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Extrusion Production of 3D Printer Filament for Additive Manufacturing

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Abstract
Additive manufacturing, also known as 3D printing, is becoming a go-to production method for short production runs and rapid prototyping on a commercial scale. The growth of additive manufacturing is due to many factors including development of concept modeling, product design, prototyping, and customized parts. Pittsburg State University’s College of Technology strives to stay at the forefront of processing materials for additive manufacturing. The capability of making our own 3D printer filament would allow students to work with new and different materials and would allow students to learn at the forefront of 3D printing technology. The Wayne Yellow Jacket Extruder and Brabender Puller and Winder was used to produce 1.75 mm 3D-printing filament. The Yellowjacket required a lid on the hopper that was fabricated via thermoforming. The Brabender puller and winder was necessary for controlling the filament speed entering the winder and isolating the tension created by the spool from the extruder. When extruding plastic, the thickness and cross-sectional profile are dependent on the rate of cooling; therefore, a cooling trough was designed and fabricated. Polyactic acid (PLA) or acrylonitrile butadiene styrene copolymer (ABS) was used to extrude filament from this line. Successful extrusion of 3D printing filament will allow students to produce their own filament as needed for additive manufacturing using the existing Stratasys FDM 1600 and the student-built 3D printer.

Introduction
Additive manufacturing, also known as 3D printing, is becoming a go-to production method for short production runs and rapid prototyping on a commercial scale. Additive manufacturing is a process that adds successive layers of material to create an object leaving no scrap or waste. This differs from traditional, or subtractive manufacturing, that involves removing excess material that then becomes waste. The growth of additive manufacturing is due to many factors including: development of concept modeling, product design, prototyping, and customized parts. Additive manufacturing is becoming indispensable in R&D departments and design departments. Wherever it is introduced, it accelerates work and cuts down on prototyping costs. The technology continues evolving rapidly as new and larger printers are being introduced, new materials are being used, and innovation regarding new ideas of how to use a 3D printer continues to expand.1,2

The growth of additive manufacturing is accelerating at a rapid rate in the area of plastic product development. The use of additive manufacturing grew from 29% in 2017 to 39% in 2018.3 Additive manufacturing is becoming more accessible to the everyday consumer as well. Currently, 3D printers are available to the retail consumer that allow consumers to set up printers in their homes to make their own self-designed small parts. In 2015 alone, more than 278,000 additive manufacturing printers valued under $5,000 were sold globally. The number of printers sold doubled consistently since 2015.4 Additive manufacturing is on the rise due to its ability to make complex parts and has advantages over other traditional plastics manufacturing techniques.

Objectives
In order to achieve our goals, our study sought to address the following objectives:

- Investigation of requirements of 3D printer filament
- Investigate commercially available filament production systems
- Determine which components need to be procured
- Design and assemble stand for extruder
- Purchase and install proper electrical connections
- Design and fabricate cooling trough and stand
- Conduct 3D printing trials using filament produced at PSU
- Develop work instructions

Materials and Methods
The following materials and methods were used:

- Resins
  - Virgin and regrind mix of injection molding-grade Acrylonitrile Butadiene Styrene (ABS)
  - Samsung Starex ABS
  - Chevron Phillips Marlex 6004 High Density Polyethylene
- Equipment
  - Wayne Yellow Jacket extruder (model no. 8665)
  - Brabender puller/winder (model no. 846720)
  - Fabricated cooling trough

Results
An 8-foot cooling trough was fabricated by cutting and welding sections from a 20-foot trough. The trough stand was designed and fabricated using 2” X 2” square tubing, and painted royal blue to match the newly acquired Brabender puller/winder. The completed cooling trough and stand can be seen below in Figure 4.

Results From Trial Runs
Trial runs were performed as detailed in Table 2 below. Speeds of the extruder and winder were altered to determine the different sizes of filament that can be produced.

Table 2: Results From Trial Runs

<table>
<thead>
<tr>
<th>Screw Speed</th>
<th>Melting Pressure</th>
<th>Melting Temperature</th>
<th>Take Off Diameter</th>
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<tr>
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<td>°F</td>
<td>m/min</td>
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<tr>
<td>18</td>
<td>1720</td>
<td>415</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Materials and Methods
The cooling trough (shown in Figure 4 in Results) is the next step in the extrusion line:

- Filament is pulled through an 8-foot cooling trough.
- The trough was designed and fabricated from an existing, 20-foot trough.
- The trough is full of water to cool the molten material into a solidified state.

The last step in PSU’s extrusion line is the Brabender Puller/Winder (as shown below in Figure 3 below):
- It is used for taking off and winding up the filament from the cooling trough.
- It is equipped with an oscillating unit that ensures even and steady winding of the extrudate.
- Brabender is an industry favorite due to its compact design and ease of learning the operational software.

Future Work
As an extension of this work we would like to further explore:

- Work instructions need to be written for the extrusion line.
- Temperature and speed parameters for the extruder and winder must be identified.
- Conduct 3D printing trials using filament produced at PSU.
- Expand extrusion die to create correct size filament.

Acknowledgements
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References