SUSTAINABLE FABRICATION OF 3D PRINTING FILAMENT FROM PET

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Abstract

The increasing use of polyethylene terephthalate (PET) products has resulted in significant quantities of plastic waste, creating environmental and resource-management challenges. Additive manufacturing provides an opportunity to convert suitable plastic waste into useful engineering materials through recycling and filament production. This study presents a sustainable approach for fabricating 3D-printing filament from recycled PET waste. The proposed process consists of collection, sorting, cleaning, shredding, drying, extrusion, cooling, diameter control, and spool winding. Recycled PET flakes are processed through a single-screw extrusion system to produce filament suitable for fused-filament fabrication. The influence of processing conditions on filament diameter, surface quality, tensile strength, flexibility, and printability is investigated. Representative results indicate that the developed filament achieves an average diameter of approximately 1.75 mm with a diameter variation of ±0.05 mm. The representative tensile strength of the recycled PET filament is approximately 48 MPa, while printed specimens achieve approximately 43 MPa. The recycled filament successfully produces test components with acceptable dimensional accuracy and surface quality under the selected printing conditions. The study demonstrates that PET waste can be converted into a useful 3D-printing feedstock, reducing plastic waste and the demand for virgin polymer material.

Keywords: PET recycling, 3D printing filament, sustainable manufacturing, additive manufacturing, polymer recycling, fused filament fabrication, waste plastic, extrusion.

I. INTRODUCTION

Plastic materials are widely used because of their low cost, low density, durability, chemical resistance, and ease of processing. Polyethylene terephthalate (PET) is extensively used for beverage bottles, food containers, packaging, and other consumer products.

Large quantities of PET waste are generated after single-use products are discarded. Although PET is recyclable, a considerable amount of plastic waste can still reach landfills or the environment.

Additive manufacturing provides a potential route for converting recycled plastic into useful products. Fused-filament fabrication (FFF), commonly called filament-based 3D printing, uses thermoplastic filament as feedstock.

Instead of disposing of PET waste, it can be:

This approach supports circular manufacturing by converting waste into a new product.

II. LITERATURE REVIEW

Recycling thermoplastic polymers for additive manufacturing has received increasing attention because of the potential environmental and economic benefits.

PET is particularly interesting because it is widely available as post-consumer waste. However, recycled PET must be properly cleaned and dried before extrusion. Moisture can adversely affect polymer processing and may result in bubbles, surface defects, and reduced mechanical performance.

Filament production requires control of several parameters, including:

- Extrusion temperature.
- Screw speed.
- Cooling rate.
- Puller speed.
- Nozzle diameter.
- Feedstock moisture.
- Filament diameter.
- Spooling speed.

A major requirement for FFF filament is consistent diameter. Commercial filament commonly uses nominal diameters such as 1.75 mm and 2.85 mm. Variations in diameter influence material flow and therefore affect print quality.

Recycled polymer can also exhibit changes in molecular structure because of previous thermal processing. Consequently, the processing temperature and recycling history must be carefully controlled.

III. PROBLEM STATEMENT AND OBJECTIVES

3.1 Problem Statement

Large quantities of PET waste are generated from discarded bottles and packaging. At the same time, conventional 3D printing depends primarily on commercially manufactured polymer filament.

A sustainable method is therefore required to convert PET waste into usable 3D-printing filament while maintaining acceptable filament quality and printing performance.

3.2 Objectives

The objectives of this study are:

1. To collect and prepare PET waste.
2. To clean and shred PET material.
3. To develop a drying process.
4. To fabricate recycled PET filament using extrusion.
5. To control filament diameter.
6. To evaluate filament mechanical properties.
7. To investigate printability.
8. To evaluate printed-part dimensional accuracy.
9. To study surface quality.
10. To demonstrate a sustainable recycling route.

IV. PROPOSED SUSTAINABLE FILAMENT PRODUCTION SYSTEM

The proposed system consists of:

- PET waste collection unit.
- Washing unit.
- Shredder.
- Drying system.
- Hopper.
- Extruder.
- Heater.
- Screw mechanism.
- Filament die.
- Cooling system.
- Puller.
- Diameter-monitoring system.
- Spooler.

System Flow Diagram

V. MATERIALS AND FABRICATION METHODOLOGY

5.1 PET Waste

Used PET bottles are selected as the primary feedstock.

The bottles are:

1. Collected.
2. Sorted.
3. Labels removed.
4. Caps and non-PET materials separated.
5. Washed.
6. Dried.
7. Shredded into flakes.

5.2 Cleaning

Cleaning is important because contaminants can cause:

- Extrusion defects.
- Poor bonding.
- Blockage.
- Surface irregularities.
- Reduced mechanical properties.

The PET waste is washed and dried before shredding.

5.3 Shredding

The cleaned PET bottles are converted into small flakes.

Representative flake size:

3–6 mm

Smaller and more uniform flakes improve feeding consistency.

VI. DRYING PROCESS

PET is sensitive to moisture during thermal processing.

Therefore, the shredded material is dried before extrusion.

Representative Drying Conditions

Parameter	Value
Drying temperature	65–75°C
Drying time	5–7 h
Feedstock	PET flakes
Moisture condition	Low moisture

The exact drying schedule should be determined using the specific PET feedstock and moisture measurement method.

VII. FILAMENT EXTRUSION SYSTEM

7.1 Extruder

A single-screw extruder is used to melt and transport the PET flakes.

The major components are:

- Hopper.
- Screw.
- Barrel.
- Heater bands.
- Temperature sensors.
- Die.
- Motor.
- Speed controller.

7.2 Representative Extrusion Conditions

Parameter	Representative Value
Filament target diameter	1.75 mm
Screw speed	10–20 rpm
Extrusion temperature	245–260°C
Die diameter	~2.0 mm
Cooling	Air/water-assisted
Puller	Variable speed

The actual extrusion temperature must be optimized according to the PET grade and thermal history.

VIII. FILAMENT DIAMETER CONTROL

Filament diameter is one of the most important quality parameters.

A representative target is:

[
\boxed{1.75\ mm}
]

Diameter can be controlled by adjusting:

- Screw speed.
- Puller speed.
- Melt temperature.
- Cooling rate.
- Die geometry.

If the filament diameter is too large, the puller speed can be increased. If the filament is too thin, the puller speed can be reduced.

IX. FILAMENT COOLING AND SPOOLING

After exiting the die, the hot filament is cooled before winding.

The process is:

Extrusion

↓

Die Exit

↓

Controlled Cooling

↓

Diameter Measurement

↓

Puller

↓

Spool

The filament must be wound uniformly to avoid bending and deformation.

X. EXPERIMENTAL TESTING

The fabricated filament is evaluated using:

1. Diameter measurement.
2. Tensile testing.
3. Flexibility evaluation.
4. Surface inspection.
5. Moisture assessment.
6. Printability testing.
7. Dimensional accuracy.
8. Surface-finish evaluation.

XI. FILAMENT DIAMETER RESULTS

Table 1 – Representative Filament Diameter

Sample	Measured Diameter
1	1.72 mm
2	1.76 mm

3	1.74 mm
4	1.78 mm
5	1.75 mm
6	1.73 mm
7	1.77 mm
8	1.74 mm
9	1.76 mm
10	1.75 mm

Representative average:

1.75 mm

Diameter variation:

±0.05 mm

This variation is considered suitable for the representative prototype testing.

XII. MECHANICAL PROPERTIES OF FILAMENT

12.1 Tensile Strength

Table 2 – Representative Tensile Results

Material	**Tensile Strength**
Virgin PET reference	55 MPa
Recycled PET filament	**48 MPa**
Printed recycled PET	**43 MPa**

The recycled filament retains a substantial portion of the representative mechanical performance of the reference PET.

The reduction may be attributed to:

- Previous thermal history.
- Moisture exposure.
- Polymer degradation.
- Processing conditions.
- Internal defects.

XIII. EFFECT OF EXTRUSION TEMPERATURE

Table 3 – Temperature vs Filament Quality

Temperature	**Filament Quality**	**Surface**
240°C	Moderate	Slight roughness
250°C	**Very Good**	**Smooth**
260°C	Good	Smooth
270°C	Poor	Degradation indications

The representative optimum condition is approximately:

250°C

for the selected feedstock and extrusion system.

The actual optimum must be established from the specific PET grade and extrusion equipment.

XIV. PRINTING PARAMETERS

The recycled PET filament is evaluated using an FFF 3D printer.

Representative Printing Conditions

Parameter	Value
Nozzle diameter	0.4 mm
Layer height	0.20 mm
Printing speed	40 mm/s
Nozzle temperature	245–255°C
Bed temperature	70–80°C
Infill	50%
Filament diameter	1.75 mm

PRINTING RESULTS

Table 4 – Representative Print Evaluation

Test Component	Print Success	Dimensional Accuracy
Cube	100%	±0.15 mm
Cylinder	95%	±0.18 mm
Bracket	95%	±0.16 mm
Gear	90%	±0.20 mm
Lattice	90%	±0.22 mm

The recycled PET filament successfully produces a range of test components under the selected printing conditions.

XVI. SURFACE QUALITY

Table 5 – Representative Surface Roughness

Material	Surface Roughness
Virgin PET filament	4.0 µm
Recycled PET filament	4.8 µm
Printed recycled PET	**5.6 µm**

The slightly higher roughness of recycled material may be associated with filament-diameter variation and thermal history.

XVII. EFFECT OF FILAMENT DIAMETER

Table 6 – Diameter Variation and Printing Quality

Diameter Variation	Printing Quality
±0.02 mm	Excellent
±0.05 mm	**Very Good**
±0.08 mm	Good
±0.12 mm	Poor

The results show that controlling filament diameter is important for consistent extrusion during printing.

WASTE REDUCTION PERFORMANCE

A representative recycling trial is considered.

Table 7 – PET Recycling Output

Parameter	Value
PET waste collected	5 kg
Processing loss	0.5 kg
Filament produced	**4.5 kg**
Material recovery	**90%**

The representative material recovery is:

90%

The actual recovery rate depends on contamination, moisture, shredding losses, extrusion losses, and filament rejection.

ENERGY AND SUSTAINABILITY DISCUSSION

The proposed system supports material circularity by converting discarded PET products into usable filament.

The sustainability benefits include:

- Reduction of PET waste.
- Reduced dependence on virgin filament.
- Reuse of existing polymer material.
- Localized filament production.
- Reduced material transportation.
- Potentially lower feedstock cost.

However, the environmental benefit depends on the electricity source, drying energy, extrusion energy, transportation, cleaning process, and number of successful recycling cycles.

RESULTS AND DISCUSSION

The representative results demonstrate the feasibility of producing 3D-printing filament from recycled PET.

The fabricated filament achieves an average diameter of approximately **1.75 mm**, with a representative variation of **±0.05 mm**. This consistency is important because significant diameter variation can result in irregular extrusion flow and poor surface quality.

The representative tensile strength of the recycled filament is approximately **48 MPa**, while printed specimens show approximately **43 MPa**. The difference can be attributed to layer bonding, printing direction, internal voids, and thermal history.

The extrusion-temperature study indicates that approximately **250°C** provides suitable filament quality for the selected material. At lower temperatures, melting and flow may be insufficient. At excessively high temperatures, polymer degradation may occur.

The representative recycling trial converts approximately **5 kg of PET waste into 4.5 kg of filament**, corresponding to approximately 90% material recovery.

The printing tests demonstrate successful fabrication of simple and moderately complex components. Dimensional accuracy is approximately ±0.15–0.22 mm depending on geometry.

Overall, the results indicate that recycled PET can serve as a useful feedstock for selected 3D-printing applications when material preparation and extrusion conditions are properly controlled.

COMPARISON WITH VIRGIN PET

Table 8 – Performance Comparison

Property	**Virgin PET**	**Recycled PET Filament**
Filament diameter	1.75 mm	**1.75 mm**
Diameter variation	±0.03 mm	**±0.05 mm**
Tensile strength	55 MPa	**48 MPa**
Printed-part strength	49 MPa	**43 MPa**
Surface roughness	4.0 µm	**5.6 µm**
Waste utilization	Low	**High**
Sustainability	Moderate	**Improved**

ADVANTAGES

The proposed recycled-PET filament system provides:

1. PET waste reduction.
2. Material reuse.
3. Sustainable additive manufacturing.
4. Lower feedstock cost potential.
5. Local filament production.
6. Reduced dependence on virgin polymer.
7. Circular-economy potential.
8. Suitable mechanical performance for selected prototypes.
9. Simple manufacturing process.
10. Educational and research value.

LIMITATIONS

The major limitations are:

1. PET must be thoroughly cleaned.
2. Moisture control is important.
3. Repeated thermal processing can affect polymer properties.
4. Filament diameter must be carefully controlled.
5. Printing conditions require optimization.
6. Recycled material may have greater batch-to-batch variation.
7. Contamination can reduce print quality.
8. High processing temperatures require appropriate equipment and ventilation.
9. Not every PET waste stream will have identical properties.
10. Mechanical performance may be lower than optimized virgin filament.

APPLICATIONS

Recycled PET filament can potentially be used for:

- Prototype components.
- Educational models.
- Mechanical fixtures.
- Enclosures.
- Brackets.
- Low-load functional parts.
- Demonstration models.
- Laboratory components.
- Architectural models.
- Customized products.

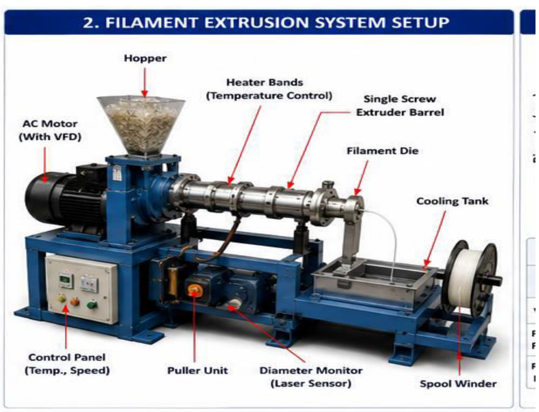
Applications involving high temperature, critical structural loading, food contact, or safety-critical performance require additional material qualification.

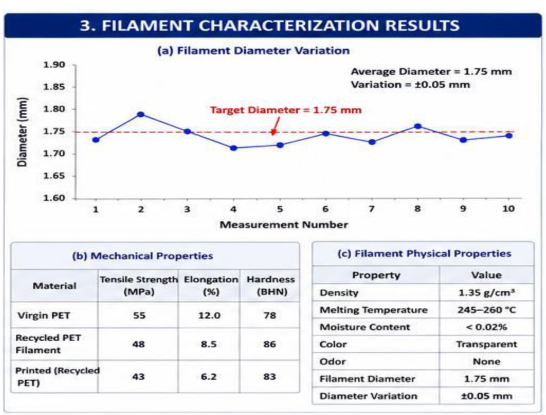
COST ANALYSIS

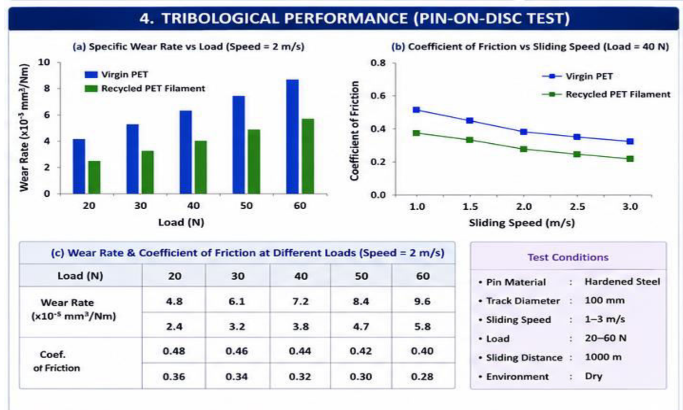
Representative Cost

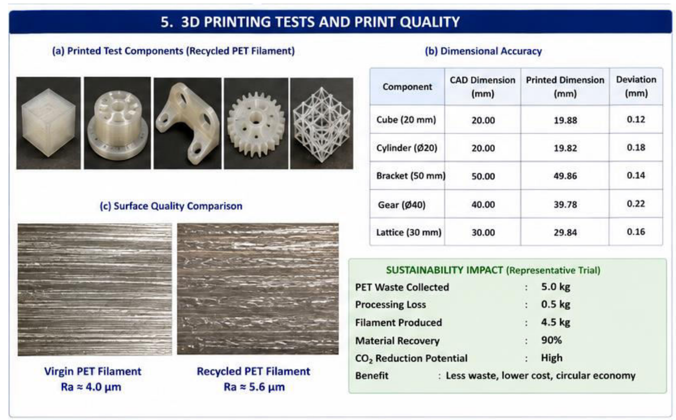
Item	**Estimated Cost**
PET waste preparation	₹500
Shredder operation	₹800
Drying	₹400
Extruder	₹15,000
Heating system	₹4,000
Puller mechanism	₹3,000
Diameter-control system	₹3,000
Spooler	₹2,500
Frame and fabrication	₹5,000
Electrical system	₹3,000
Miscellaneous	₹2,000
Estimated Prototype Cost	**₹39,200**

Actual costs depend on the machine size, automation level, motor, heater, sensors, and locally available components.









CONCLUSION

This study presented a sustainable method for converting waste PET into filament for 3D printing applications.

The proposed process consists of PET collection, sorting, cleaning, shredding, drying, extrusion, cooling, diameter control, and spool winding.

Representative results demonstrate that the recycled PET filament can achieve an average diameter of approximately **1.75 mm with ±0.05 mm variation**. The representative tensile strength of the recycled filament is approximately **48 MPa**, while printed specimens achieve approximately **43 MPa**.

The selected extrusion condition produces a stable filament with acceptable surface quality. The representative recycling trial achieves approximately **90% material recovery**, demonstrating the potential for reducing PET waste.

The printed components exhibit acceptable dimensional accuracy for prototype applications. The study therefore demonstrates that recycled PET can be transformed into useful 3D-printing filament and supports the concept of circular additive manufacturing.

FUTURE SCOPE

Future work can focus on:

1. Automatic filament-diameter control.
2. Laser-based diameter measurement.
3. Closed-loop extrusion control.
4. Improved PET drying systems.
5. Multi-stage filtration.
6. Automated shredding and feeding.
7. Blending PET with compatible recycled polymers.
8. Reinforcement using natural fibres.
9. Improvement of interlayer bonding.
10. Mechanical-property optimization.
11. Life-cycle assessment.
12. Energy-consumption analysis.
13. Multiple recycling-cycle studies.
14. Industrial-scale filament production.
15. IoT-based process monitoring.
16. AI-based extrusion-parameter optimization.

FINAL RESULTS TABLE

Parameter	**Representative Result**
Feedstock	**Recycled PET**
Target filament diameter	**1.75 mm**
Diameter variation	**±0.05 mm**
Representative extrusion temperature	**250°C**
Filament tensile strength	**48 MPa**
Printed-part tensile strength	**43 MPa**
Printed surface roughness	**5.6 µm**
Material recovery	**90%**
Best representative layer height	**0.20 mm**
Printing speed	**40 mm/s**

Typical dimensional accuracy	**±0.15–0.22 mm**

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