurposing PET (Polyethylene Terephthalate) bottles into sustainable and cost-effective 3D printing filament. PET bottles, widely used for packaging beverages and other consumer goods, contribute significantly to plastic waste and environmental pollution. Addressing this issue, our research focuses on developing an efficient thermal recycling process to convert PET waste into high-quality filament suitable for additive manufacturing. The methodology includes assessing material characteristics, mechanical properties, and printability to ensure that the recycled filament meets industry standards. In addition to process optimization, the study evaluates the environmental impact of using recycled PET compared to conventional filament sources such as PLA and ABS. By analysing energy consumption, carbon footprint reduction, and waste management benefits, we demonstrate the viability of integrating recycled PET into mainstream 3D printing applications. This research contributes valuable insights into sustainable manufacturing by promoting circular economy principles and reducing reliance on virgin plastic materials. The findings of this study provide a practical solution for mitigating plastic waste while fostering innovation in the 3D printing industry. By transforming discarded PET bottles into functional 3D printing filament, this project supports global sustainability efforts, making environmentally responsible production both accessible and economically feasible. The first section of the article outlines the preparation of recycled bottle material and the mechanical setup using mostly 3D printed parts. Second section details the electronic system for temperature control, filament winding, and cooling/heating functions. In the third section, filament production process and machine operation process explained step by step. Finally, presents experimental results comparing the recycled filament's properties with commercial alternatives.

Keywords: *3D printing filament, plastic recycling, PET waste, sustainable manufacturing, circular economy.*

1. INTRODUCTION

The widespread use of plastic bottles in India reflects a convenience-driven lifestyle but comes with a significant environmental cost. India generates approximately 14 million tons of plastic waste annually, with only 30% being recycled. Among this, plastic bottles contribute heavily, with around 20,000 tonnes discarded daily, leading to severe environmental and health concerns. Improper disposal results in soil and water contamination, disrupts ecosystems, and strains waste management systems. To address this crisis, a collective commitment to reducing, reusing, and recycling plastic waste is essential. Shifting towards sustainable alternatives, minimizing waste, and encouraging responsible consumption can help mitigate the impact. Promoting local recycling initiatives and circular economy principles will further support environmental sustainability. By embracing eco-friendly practices, India can reduce plastic waste, alleviate environmental strain, and foster a healthier, more sustainable society. Tackling plastic waste by recycling PET bottles to reduce carbon emissions and promote sustainability in additive manufacturing. The research aims to provide cost-effective, eco-friendly 3D printing filament alternatives while fostering circular economy principles through local recycling efforts. This review explores Polyvinylidene fluoride (PVDF) as a sustainable, low-energy alternative to conventional piezoelectric materials. It assesses manufacturing processes to enhance efficiency while minimizing environmental impact [1]. This study investigates the production of high-quality 3D printing filament from recycled PET waste by evaluating its rheological, chemical, thermal, and mechanical properties. Findings reveal that recycled PET filaments perform similarly to virgin PET, proving their suitability for additive manufacturing [2]. This PRISMA-based review analyzes 88 studies (2013–2023) on recycled plastics in additive manufacturing, focusing on thermal, mechanical, and rheological properties. Findings reveal a strong emphasis on mechanical properties, with gaps in thermal and rheological insights, highlighting the need for life cycle assessments [3]. This study presents a sustainable approach to converting plastic waste into additive manufacturing (AM) feedstock by recycling PET bottles into filaments using an in-house extrusion system. Mechanical analysis showed that rPET/PA6-CF composites had higher tensile strength, while rPET exhibited better failure strain and Young's modulus, supporting their viability for industrial applications [4].

This study explores recycling waste plastic toys into high-quality 3D printing filaments while retaining their original color. Mechanical analysis showed comparable properties to virgin materials, proving the process to be both environmentally friendly and cost-effective [5]. In this project, a machine that uses a thermoplastic extrusion process to turn PET plastic bottles into 3D printer filament is designed. It effectively reduces plastic waste and advances sustainability by producing reliable, high-quality filament. Automation, increased material use, and energy efficiency will be the main areas of future advancements [6]. This study investigates the use of a straightforward method appropriate for hobbyists to recycle PET bottles into 1.75 mm filament without fragmentation. When tested using FDM printing, the resultant filament demonstrated mechanical qualities similar to PLA, making it suitable for a range of uses [7].

Aside from the irreplaceable, extremely affordable, and quick stage of turning a computer model into a tangible product, 3D printing also enables us to create components that are not possible with conventional techniques. Many components and materials are thrown away as waste during the prototyping process, such as failed prints, badly designed models, or subpar print optimization. Making a completely gratifying part results in a lot of waste that is thrown away. We can relate this wasteful practice to our passion and work because we live in a time where masses of trash are produced, including a lot of PET bottles. Like other researchers, we want to lessen our influence on the environment and hunt for ways to reuse materials for 3D printing [8–10].

Using FEA in SolidWorks, this study examines the production of consistent 1.65 mm 3D printing filament from recycled PET bottles and contrasts its mechanical characteristics with PLA. The findings demonstrate that recycled PET is a practical and environmentally responsible substitute for sustainable additive manufacturing [11]. This article describes the creation of a filament-making machine with 3D printed components, including the manufacturing of filaments, mechanical and electronic systems, and material preparation. Additionally, experimental results contrasting the qualities of the recycled filament with those of commercial alternatives are shown [12]. The prospect of recycling plastic trash into 3D printing filaments as a sustainable substitute for conventional waste management is examined in this article. It examines thermoplastics' capacity to be recycled, their post-processing characteristics, and the various commercial and do-it-yourself filament manufacturing techniques [13].

This article describes a straightforward device that turns used PET bottles into filament for 3D printers. This research paper evaluates the mechanical properties, production methodology, production process and environmental benefits of recycled PET filaments, comparing them with commercially available 3D printing filaments. This study also discusses scalability, industrial applications, and policy recommendations for integrating recycled PET filament into mainstream manufacturing.

2. EXPERIMENTAL METHOD

A. *Aim of the study:*

- Recycled Filament Production: Develop 3D printing filament from recycled PET bottles, ensuring industry-standard quality and diameter consistency.

- Sustainability Focus: Repurpose PET waste into eco-friendly filament, demonstrating an environmentally responsible manufacturing approach.
- Custom Filament Options: Produce filaments in various diameters (e.g., 1.75mm, 2.85mm) to support different 3D printer requirements.
- Quality Control & Testing: Implement rigorous testing for diameter tolerance, tensile strength, and printability to ensure high-performance filament.
- Demonstration & Cost Analysis: Showcase 3D-printed objects using recycled filament and conduct a cost analysis comparing recycled and commercial filaments.

B. Problem Statement: Plastic waste bottles in India create major environmental and health issues due to inadequate recycling solutions. This research project explores converting plastic waste bottles into 3D printing material, ensuring quality and sustainability. By repurposing plastic waste, we aim to reduce pollution and benefit both the environment and society.

2.1 The Process of Preparation of the Material from PET Bottles

A. Material Used:

Variety of components used in our research project is fabricated based on its design and selection criteria. All these components are mentioned as below.

PET Bottles: We have gathered used PET bottles of various shapes and sizes, typically 250 ml to 2 liters. Material: Made from transparent or semi-transparent Polyethylene Terephthalate (PET), Condition: Must be clean, dry, and free of labels, caps, and liquid residues as shown in Fig. 1.

Fig. 1 Collected Used PET Bottles

Fig. 2 Bottler Cutter

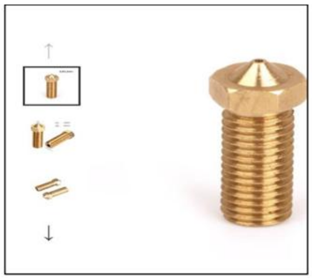

Fig. 3 Nozzle

Bottle Cutter: A manual or motorized tool designed to cut PET bottles into strips using a blade or wheel cutter, equipped with two high-quality bearings for smooth and precise cutting as shown in Fig. 2.

V6 Volcano Brass Nozzle: As given in Fig. 3, a nozzle of type V6 is used of Inlet diameter: 3mm - Entry size for feeding the PET strip, Outlet diameter: 1.2 mm – Extrusion opening for melted filament, Material: Brass or stainless steel for durability and thermal conductivity, Drilling: 1.2 mm outlet is drilled into a 1.6 mm hole to support 1.75 mm and 2.85 mm filament production.

Ceramic Heater: A 12V DC, 40W ceramic heating element is used as shown in Fig. 4 for efficient and consistent heating. This is made of material Ceramic. It features a threaded screw-on connector for heater block compatibility.

Aluminium Heater Block: A heater block is used made of material Aluminum for efficiently transfer of heat from the heater to the nozzle. Compatibility: Designed to fit the V6 Volcano nozzle and securely hold it in place. This component is shown in Fig. 5

Fig. 4 Ceramic Heater

Fig. 5 Aluminium Heater Block

Fig. 6 Thermo Controller

Thermo Controller TC 49P or TEX C100 with Solid State Relay & K- type Thermocouple: Thermo controller as given in Fig. 6 of type: PID (Proportional-Integral-Derivative) and specification TC 49P temperature controller for precise temperature regulation is used in our experiment.

Thermocouple Type: K-type: K-type thermocouples are commonly used in 3D printers. Input Voltage: Appropriate input voltage based on your heating element voltage (e.g., 12V or 24V), Temperature Range: 0°C to 400°C (32°F to 752°F) is utilized as mentioned in Fig 7.

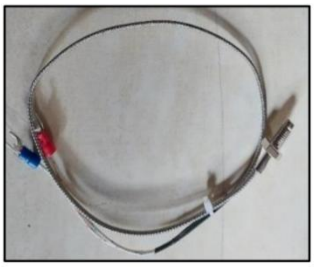

Fig. 7 K- Type Thermocouple

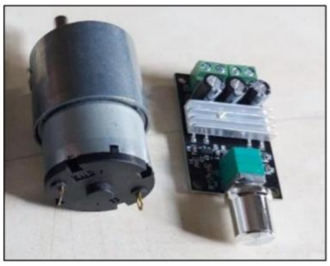

Fig. 8 High Torque Motor and PWM Controller

Fig. 9 SMPS

High-Torque Motor and PWM Controller: A high torque motor and PWM controller as shown in Fig 8 is employed in our experiment. Torque: Sufficient to pull filament smoothly without stalling. Control: Compatible with PWM controller for precise speed regulation. Voltage: Must match the power supply.

10A 12V SMPS (Switched Mode Power Supply): Output Voltage: Delivers a stable 12V DC output, Current Rating: Capable of supplying at least 10A for safe operation of all components, Safety Features: Includes overcurrent and overvoltage protection to safeguard equipment, Supply (e.g., 12V) for optimal efficiency. The used switched mode power supply SMPS is shown in Fig 9.

2.2 Processes Performed:

Variety of processes are required to perform to achieve the objective of our research project is as given below.

Finding waste PET Bottles & Removing Label: Collection of waste PET Bottles: PET bottles are collected from various sources, such as recycling centres, waste collection sites and from kabadiwalas of the city as shown in Fig. 10.

Label Removal: Labels are removed from the bottles to ensure clean and uniform material for processing.

Preparing PET Bottles: Water Addition and Heating: Water is added to the PET bottles, and they are heated on a gas burner for a period of time. This is shown in Fig. 12. This process helps to soften the PET material, making it more pliable and easier to work with.

Surface Smoothing: Heating the bottles also helps to smooth out the surface of the PET material. This smoothing process makes the bottles easier to cut into strips, as it reduces the likelihood of jagged edges or uneven surfaces.

Cutting PET Bottles into Strips: Use of Cutter: A specialized cutter is employed to slice the PET bottles into thin strips. This cutter is designed to ensure precise and uniform cuts, resulting in strips of consistent width and thickness as shown in Fig. 11.

Further Processing: Once cut, these strips are then subjected to further processing to convert them into filament. This involves additional heating and shaping processes to achieve the desired filament characteristics. To make this process easier bottles are first heated on gas burner with some amount of water in bottle.

Fig. 10 Collected Waste PET Bottles

Fig. 11 Bottle Cutter

Fig. 12 Water Addition and Heating

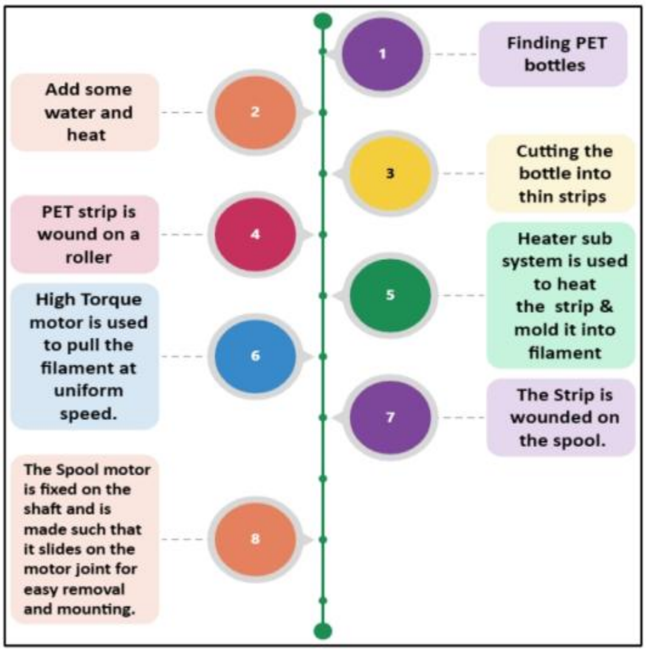

Fig. 13 Eight step process of manufacturing filament

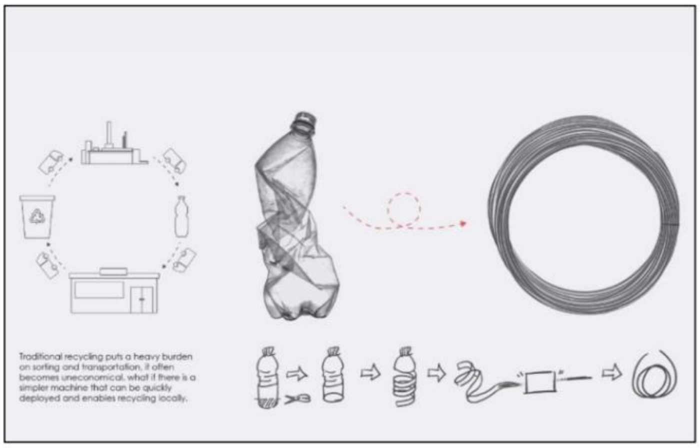

Fig. 14 Schematic representation of entire conversion process of bottles to filament

Fig. 13 explains the step by step method of converting used PET bottles into filament for 3D printer application. First step is finding and collection of used bottles. Second step is adding some water and lightly heating used bottles on gas burner one by one. Third step is cutting bottles into thin strips with the help of cutter. Fourth step is wounding thin produced strips on a roller. Fifth step is to heat the strip with the help of heater and mould it into filament. Sixth step is to pull the produced filament with the help of high torque motor. A uniform speed of pulling can be maintained with the help of high torque motor. Then this manufactured filament strip is wounded on the spool. The spool motor is fixed on the shaft and is made such that it slides on the motor joint for easy removal and mounting. Hence these eight step process is developed as shown in Fig. 13 to manufacture filament product for the application of 3D printer. The schematic representation about entire process and steps from raw used bottles to manufactured final product filament is given in Fig. 14

3. RESULT AND DISCUSSION:

A. Heating and Extrusion PET Strips into Filament:

Heater Subsystem: The PET used bottle strips are fed into a heater subsystem as shown in Fig. 15, where they are heated to a specific temperature (150 - 200°C). This heating process is crucial for softening the PET material and making it malleable for moulding.

Extrusion Process: Once heated, the softened PET strips are moulded into filament as shown in Fig. 16 using a specialized moulding mechanism. This mechanism is fabricated in our institute laboratory. The said mechanism shapes the strips into a continuous filament, which is the input material used for 3D printing machine. The filament is then cooled in open air normal temperature and solidified to maintain its shape and dimensions.

Puller Arrangement: The puller arrangement is an essential component of the filament production process, responsible for pulling the filament from the heater and maintaining a consistent speed. The puller arrangement includes a high-torque motor, which is controlled by a PWM (Pulse Width Modulation) controller. The PWM controller regulates the speed of the motor, ensuring that the filament is pulled at a uniform speed. The entire puller arrangement is given in Fig. 17. The puller components like wheels and shaft are manufactured using our institute 3D printing facility. Because of this the weight of the puller system is reduced hence entire project weight. The final product that is, 3D printer filament is wounded on the shaft of puller as shown in Fig. 17. Most of the parts of the project are fabricated or manufactured in our institute labs only.

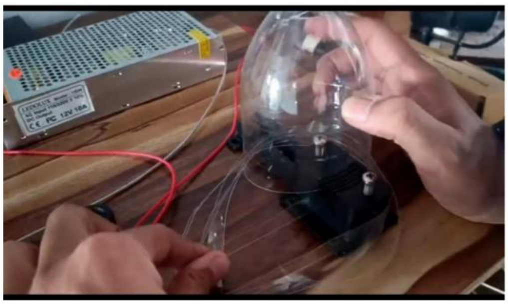

Fig. 15 Heater Subsystem

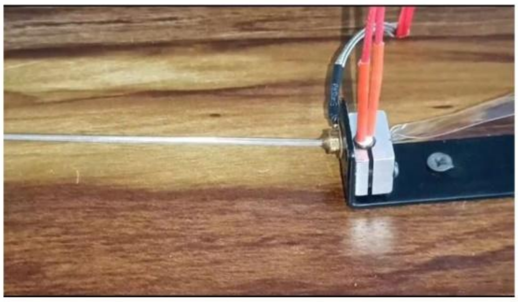

Fig. 16 Extrusion process of Filament

Fig. 17 Puller Mechanism Developed

Uniform Speed: The motor pulls the filament at a constant rate, ensuring that the filament is produced with consistent quality and dimensions. This uniform speed is crucial for ensuring that the filament is suitable for use in 3D printing applications.

Quality Control: The puller arrangement plays a critical role in the quality control process, as it helps to ensure that the filament meets the required specifications for diameter and consistency.

Spooling Process: Winding onto Spool: The filament is carefully wound onto a spool as shown in Fig. 18 to ensure it is stored neatly and is easy to handle during the printing process.

Motor Support and Attachment: A 3D printed motor support is used to hold the motor in place, while a separate spool motor joint part, also 3D printed, is used to attach the spool to the motor shaft. This arrangement allows for precise control over the spooling process. These motors are manufactured in our department 3D printing facility.

Fig. 18 Spool of the Filament

Fig. 19 SMPS

Power Supply: Switched Mode Power Supply (SMPS): An SMPS as shown in Fig. 19 is utilized to power the motor, PWM (Pulse Width Modulation) controller, and ceramic heater. This type of power supply is chosen for its efficiency and ability to provide stable power output to the various components of the system. Efficient Power Distribution: The SMPS efficiently distributes power to the motor, PWM controller, and ceramic heater, ensuring they receive the appropriate voltage and current for optimal performance. Reliable Operation: By using an SMPS, the system can operate reliably and efficiently, minimizing the risk of power-related issues and ensuring consistent performance during the filament production process.

B. Testing of Final Product:

Fig. 20 represents the final product developed from our research project. Also the same product is utilized as an input material to function 3D printer. The testing is done in our institute laboratory itself. It is found that our filament worked properly in 3D printer without any problems in the machine. Hence our product is reliable to produce the 3D printing parts in bulk. Product can be used for the commercial purposes. The chemical composition testing of the produced filament is left to be done which could be a future research scope.

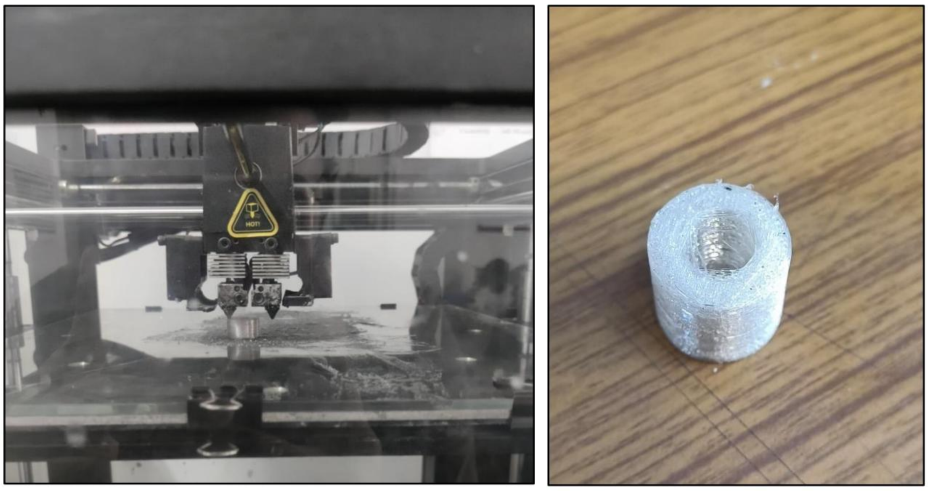

Fig. 20 Final Manufactured Product and Actual use of Developed Product as Input Material to Operate 3D Printer

The Solidworks software is utilized to create the actual model of our research project as shown in Fig. 21. Then all the project components like heater system, puller system, spool, motor, bottle holder, relay and other electronic parts required are properly mounted on the plywood board as shown in Fig. 22. The project is tested after entire complete assembly. The entire wiring part of the project is hidden below the plywood flat.

All components are actually connected with the help of typical wiring diagram. The pictorial view of the wiring circuit diagram is represented in Fig. 23.

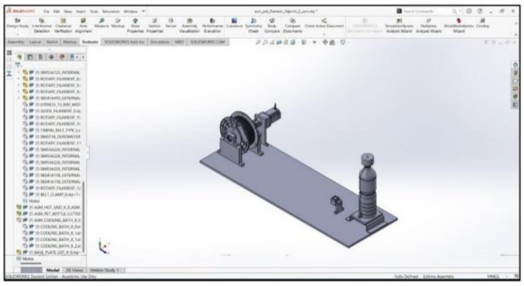

Fig. 21 Project Assembly in Solidworks software

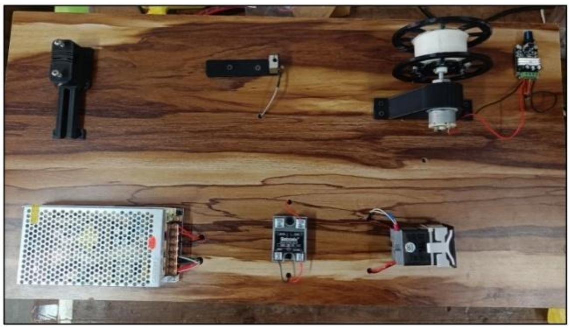

Fig. 22 Actual Project model prepared

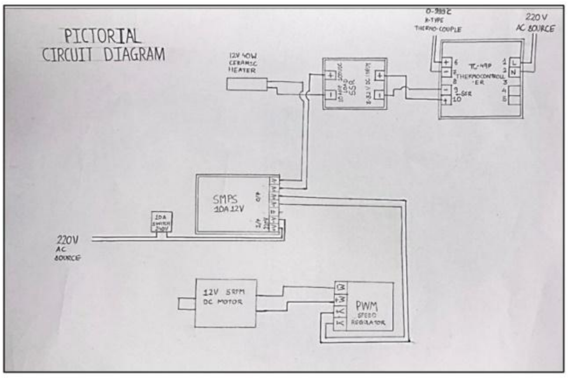

Fig. 23 Actual circuit used in our project

Table 1 Data of PET bottles for surface smoothness and strip quality (As per manual approximation observed)

Sr No.	Bottle Company	Surface Smoothness	Strip Quality
1	Bailey	9/10	10/10
2	Bisleri	9/10	9/10
3	Kinley	8/10	7/10
4	Coca Cola/Pepsi	6/10	5/10
5	Mountain Dew/Sprite	2/10	2/10

Table 2 Printing Parameters of Individual Materials

Sr. No.	Material	Printing Temperature	Hot bed temperature	Print speed
1	Recycled PET	260 ± 5	85	Medium
2	PLA	205 ± 10	≤ 60	Medium-High
3	PLA Matte	215 ± 10	≤ 60	Medium-High
4	ePLA	230 ± 10	50 - 60	Medium-High
5	PLA Cosmic	205 ± 10	≤ 60	Medium-High
6	PLA Tough	210 +10	≤ 60	Medium-High
7	Wood	200 +10	≤ 60	Medium
8	PETg	240 +10	≤ 70	Medium
9	PET color	250 +20	≤ 70	Medium
10	Carbon Fibre	240 +15	≤ 70	Medium
11	ABS	245 +10	≥ 100	Medium
12	ASA	240 +10	80 - 90	Medium

The surface smoothness of bottles and strip quality is observed manually and the manual judgement values are given in table 1.

Table 2 represents the most popular materials used in 3D printing will be used in experiments such as PET-G, ABS, and PLA etc. I called my recycled filament BPET (BottlePET). All print parameters of individual materials were selected to obtain the best print quality. Printing speed, infill and nozzle size were the same for each print. All PET prints were made from the same sample of the PET.

Hence we have successfully able to produce a sustainable product from the waste bottles. This concept will definitely contribute in the reduction of level of nation's carbon footprint. We assure that this research will be definitely useful to society since it will reduce the environmental pollution. Again this will be useful to environmental industries to enhance their product features.

Conclusion:

- The design and model of a filament machine were presented in this research, along with a different method for producing environmentally friendly filament. In straightforward tests, we compared the machine and filament to widely accessible filaments. Receiving a filament made from common plastic bottles that can be used in a standard 3D printer was a success.
- The research presented in the paper made it possible to analyse the produced material, which has a lot of promise for future development of durable materials as well as for promoting waste recycling. It takes more time and in-depth research to create and use PET filament with 3D printer production parts.
- Key components such as the heater subsystem, puller arrangement, and power supply are carefully designed and integrated to ensure efficient and consistent filament production. The use of 3D printed parts for the motor support and spool motor joint adds a layer of customization to the project.
- It is a prototype, and the machine needs to be fixed for its numerous flaws. Numerous solutions for comparable machines are available.
  Making granules and then processing them is the most common method of turning plastic bottles or garbage into filament; however, this is a more involved procedure and requires a larger equipment than the one described in this article. The low cost of the gadget is influenced by the fact that, in contrast to another construction machine featured in this article, 90% of its parts are 3D printed.
- Overall, this project not only provides a practical solution for recycling PET bottles but also highlights the importance of sustainable manufacturing practices in the 3D printing industry. By repurposing waste material into a valuable resource, this project contributes to the promotion of a circular economy and environmental conservation.

Future Scope:

- Optimization of Processes: There is scope for further optimization of the processes involved in converting PET bottles into 3D printing filament. This includes finetuning the parameters such as temperature, speed, and pressure to enhance the efficiency and quality of filament production.
- Integration of Injection Molding: Explore the feasibility of integrating injection molding into the filament production process. This alternative method could potentially improve the efficiency and quality of filament production by using shredded plastic bottles instead of passing strips through a nozzle.
- IoT Integration: Explore the integration of IoT (Internet of Things) technology into the filament production process. This could include using sensors and monitoring devices to track and optimize various parameters such as temperature, pressure, and speed. Enable remote monitoring and control of the filament production process through IoT devices. This would allow for greater flexibility and efficiency in managing the production process.
- Material Testing and Certification: Future research could focus on conducting comprehensive material testing and obtaining certifications for the recycled PET filament. This would help in ensuring that the filament meets industry standards and is suitable for a wide range of 3D printing applications.

Acknowledgement

I am very much delighted to express thanks to my B. Tech. project students Darshit Ajmera and Yash Bharambe. I am also very much thankful to Dr. Swati and Dr. Sushopti for their continuous motivation and support to write and complete the research article in time. I am also thankful to faculty and staff of the institute who helped us to carry out the research. I am very much thankful to Somaiya Vidyavihar University, Authority, Management, Institute and Mechanical Engineering Department of K. J. Somaiya School of Engineering, Mumbai. The project work is carried out in the department Lab only.

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