Forks to Filament: Viability of Post Consumer tPLA in Additive Manufacturing

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Introduction

- Post consumer waste often ends up in landfill or industrial composting
- Reuse in FFF 3D printing as an alternative end of life pathway
- Viability tested by system modeling, material processing, and mechanical tests
- Compares between contaminated tPLA, uncontaminated tPLA and virgin PLA
- Material Flow Diagram for the stages of each process and energy usage

Objectives

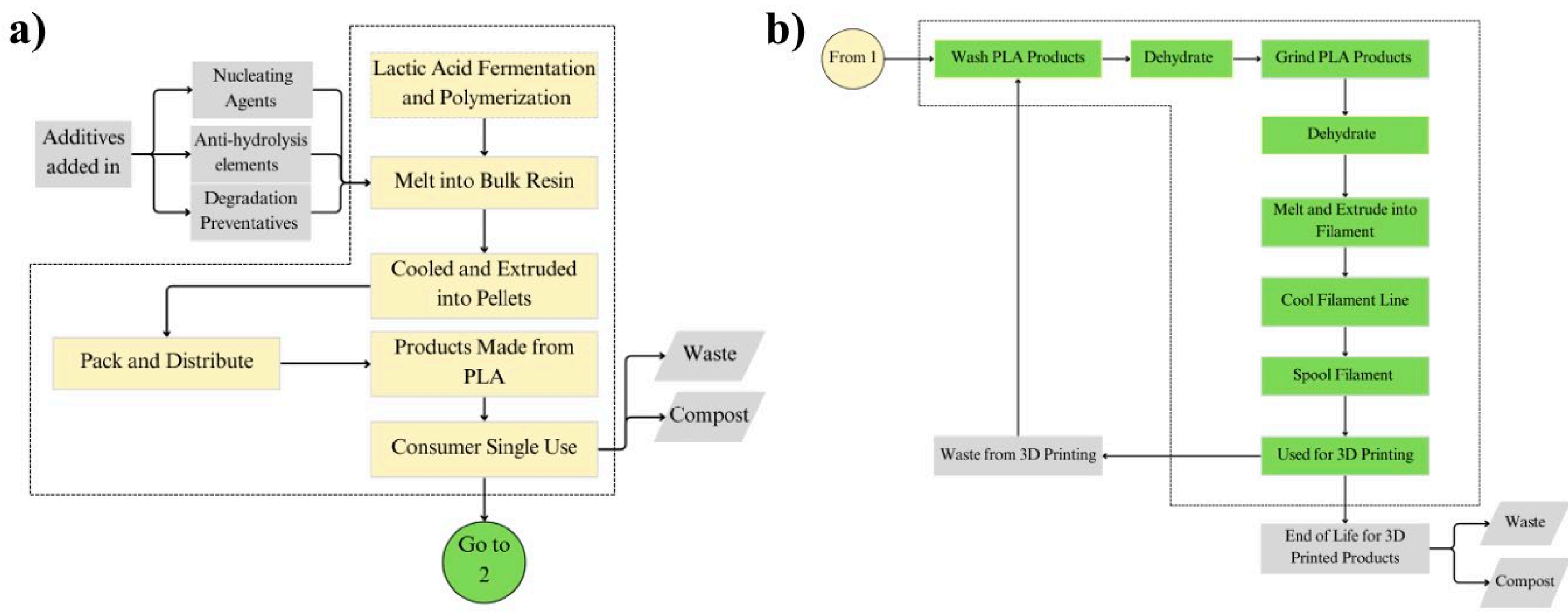

Figure 1. Material flow diagram. (a) Primary manufacturing process. (b) FFF through 3D printing process.

Table 1: Delivered electrical energy consumption by machine for the secondary process

Machine	Energy Consumption Per 1 kg of Filament [$\frac{kWh}{kg}$]
Washer	0.36
Grinder	0.02
Dehydrator	0.32
Extruder	0.67
Spooler	0.29
Printer	5.92
Total	7.58

Material Processing

1.Cleaning and Grinding: Post-consumer tPLA cutlery was thoroughly cleaned with a dishwasher to remove surface contaminants. The cleaned material was then ground into smaller particles and dehydrated to eliminate residual moisture.
2.Extrusion and Cooling: Processed tPLA particles were extruded at a controlled 160 °C to form continuous filament. The extruded filament was immediately cooled in a water bath to solidify and stabilize its shape.
3.Tensioning and Spooling: The cooled filament was passed through an accumulator to maintain consistent tension and achieve desired diameter. It was then spooled onto reels with a filament winder for storage and use in 3D printing.

Specimen Fabrication

- Bambu A1 Mini (default print settings)
- Anisotropic material (requires altering raster angle by ASTM standards)
- 10 specimens per material type

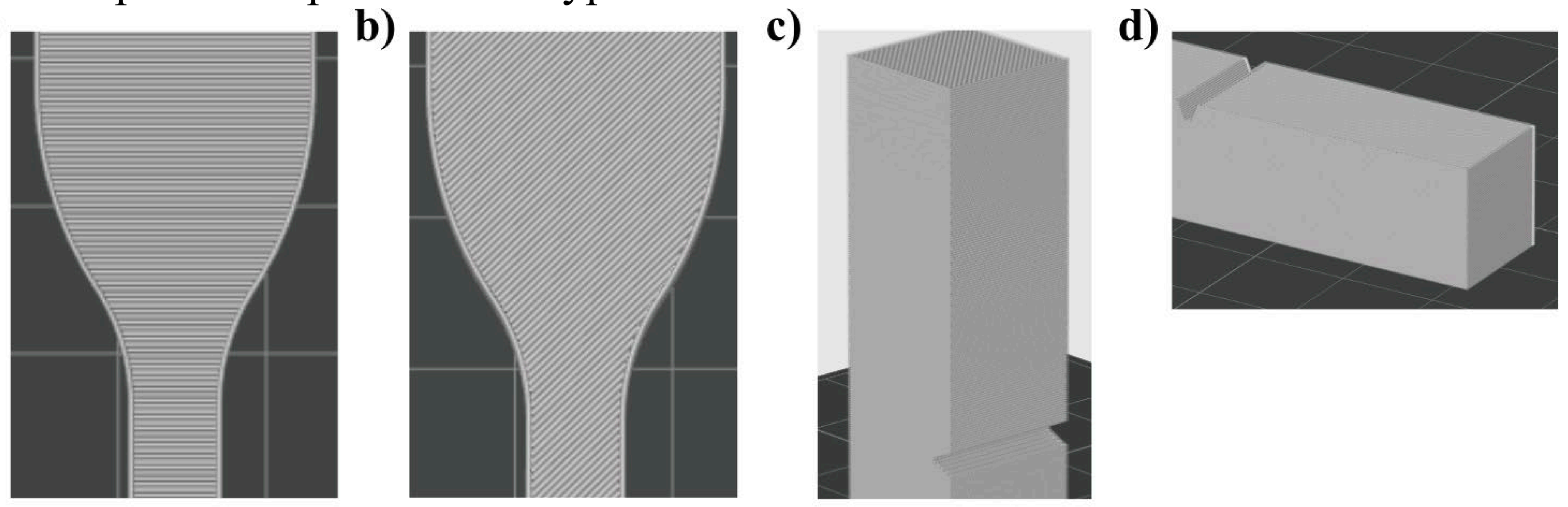

Figure 2: Print schematics at different orientations to account for specimen anisotropy for D638 tensile testing a,b, and D256 impact testing c,d. a) 0°/90° raster angle. **b)** 45°/45° raster angle. **c)** Vertically oriented. **d)** Horizontally oriented.

Mechanical Testing

- Tensile tested with 5kN load cell at 5 mm/s strain rate on Instron 3345 Universal Testing System.
- Izod impact testing for fracture / brittle failure on Tinius Olsen IT542 Universal Impact Tester
- Environmental testing conditions maintained prior to and during experimentation according to ASTM D638 / D256

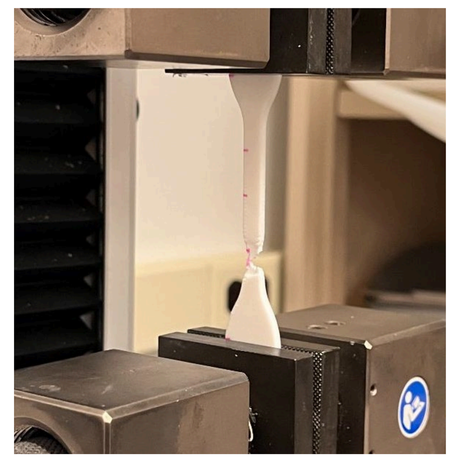

Figure 3: Tensile Test of PLA Printed at 0°/90° raster angle on Instron 3345 Universal Testing System. Gauge length and clamp positions according to D638

Tensile Test Results

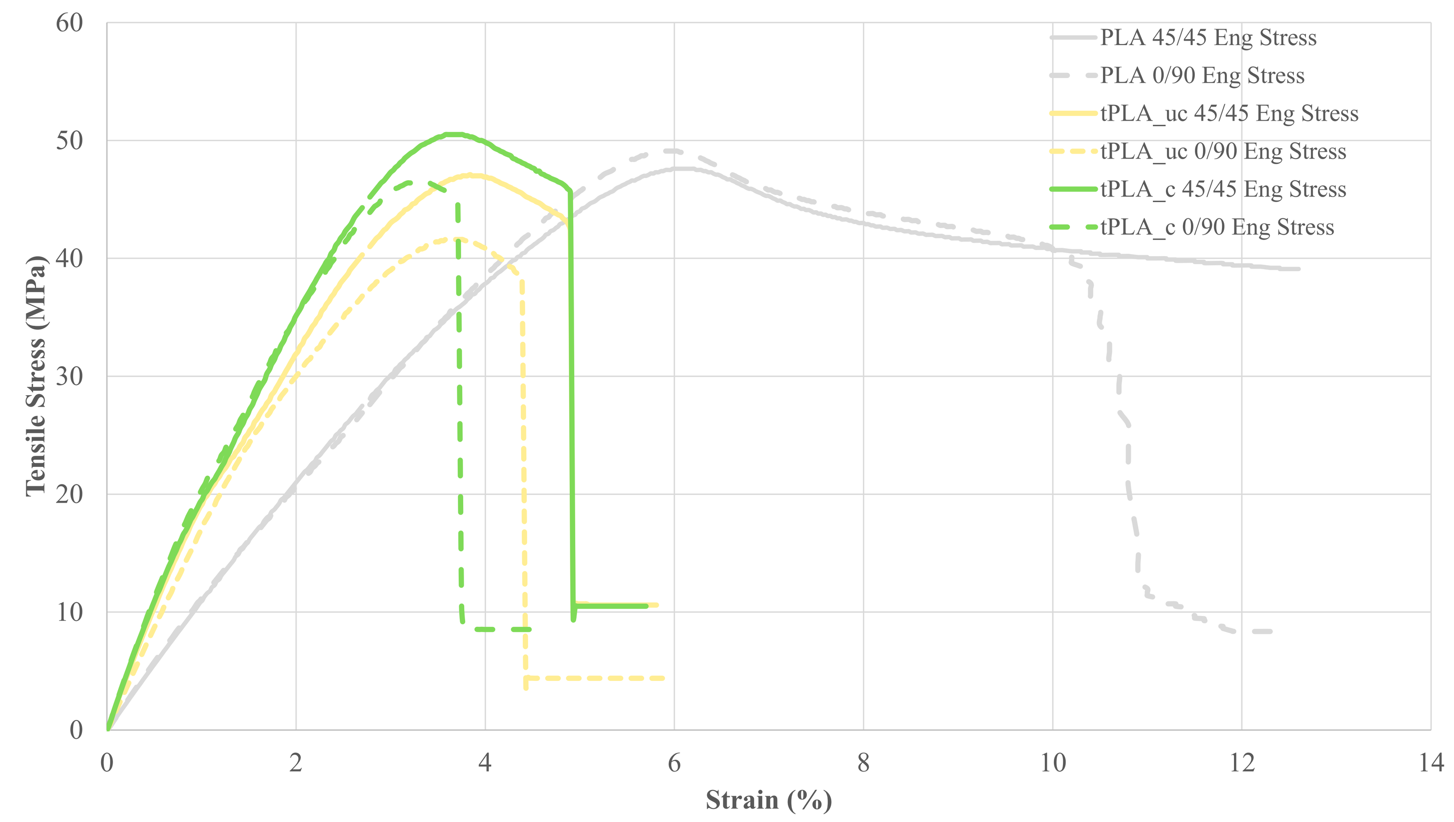

Figure 4: Select Tensile Test Results. Chosen by closest UTS to the mean UTS among sample group

- UTS calculated from P_{max} and A_0.
- Elastic region defined by $\log(\varepsilon_T)$ vs $\log(\varepsilon_N)$ plot and first slope range 1.1 ~ 0.9
- Young's Modulus calculated from elastic region using ε_T and σ_T
- Yield stress σ_Y taken at the end of the elastic region

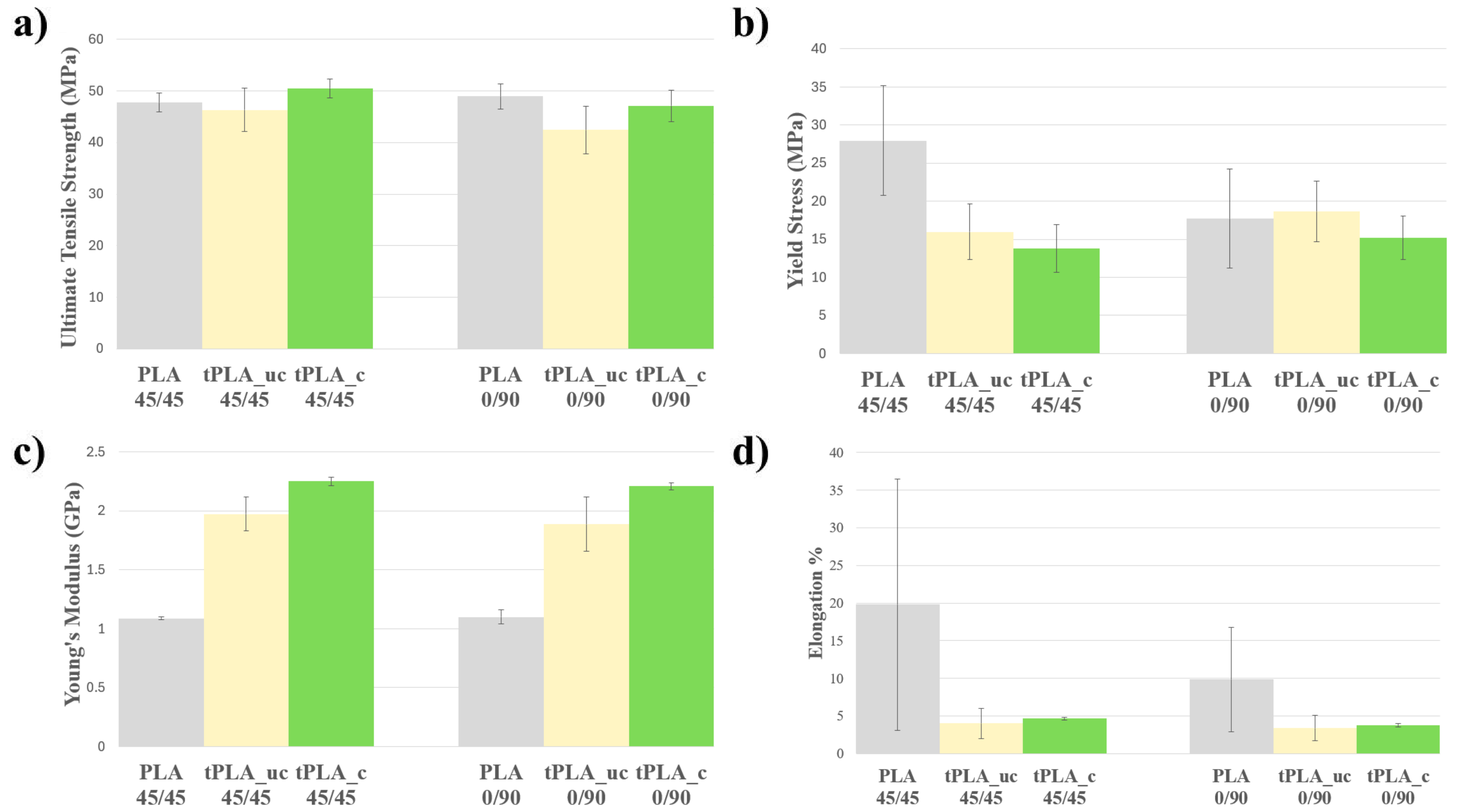

Figure 5: Data analysis of tensile testing of 0°/90° and 45°/45° raster angles comparing PLA, $tPLA_{uc}$, $tPLA_c$ in: a) Ultimate tensile strength (MPa); **b)** Yield stress (MPa); **c)** Young's Modulus (GPa); **d)** Elongation (%).

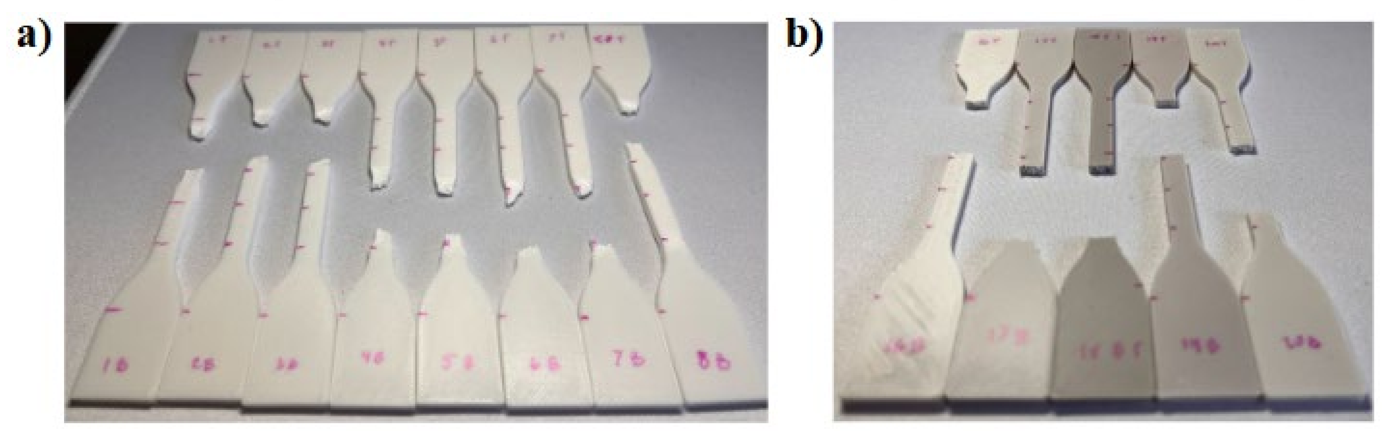

Figure 6: Tensile specimens after testing. a) PLA 45°/ 45° specimens after failure, showing yielding in gauge length. **b)** $tPLA_c$ 45°/ 45° specimens after failure, showing brittle fracture.

Impact Test Results

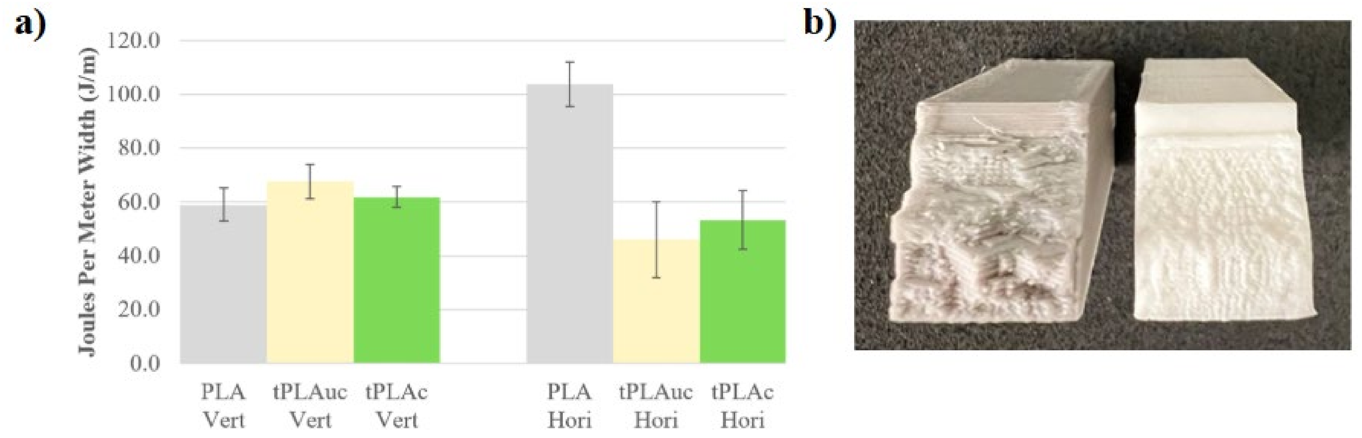

Figure 7: Data analysis from D256 impact testing of vertical and horizontal orientations comparing PLA, $tPLA_{uc}$, $tPLA_c$. a) Joules per Meter Width (J/m); **b)** Breakage of $tPLA_c$ (left) and PLA (right) specimens at horizontal print orientation

Discussion

- T-tests conducted to validate the results between similar specimens of different materials. There is statistical difference in:
  - Yielding for PLA vs $tPLA_c$, $tPLA_{uc}$
  - Young's Modulus across all material types
  - Impact Strength for PLA vs $tPLA_c$, $tPLA_{uc}$
- The total primary energy used in the secondary process is 18.57 kWh/kg, compared to the primary process of 32.65 kWh/kg. Reusing PLA uses 56% of the primary energy used to create 1kg of original PLA filament for FFF
- Challenges in material processing hinder user experience

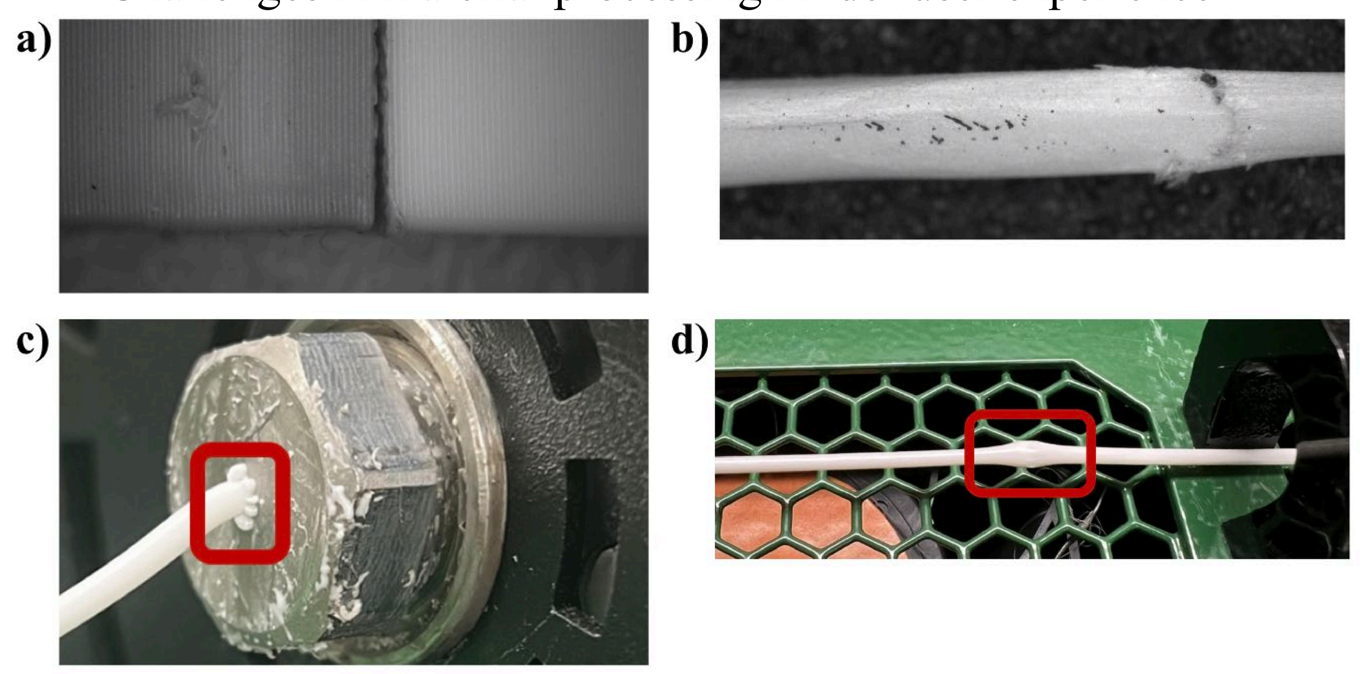

Figure 8: Key Challenges in Using Recycled tPLA in FFF 3D Printing. a) Front view comparison of horizontal impact: tPLA-C specimen (left) shows greater damage than virgin PLA (right). **b)** Residue buildup from cold pull test on contaminated tPLA-C filament. **c)** Filament bulging during extrusion caused by contamination. **d)** Die drool observed during extrusion of contaminated tPLA-C filament.

- **Limitations** include anisotropic material; contaminant propagation at grain boundaries; tested only one 3D printer; non-optimized print settings

Conclusion

- Similar properties in virgin PLA and tPLA
- Extends bioplastic life
- Reduces energy used by ~56%
- Nozzle clogging and inconsistent print quality
- Future steps: optimize material processing, refine print settings test other platforms, increase test sample size

References

Fabe, Peter, et al. *FORKS TO FILAMENT – EXPLORING THE POTENTIAL VIABILITY OF POST-CONSUMER TPLA IN ADDITIVE MANUFACTURING.* Proceedings of the ASME 2025 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, IDETC/CIE2025, Aug. 17–20, 2025, Anaheim, California. American Society of Mechanical Engineers.

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