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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 designing, prototyping, and customized parts. Pittsburg State University's College of Technology strives to stay at the cutting edge 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 Yellowjacket 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. Polylactic 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 Stratysys 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 designing, 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]

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.[2] 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 their own additive manufacturing "facility" 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.[3] Additive manufacturing is on the rise due to its ability to make complex parts and has advantages over other traditional plastics manufacturing techniques.

Figure 1. *Example of 3D Printed Parts.*[4]

In the Department of Plastics Engineering Technology at Pittsburg State University, we are on the forefront of additive manufacturing by not only producing 3D printed parts, but by producing the 3D printer filament itself. The filament is that material that is added in successive layers to create the 3D printed object. With the Wayne Yellow Jacket Extruder and Brabender puller/winder, 3D filament of varying plastic type, size, color can be produced. The Department of Engineering Technology spends over $1,000 annually on 3D filament. With the new filament extrusion line, we can produce our own fully customizable filament at a fraction of the cost. Now, students will have the ability to participate in every step of the process of taking raw material and turning it into a finished part through the process of additive manufacturing.

Objectives

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

1. Investigation of requirements of 3D printer filament
2. Investigate commercially available filament production systems
3. Determine which components need to be procured
4. Design and assemble stand for extruder
5. Purchase and install proper electrical connectors
6. Design and fabricate cooling trough and stand
7. Processing and production trials
8. Conduct 3D printing trials using filament produced at PSU
9. 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

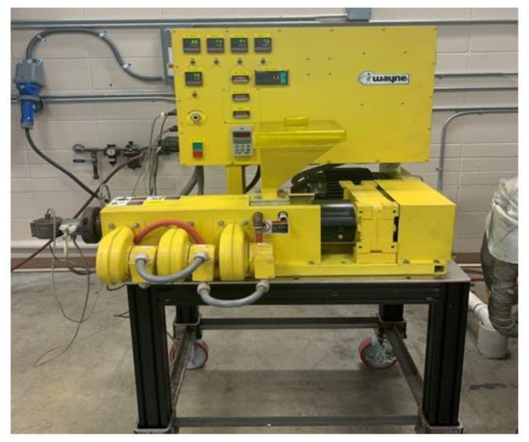

Figure 2. *Wayne Yellow Jacket Extruder.*

The Wayne Yellow Jacket extruder (shown in Figure 2) parameters:

- ¾ inch screw diameter
- 24:1 L/D (length: diameter)
- Monofilament extruder

The Yellow Jacket is the first step in the extrusion line:

1. Raw plastic is placed in the hopper
2. Gravity drops the pellets from the hopper into the barrel
3. Plastics melts in the barrel (heats shown in Table 1 below)
4. Molten material is formed into a continuous profile via the die.

Table 1: *Extruder Parameters During Testing*

Die Zone 1	Die Zone 2	Screw Zone 1	Screw Zone 2	Screw Zone 3
450 °F	450 °F	300 °F	425 °F	450 °F

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.

Figure 3: *Brabender Puller/Winder.*

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.

Figure 4. *Fabricated Cooling Trough.*

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*

Screw Speed	Melting Pressure	Melting Temperature	Take Off	Diameter
RPM	°F	°F	m/min	mm
3	637	407	3.9	0.82
5	802	408	5.7	0.77
10	1400	409	9.9	0.99
10	1200	409	7.8	0.98
12	1350	409	7.8	1.03
15	1600	411	9.0	1.20
17	1720	412	10.1	1.26
18	1790	415	10.5	1.28

Results

The extrusion line is fully operational and is capable of producing 3D filament. In order for the filament produced by the extrusion line to be used in a 3D printer, it is required to be 1.75 mm in diameter. Currently, filament of between 0.77 and 1.28 mm is being produced. To produce the desired filament diameter, the extrusion die needs to be altered.

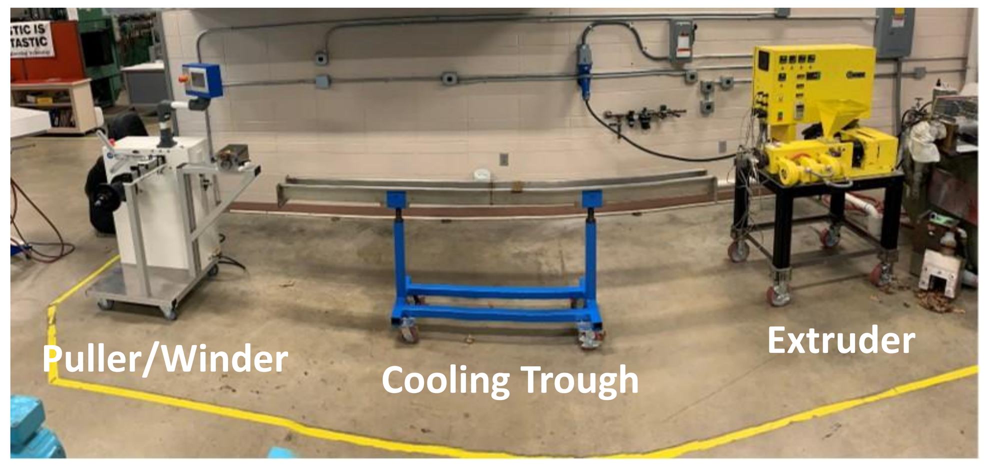

Figure 5: *Complete Extrusion Line.*

Conclusions

Additive manufacturing printing is becoming a go-to production method for short production runs and specialty parts on a commercial scale.

The work performed this year has accomplished the following:

- The under-utilized extruder system has been turned into a fully functional extrusion line suitable for the production of 3D printer filament.
- Yellow Jacket Extruder hopper lid was designed and thermoformed.
- Design and fabrication of an eight foot cooling trough from a previously unused twenty foot trough was completed.
- Brabender Puller/Winder was acquired and implemented into the filament extrusion line.
- A suitable ABS material for extrusion line was researched and obtained.

Pittsburg State administration is pushing for deeper involvement in processing materials for 3D printing manufacturing, and with the installation of the extrusion line, PSU will be at the cutting edge of processing materials for additive manufacturing.

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 puller 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

1. Kulis, M. Why 3D Printing is Useful and Will Continue to Be Useful. https://zortrax.com/blog/3d-printing-useful-continue/ ,(Accessed Mar 4, 2019).
2. Columbus, L. The State of 3D Printing, 2018. https://www.forbes.com/sites/louiscolumbus/2018/05/30/the-state-of-3d-printing-2018/#681d5e0a7b0a, (Accessed Mar 4, 2019).
3. Redwood, B. The Advantages of 3D Printing. https://www.3dhubs.com/knowledge-base/advantages-3d-printing#ease-of-access, (Accessed Mar 4, 2019).
4. 3D Printing. https://robodawgs.wordpress.com/2013/11/22/robodawgs-suceed-with-3d-printing/, (Accessed Mar 5, 2019).