"Fabrication of Spool using Plastic Waste"

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Abstract

Plastic waste is one of the most significant environmental challenges worldwide, with large quantities generated annually and only a small percentage being recycled effectively. In India, improper disposal and inadequate waste management have resulted in serious environmental pollution, affecting landfills, water bodies, and ecosystems. Recycling-based manufacturing offers a sustainable solution by converting waste materials into useful industrial products. Spools are widely used in applications such as 3D printing, textile winding, and electrical cable management; however, they are typically manufactured from virgin plastics, increasing production costs and environmental impact. This project focuses on the fabrication of spools using recycled Polyethylene Terephthalate (PET) through an extrusion-based process. The methodology includes the collection, cleaning, shredding, drying, extrusion, cooling, and assembly of PET waste into functional spool components. CAD modeling is employed to design spools with adequate strength, balance, and dimensional accuracy. Extrusion system components and process parameters are carefully selected to ensure a consistent material flow and high-quality products. The project aims to demonstrate a cost-effective and environmentally sustainable approach to utilizing PET waste, reducing plastic pollution, lowering manufacturing costs, and supporting circular economy practices.

Key Words: Fabrication, Polyethylene Terephthalate (PET), Nozzle, Spool.

1. INTRODUCTION

Plastic is a widely used material due to its lightweight nature, durability, and low cost; however, its long degradation period has created serious environmental concerns. Globally, millions of tons of plastic waste are generated every year, with only a small portion being recycled, leading to pollution of land and water ecosystems. In India, single-use plastics contribute significantly to this problem. Recycling plastic waste into useful products offers an effective solution to reduce environmental damage while generating economic value. Plastic spools are essential components in industries such as 3D printing, textiles, and electrical cabling, yet they are mostly produced from virgin plastics. This project focuses on fabricating spools from recycled PET waste, following waste-to-wealth and circular economy principles. The approach aims to reduce plastic pollution, lower production costs, promote sustainable manufacturing, and support environmentally responsible industrial practices.

2. PROBLEM STATEMENT & OBJECTIVE

2.1 Problem Statement

Plastic waste management in India faces major challenges due to low recycling rates, limited processing infrastructure, and high dependence on virgin plastics. A significant portion of plastic waste remains mismanaged, resulting in landfill overflows, environmental pollution, and microplastic contamination. At the same time, industries such as 3D printing, textiles, and cable manufacturing rely heavily on virgin plastics like ABS and HDPE for spool production, which increases production costs and carbon footprint. Despite growing interest in circular economy models, there is a lack of viable, decentralized methods and standards for producing industrial spools from recycled plastics.

2.2 Objectives

The objective of this project is to develop a sustainable process for fabricating functional spools using recycled plastics. This includes material selection, CAD-based spool design, process planning, prototype evaluation, and assessment of cost efficiency, environmental benefits, scalability, and socio-economic impact.

3. MATERIALS AND COMPONENTS

3.1 Raw Materials: Polyethylene Terephthalate (PET)

- Source: Beverage bottles, food packaging, textile fibers.
- Melting Temperature: 120–130 °C.
- Properties: Good strength, transparency, and rigidity.
- Advantages: Most of the waste material is suitable for extrusion into filaments or spool parts.
- Challenges: Dry material completely to avoid extrusion bubbles.

3.2 Machine Components

The extrusion system consists of several essential components that together ensure a stable structure, motion control, heating, and power supply

- V-Slot Aluminum Extrusion: Provides a strong, lightweight frame that enables smooth linear motion, enhancing machine stability.
- Arduino Mega 2560 with ESP8266: Acts as the central controller, handling motor control, temperature regulation, and system coordination with Wi-Fi capability.
- Creality Ender-3 LCD Display: Serves as the user interface for monitoring and controlling operating parameters.
- Hot End: Melts PET material and extrudes it accurately at controlled temperatures.
- Stepper Motor Cable: Transfers control signals from the controller to the motors with minimal interference.
- 42-40 Stepper Motor: Ensures precise and controlled movement of extrusion and feeding mechanisms.
- 12V 15A Power Supply: Delivers stable power to all electrical components for continuous operation.

4. METHODOLOGY

4.1 Methodology

Post-consumer plastic waste, primarily PET bottles, is collected and segregated based on polymer type and contamination. The waste is washed, shredded into flakes, and dried to eliminate moisture before processing. The processed plastic is extruded to form continuous strands suitable for spool fabrication. Spool designs are developed using Fusion 360, emphasizing strength, balance, and dimensional accuracy. Fabricated spools are evaluated for mechanical strength, dimensional tolerance, rotational balance, and durability under repeated winding conditions. Process data, including energy consumption, material usage, cycle time, and production cost, are recorded and analyzed to assess efficiency and economic feasibility in comparison with conventional virgin-plastic spools.

Fig-1: Flowchart

4.2 Working Principle

The system operates on the principle of thermoplastic extrusion followed by controlled shaping. Cleaned and dried PET plastic flakes are fed into the extruder, where they are heated above their melting temperature using an electrically heated hot end. A stepper-motor-driven screw conveys and homogenizes the molten plastic, which is then forced through a die to form a continuous strand. The extrudate is guided, cooled, and wound onto a spool designed using CAD for dimensional accuracy and balance. Precise temperature control and synchronized motor operation ensure uniform material flow, consistent cross-section, and defect-free spool fabrication.

4.3 Fabrication and Assembly

- **Frame Fabrication**: The machine frame is fabricated using V-slot aluminum extrusion to provide structural rigidity, accurate alignment, and ease of assembly.
- **Extrusion System Assembly**: The screw, barrel, hot end, heater, and nozzle are assembled to form the extrusion unit, ensuring proper alignment and thermal insulation.
- **Electrical and Control Integration**: Stepper motors, controller board, LCD display, sensors, and power supply are installed and interconnected for precise motion and temperature control.
- **Final Assembly and Testing**: All mechanical and electrical components are integrated, followed by alignment checks, trial runs, and performance verification to ensure safe and smooth operation.

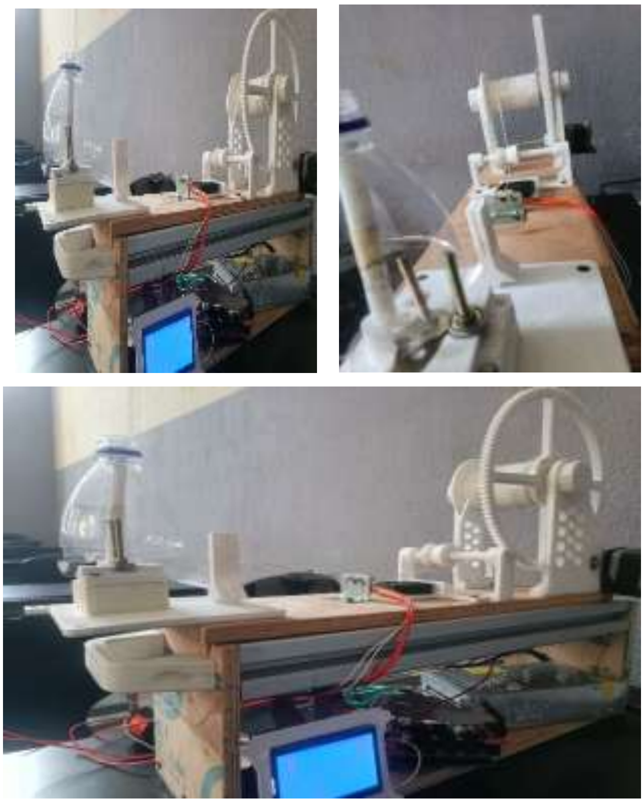

Fig-2: Model images

5. RESULTS AND DISCUSSION

Table 1: Machine Operation Parameters

Parameter	Result of (PET)
Strip Width (mm)	8-9 (mm)
Nozzle Temperature	185-190°C
Motor Speed	13-15 (RPM)
Strip Feed Rate	Operator-assisted feeding/loading
Output Diameter	1.75mm (± 0.05mm)

Table 2: Filament Production Summary

Parameter	1 Liters	2 Liters	5 Liters
Water bottle weight (g)	16	34	70
Weight of strip (g)	11	24	49
Width of strip (mm)	9	9	7.5
Thickness of strip (mm)	0.19	0.19	0.40
Filament weight (g)	12	24	49
Length of filament (m)	5	10	25
Time taken (min)	14	32	70
% Utilization	74%	70%	68%

6. CONCLUSIONS

The mechanical performance of recycled PET at 50% infill density is strongly influenced by the infill pattern. Variations in internal geometry affect load transfer, stiffness, and energy absorption.

- Gyroid infill shows the highest tensile (≈24 MPa), flexural (≈42 MPa), and impact strength (≈13.5 J/m) due to uniform stress distribution.
- Honeycomb infill provides balanced strength and stiffness with efficient material usage.
- Rectilinear infill exhibits moderate tensile strength but lower impact resistance.

- Concentric infill results in the lowest mechanical performance because of non-uniform load paths.

Young's modulus increases from about 1.15 GPa (concentric) to 1.32 GPa (gyroid), indicating improved stiffness with optimized infill geometry.

Overall, gyroid infill delivers superior mechanical properties, demonstrating that infill pattern selection is critical for enhancing the performance of recycled PET filaments.

Mechanical Performance of Recycled PET with Different Infill Patterns

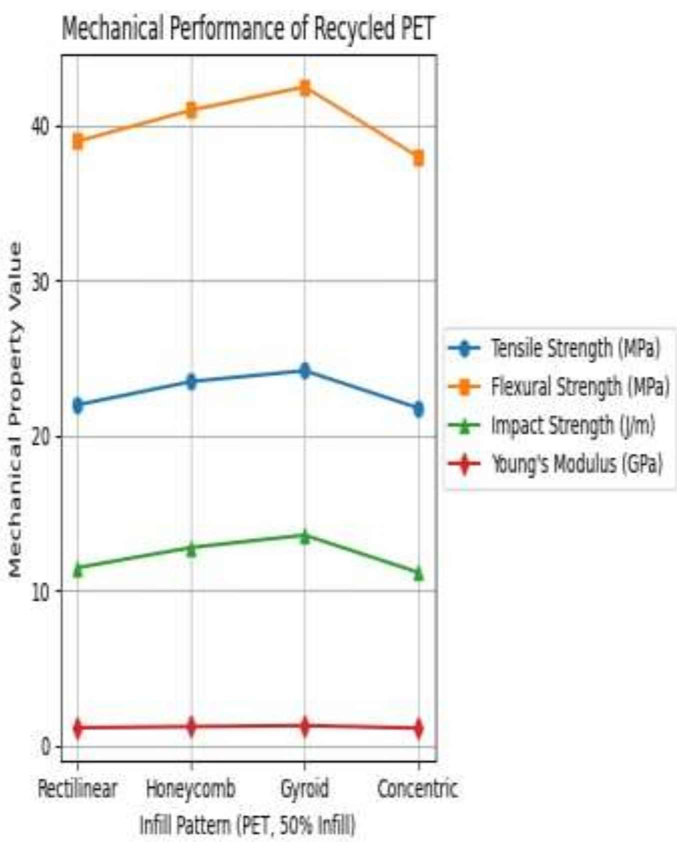

Fig-3: Graph of Recycled PET Performance

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