

Executive Summary

The rapid expansion of additive manufacturing (AM) has highlighted a critical sustainability gap, particularly in Selective Laser Sintering (SLS), where up to 50% of the polymer powder remains unsintered and often discarded as "aged" waste. This project investigates a high-value recovery pathway for these materials by transitioning from SLS to Fused Deposition Modeling (FDM). We successfully converted recycled SLS-grade Nylon 12 (PA12) powder into FDM filament via single-screw extrusion. By optimizing critical process parameters, specifically maximizing the thermal profile of a Creality Ender 3 3D Printer to 260°C and standardizing feed rates to 55 mm/s, we achieved the interlayer adhesion necessary to produce structural specimens. This research demonstrates a viable "circular economy" model for engineering-grade polymers in manufacturing.

Background

- **The Sustainability Challenge:** In the current industrial landscape, Nylon 12 is a premier material for high-performance parts. However, the high refresh rates in SLS manufacturing result in massive quantities of partially degraded powder.
- **The Pivot to FDM:** While initial studies focused on laser fusion, inconsistent laser absorption in recycled powders led to a research pivot toward Fused Deposition Modeling. FDM allows for direct thermal control, making it more resilient to the varied particle sizes found in recycled waste.
- **Societal Impact:** By establishing parameters to reuse this "waste" on low-cost FDM hardware like the Creality Ender 3, we democratize access to engineering-grade recycled materials and reduce the carbon footprint of the additive manufacturing industry.

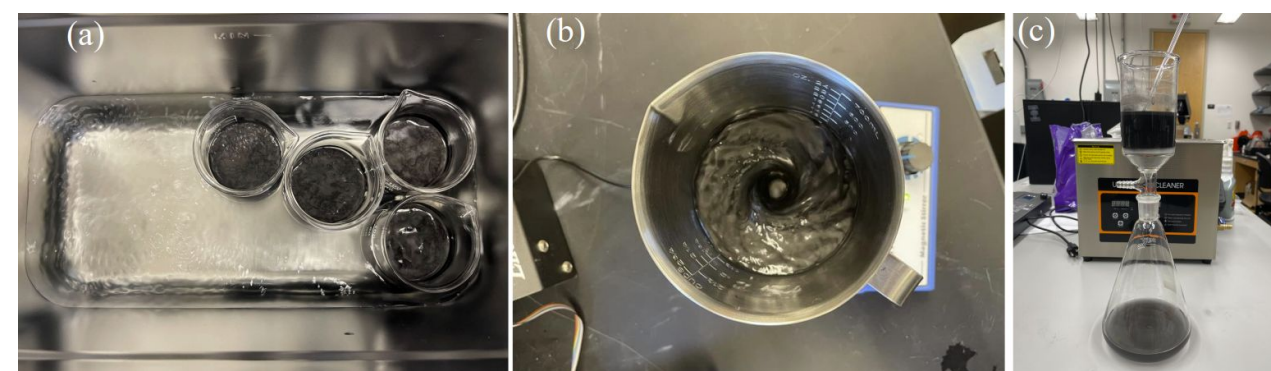


Figure 1: (a) Beakers containing graphite-IPA suspensions during ultrasonication. (b) Graphite-IPA-Nylon 12 suspension during magnetic stirring (c) Vacuum-assisted filtration of the mixture through a Buchner funnel

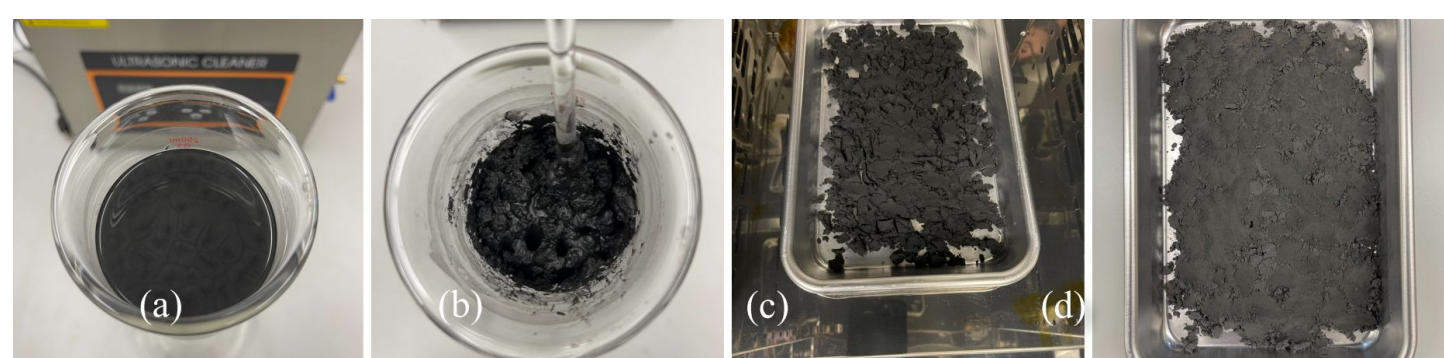


Figure 2: (a) Graphite-IPA-Nylon 12 mixture in the Buchner funnel prior to filtration (b) Composite powder cake collected in the Buchner funnel after filtration. (c) Composite powder cake in the industrial oven prior to the start of the drying cycle (d) Nylon 12-graphite powder after oven drying at 70°C for 12 hours.

Experimental Setup

- **Materials Processing:** Aged SLS Nylon 12 powder was sieved and processed through a desktop filament extruder to produce a 1.75mm diameter filament.
- **Hardware Optimization:**
 - **Printer:** Creality Ender 3 (utilizing a high-temp heating element).
 - **Hotend:** Modified to reach 260°C to facilitate the flow of high-viscosity PA12.
 - **Nozzle:** 0.4 mm hardened steel to withstand potentially abrasive recycled particles.
 - **Adhesion Layer:** Glass bed treated with a specialized polymer adhesive (Glue Stick) to manage the high shrinkage coefficient of PA12.
- **Software Configuration:** Ultimaker Cura was utilized to slice the STL file into G-code with the following settings, which were optimized after multiple printing attempts:
 - **Layer height:** 0.2 mm
 - **Wall thickness:** 1.0 mm
 - **Infill density:** 60%
 - **Infill Pattern:** Lines
 - **Nozzle temperature:** 260°C
 - **Bed temperature:** 80°C
 - **Print speed:** 300 mm/s
 - **Travel speed:** 120 mm/s
 - **Initial layer speed:** 15 mm/s

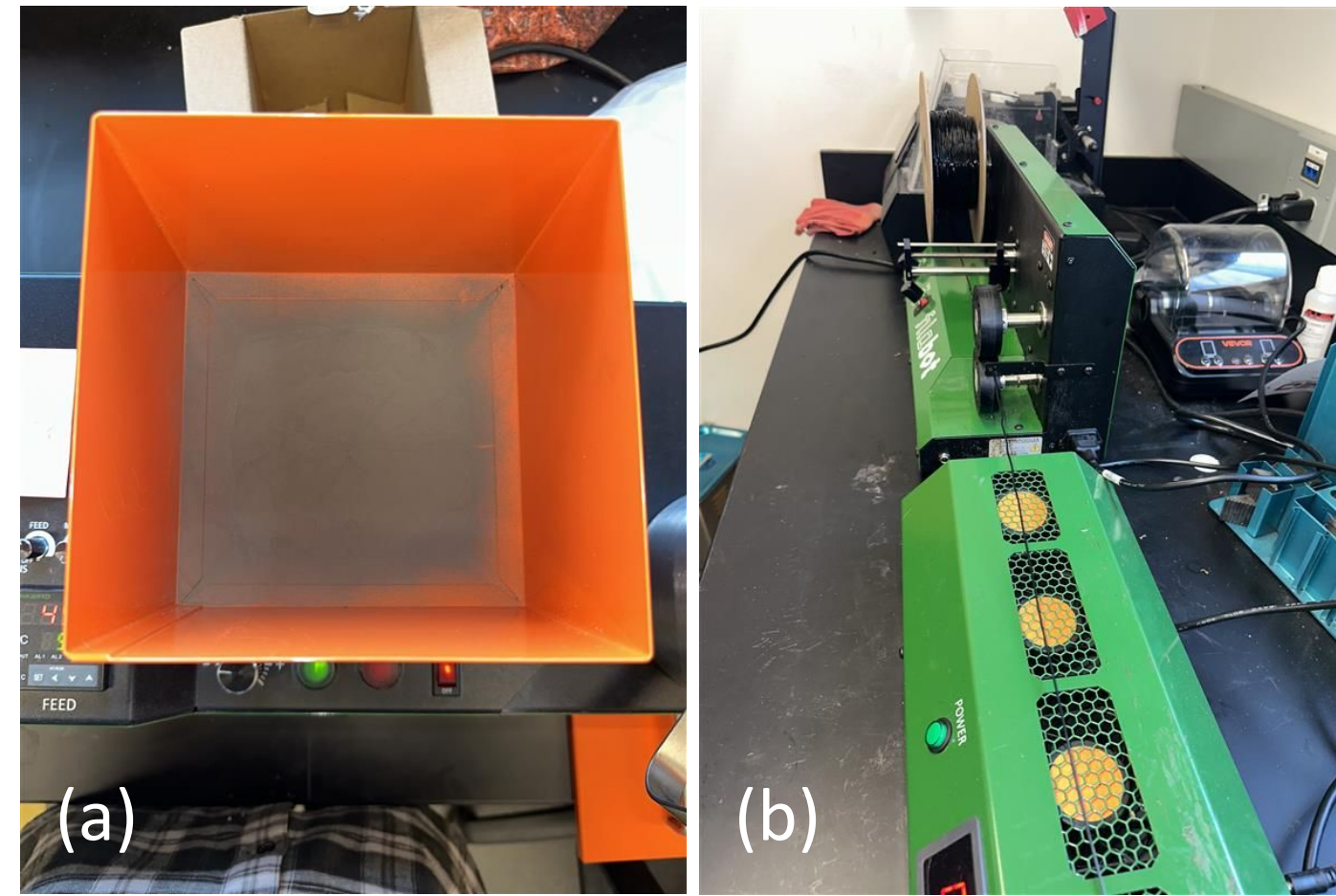


Figure 3: Filament Fabrication and Material Intermediate (a) Recycled Nylon 12 powder (PA12) loaded into the hopper of a single-screw desktop filament extruder. (b) Single-screw extrusion and cooling line used to convert unsintered SLS-grade powder into a functional, free-flowing FDM feedstock.



Figure 4: Spooled 1.75 mm diameter filament produced from recycled SLS waste, optimized for use in FDM additive manufacturing processes.

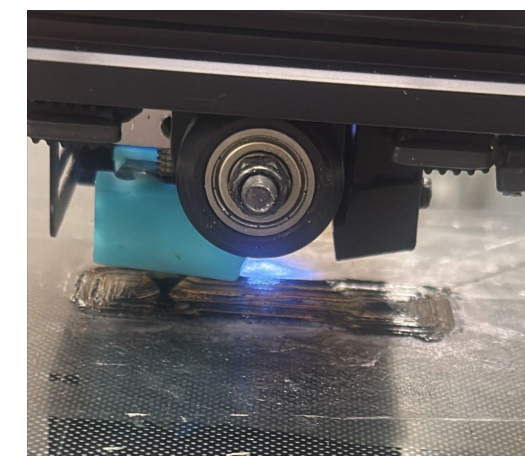


Figure 6: Sub-sized ASTM E8 tensile specimen during the final stages of the Fused Deposition Modeling (FDM) process on the Creality Ender 3.

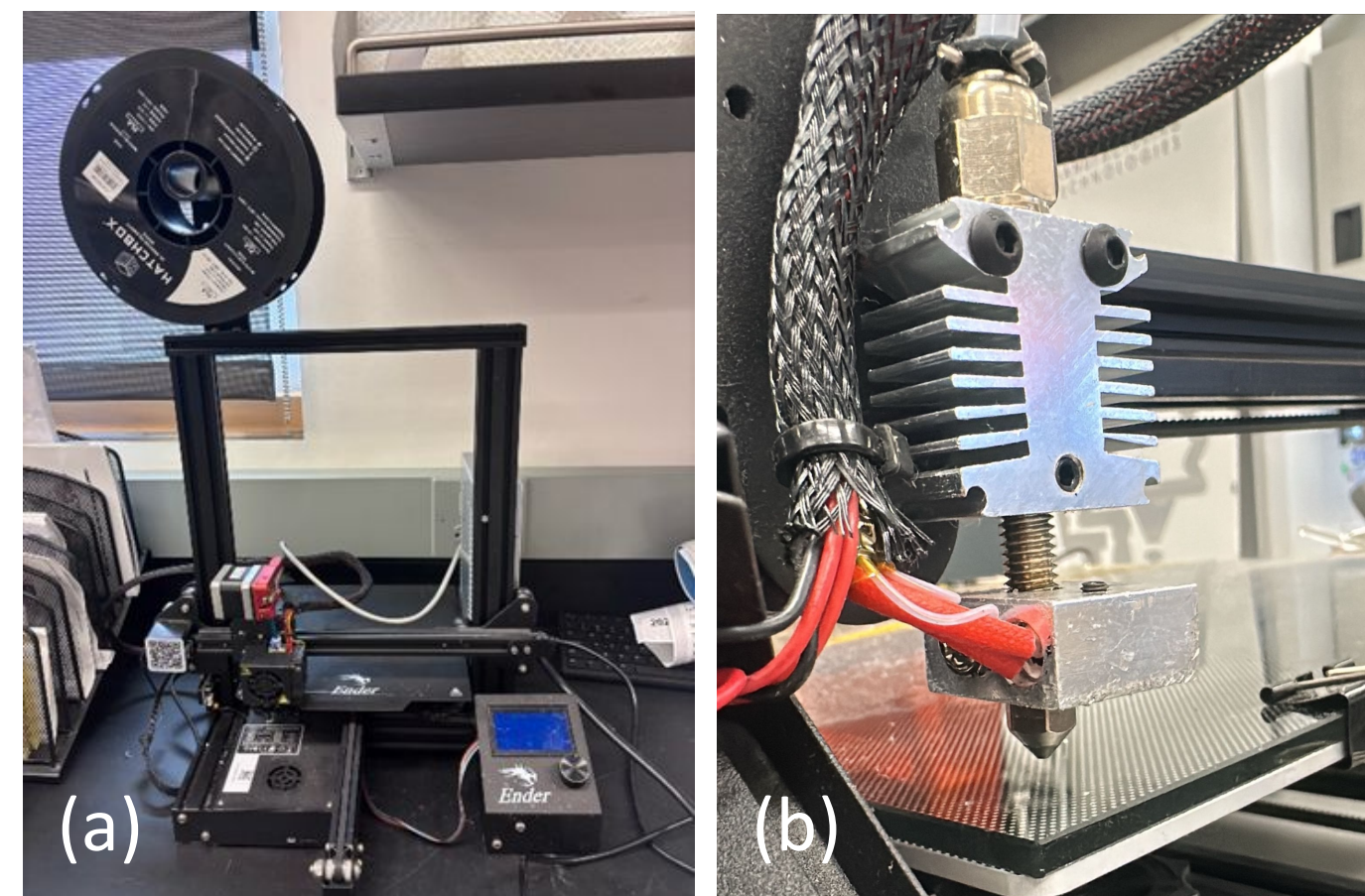


Figure 5: Hardware Configuration for High-Temperature FDM (a) Modified Creality Ender 3 3D printer utilized for the fabrication of structural specimens from high-viscosity recycled Nylon 12. (b) Close-up of the modified hotend assembly, capable of maintaining a constant 260°C nozzle temperature to ensure proper polymer fusion and interlayer adhesion.

Experimental Test Plan

Our methodology followed a three-phase optimization cycle:

- **Phase I (Extrusion):** Testing various screw speeds and temperatures to achieve a uniform 1.75mm filament diameter without inducing further thermal degradation of the recycled PA12.
- **Phase II (Slicing & Flow):** Calculating the optimal feed rate (55 mm/s) to balance print speed with the melting capacity of the Creality Ender 3 hotend at 260°C.
- **Phase III (Mechanical Sampling):** Printing sub-sized ASTM E8 tensile specimens (dog-bones) with a 0.2 mm layer height and a rectilinear infill pattern at 60% density to prioritize longitudinal strength for tensile characterization.

Experimental Results

- **Thermal Consistency:** Maintaining a constant 260°C nozzle temperature was verified as the threshold for preventing "cold-set" delamination between layers.
- **Morphological Analysis:** The printed dog-bones exhibited a high degree of translucency, suggesting a reduction in internal voids and high polymer chain fusion.
- **Warp Management:** Using a bed temperature of 80°C combined with 0% cooling fan speed successfully eliminated part lifting, which is the primary failure mode for Nylon-based FDM prints.
- **Process Efficiency:** Optimized G-code allowed for a 100% completion rate, producing uniform specimens for future baseline tensile testing.

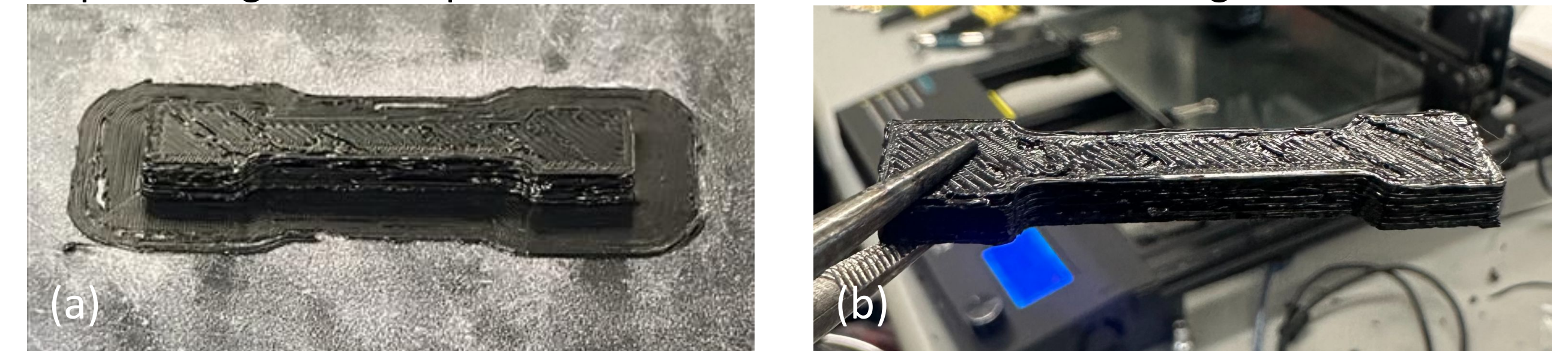


Figure 6: Morphological Results of ASTM E8 Specimens (a) Sub-sized ASTM E8 tensile specimen during the final stages of the Fused Deposition Modeling (FDM) process on the Creality Ender 3. (b) Completed recycled Nylon 12 specimen exhibiting a high degree of translucency, suggesting optimal polymer chain fusion and a reduction in internal voids.

Conclusions

The successful production of ASTM E8 specimens from recycled SLS powder confirms that degraded AM waste can be upcycled into functional engineering components.

- **Key Insight:** SLS-grade Nylon 12 requires printing at the absolute upper limit of standard FDM hardware (260°C) to ensure structural integrity.
- **Future Work:** The next phase of this research will re-introduce recovered graphite from battery recycling into the filament extrusion process to enhance the tensile modulus and explore potential electrical conductivity in recycled composites.
- **Acknowledgments:** This work was conducted at the Sustainable and Intelligent Manufacturing (SIGMA) Lab at the University of Texas at Arlington.

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