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The Practicality and Scalability of Respooling 3-D printing Thermoplastics A Multidisciplinary Research Project by the Canino School of Engineering Technology at SUNY Canton (WIP)

Mr. Matt Jamison Burnett,

Matt Burnett is a native of the Adirondack Mountains of Northern NY state. Working in paint, video and environmental installation, Burnett's work explores the history, paradoxes and environmental dilemmas of nature/culture relationships.

Burnett is currently a Professor in the Graphic and Multimedia Design Program at the State University of New York Canton. In his "Sustainability Lecture Series" at Canton, Burnett combines interdisciplinary teaching with a broad spectrum of speakers from various disciplines. His guests have included scientists, economists, theologists, engineers, and activists. In 2015 Burnett hosted Bill McKibben , the founder of 350.org and author of "the Burnett graduated from SUNY Plattsburgh in 1999 with a BA in Fine Arts, and in 2006 with an MFA in Studio Arts from Maine College of Art. He has since exhibited his work across the United States and Internationally. In addition to painting, he is known for new media environmental installations in the Northeast US, including Mt. Desert Island, Saranac Lake, Portland ME, St. Lawrence University, and Weymouth Nova Scotia.

During 2017 he was a visiting fellow at Munich University of Applied Sciences, where he developed and auditioned his latest project, "Convergence."

He currently develops resources and workshops for 3-D printing, 3-D design and 3-D imaging. He has worked with several institutions on setting up 3-D resources and currently teaches courses on 3-D printing and Design at Munich University of Applied Science, St. Lawrence University and SUNY Canton

Michael A Wilson, SUNY Canton

My name is Michael Wilson. I attend SUNY Canton as a Graphic and Multimedia Design student earning my Bachelor of Science degree.

Mr. Anthony Filoso, State University of New York, Canton

I am a senior at SUNY Canton, I am a Business Management major with a minor in Sustainability. As apart of our project for ASEE, my focus has been on the financial feasibility of this project.

The Practicality and Scalability of Respooling 3-D printing Thermoplastics

Joseph Lopez, Logan Coggins, Michael Wilson, Joshua Staring, Raheem Pierre, Rebecca Martin, Ornessa Brown, Thomas Schofell, Elisha Byrd, Anthony Filoso

Advisors: Matt Burnett, Graphic and Multimedia Design; Robin McClellan, Renewable Energy Systems

Abstract

Considering the pervasive environmental problem of waste plastics, the development of Fused Filament Fabrication (FFF) must address the reusable potential of PLA and other thermoplastics. In this project the renewable potential of used thermoplastics with contemporary Fused Filament Fabrication (FFF) processes is examined. In examining the utility of existing methods for reclaiming plastics for FFF printing, we must A) determine the quality of reclaimed plastics, B) determine the achievable consistency of the reclaimed plastics, C) use this data to calculate the scalability of this process and its entrepreneurial potential.

In this project (a work in progress), which was supported by a grant through The New York State Association for Reduction, Reuse and Recycling Inc, the research team (comprised of undergraduate students) has acquired the respooling equipment (Filabot EX2 system), restructured the 3-D lab at SUNY Canton to collect and store used filament, and established a design of experiments statistical analysis for comparing print quality characteristics of the reprocessed filament to its factory standards. A cost analysis model has been developed to analyze the cost benefit and scalability of this process.

The overall goal is successful implementation of the Filabot equipment, establishing student protocols and workflows to collect and process the Polylactic Acid (PLA) filament for remelting, and working towards 0% PLA waste at SUNY Canton. A key aspect of this study is to be able to quantify the quality differences of the reprocessed filament. Some of the parameters being considered are: layer strength, layer quality, brittleness, moisture content, product consistency. Once this process is established, the data will be included in the cost benefit analysis. The resulting date will be published as a tool for other institutions handling their printing waste.

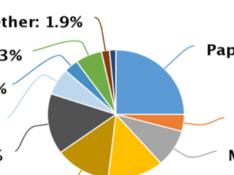

Figure 1. Total MSW Generated by Material, 2017. EPA.GOV

Outcomes

Successfully installing and testing the Filabot equipment

Measured by: installing the equipment and successfully remelting the test batches (Fall 2019).

Successfully establishing protocols to collect and store all recyclable pla waste

Measured by: establishing a clear measurement of how much pla waste is currently generated in all printer classrooms, and then performing this measurement at the end (The goal would be getting as close to 0% pla waste as possible).

Establishing a quality comparison between reclaimed PLA filament and brand-new PLA filament

Developed a statistical analysis model factoring layer quality, layer strength, print success, saturation, dehydration, print speed, and layer height. This data was printed and collected on three different printers in three different lab spaces in April 2020. These test were oriented toward answering hypotheses about the two types of filament---recycled and new (out-of-the-box) filament.

Successfully establishing the student workflow to remelt and process all pla waste

Measured by: student protocols will be developed by the research team, and checked by its advisors, Professors Robin McClellan and Matt Burnett.

Creating a cost/benefit analysis to understand the market viability of this for institutions (how many printers would need to be in used for this to pay for itself)

Measured by: Once the other goals are met/underway, this analysis would be developed with participation from students and faculty from the School of Business and Liberal studies. The students will be tasked to measure all of the costs (both internalized and externalized) and develop a plan for the most efficient and beneficial use of this equipment.

Methods

Figure 2. The Filabot remelting system Courtesy of Filabot 2020

Printing Procedure---Recycled Material

1. Select filament sample to be used. Take note of batch number, date produced, humidity content, and color.
2. Cross reference the usage records of the sample to reduce redundancy of tests, select test 3D model for printing (typically called a "Benchy", short for benchmark), and make sure enough filament remains for desired test.
3. Check the 3D model for errors/inconsistencies using your preferred modeling software (e.g., Meshmixer, Fusion 360, Sketchup). Repair the model as needed.
4. All slicing for different test runs should utilize the same model and when possible g-code to avoid inconsistencies in the model or software aspect. Prepare the model for production on your specific printer in a designated "slicing" program

Parameter	Description	"Standard" Value For PLA
Orientation	Orientation of model to the print-bed.	Base parallel to print-bed.
Temperature	Temperature of extruder(s) and print-bed (if heated)	215 °C Extruder(s) 45 °C Print-ded
Speed	Speed of extrusion, typically measured in mm/min.	3600 mm/min
Infill %	The amount of a repetitive structure used to take up space inside an otherwise empty 3D print (0% being no infill to 100% being solid plastic).	30%
Layer Height	The height of individual layers of filament used to build the model. Layer height and definition of a print share an inverse relationship.	0.3mm =lower quality 0.1mm =higher quality
Fan Speed	The speed at which cooling devices operate during the printing process.	Need Value "100"is indiscriminate to the general public
Moisture Content	Because filament is hydrophilic, we will establish a pre-drying protocol to minimize its influence	All filament for testing will be pre-processed in dehydrator

Figure 3. Parameters Considered in Qualitative Analysis of Quality between Reclaimed and New Filament

PLA Collection, Storage and Measurement

FFF printing happens in two locations at SUNY Canton and several departments use this process. Therefore, the management of pla purchasing, storage and waste is a considerable challenge. Developing consistent protocols and successful management and measurement of printing was an essential part of the project over 2019-2020.

From September to December 2019 the lab used several blue 5 gallon recycling containers to collect pla scraps. Additional signage was introduced to avoid cross contamination of garbage to pla or pla to garbage. Still, with no regular oversight of the vessels cross contamination continued and there is no clear accounting for what percentage of pla waste is collected. The amounts collected between 2018-2020 at SUNY Canton were weighed. They are mixed amounts of the following PLA filaments: Hatchbox, Esun and Gizmodorks. Using purchasing records we can isolate some colors that are all one brand, which is essential in understanding their chemical compositions (which vary from brand to brand).

Blue PLA 685.21 g Orange PLA 1546.94 g Tan PLA 130.94 g
White PLA 2875.76 g Green PLA 487.00 g

Total Collected 2018-2019= 5725.9 g

Moisture Content

This study began with the preconceived notions that moisture saturated PLA is detrimental to the print making process. Through our testing, along with research on the material properties of PLA, we have arrived at the following conclusions: If PLA is kept in storage for too long it needs to be re-saturated in order to gain back it's original quality for printing. Purchased PLA and recycled PLA differ in strength. When placed into a modified vise with a torque wrench providing the Pounds Per Square Inch (PPSI) to the controlled objects there was a 5 PPSI difference from the recycled control group. This correlates to a lesser layer strength of prints made from recycled PLA than the prints of purchased PLA. With further testing we hope to quantify this discrepancy and develop counter-measures to increase the quality of recycled PLA.

Extrusion of Pulverized Filament on the Filabot EX2

Over our test period in 2019 we have isolated the following key parameters that impact the utility of extruded plastic in terms of it being reused in FFF printers:

1) Moisture Content

2) Size of Pulverized Plastic

3) Consistency of Pulverized Plastic

4) Speed of Extrusion

5) Airflow

Figure 4. PLA filament collected at SUNY Canton 2018-2019

Further optimization is required in order to achieve a consistent diameter output. Being able to measure, monitor, and create consistent reclaimed rolls of filament is crucial for utility and further quality comparisons depend on this.

Pulverization/Grinding of Plastic

The used filament comes in a variety of densities and sizes. We have used an industrial sized paper shredder and scissors to reduce the material to a consistent size, which is tedious and not scalable to larger amounts of waste.

The mean amount of extrudable plastic pellets using This method was 18 grams of pellets per person per hour.

Figure 5. Using scissors for PLA pelletization

Ryobi Lawn and Leaf Shredder	Inconsistent size output, frequent jams reported $22 3
Scissor Manual Reduction	18 grams per person per hour too slow, tedious NA
Amazon Basics 15 sheet Cross Cut Shredder	Can shred CDs, credit cards, other consumers report utility for PLA $113
DIY Plastic Grinder	Too many variables and time demanding $100
INTBUYINGF 220V Heavy Duty Plastic Shredder Bottle Grinder	Too expensive, but may be useful for scaling up $1600

Balancing cost and projected use, we chose the AmazonBasics 15 sheet Cross-Cut Paper Shredder as the best solution for plastic shredding for the short term this semester. Once the cost benefit analysis suggests a market for managing more plastics a more industrial solution would be necessary for more volume.

AmazonBasics 15-Sheet Cross-Cut Paper, CD Credit Card Office Shredder:

15 sheet crosscut paper/CD/credit-card shredder
Shred size of 5/32" x 1-7/32" (4 x 31mm), security level P-4 20 minute continuous run time
Protection against overheating and overloading
LED indicators: Standby/Overheat/Overload/Door open/Bin full 6 gallon pullout basket; casters included
4-mode switch: Auto/Off/Forward/Reverse
Also destroys CD/DVD, credit-card, staples, and small paper Clips

Figure 6. The AmazonBasics 15 sheet crosscut shredder

Refined Protocol for Filament Extrusion

1. Run pulverized filament through the dehydrator
2. Purge the Filabot (using supplied pellets)
3. Set temperature to 180 C
4. Apply 1 cup of pulverized plastic
5. Engage worm gear
6. Record ambient temperature
7. Once extruding, adjust speed and fan power until consistent diameter is achieved
8. Begin spooling.
9. If there is a flaw noted, snip the roll, continue extruding and start a new roll
10. Record all information about time, temperature and machine settings and attach to the roll.

Cost Benefit Analysis

Formulas:

ARR = Accounting Rate of Return (percent of rate on return on an asset compared to initial cost) = %

Formula = Estimated Cost Savings (negative profit) / Initial Investment (actual machines)

Classification of costs:

DM = "Direct Materials", actual materials

DL = "Direct Labor" costs we can trace to cost object (such as labor processing),

OH = "OverHead" costs hard to determine how much of the machine cost goes into one roll

Benefits:

DM - Roll of recycled PLA = $21/Kg

DM - Savings on MSW disposal ~ $163 / ton = $0.18 / Kg

Costs:
Filabot $3,900 – OH
Grinder = $194.99 – OH
Dehumidifier = $38.67 – OH

Industrial space avg ($/ft^2) – OH COST (RENT)
- At an estimated 64 square foot of warehouse space, based on the national average of $6.53/ square foot, yearly cost would be $417.92
64 square feet x $6.53 per square feet = $417.92
Electricity = $ / Kg - OH
- Dehydrating
0.075KWh x $0.1930 x 1.00 hrs = ~ $0.014 / 1 KG roll
- Shredding
0.075KWh x $0.1930 x 1.5 hrs = ~ $0.022 / 1 KG roll
- Filabot: 75 watts
1 KG takes 45 minutes
- NY average KWh $0.1930 / KWh
0.075KWh x $0.1930 x 0.75 hrs = ~ $0.011 / 1 KG roll

Labor processing = ($/hr x hrs) – DL
- $15,000.00 salary allocated to professor of GMMD 495
- $15.00 / hour of pay for students involved in project (New York State minimum wage)

Labor collecting –
•1 Kilogram (Kilo) = 1,000 grams (g)
•Spring Semester 2018 – Spring Semester 2019 = 5725.9 g
•1 Semester = 15 weeks
•Work Time: 1 day/week x 8 hours/day = 8 hours/week
3 Semesters x 15 weeks = 45 weeks
5725.9 g / 45 weeks = 127.24 g/week
1,000 g / 127.24 g/week = 7.859163 weeks
8 weeks/semester = 1 Kilogram of collected PLA
8 weeks x 8 hours/week = 64 hours
How long it takes to grind and recycle through the Filabot?
- The shredding process takes approximately 90 minutes to shred 1 KG
- The dehydration process takes roughly an hour

Conclusions

1. Collection of 3-D printing material waste must be directly managed to achieve minimal contamination of foreign materials.
2. Moisture was found to have a measurable impact on some of the printing outcomes. Differences in layer strength and layer quality were consistently recorded corelating to moisture content.
   A. Completely dehydrating filament did not in of itself yield the best printing outcomes
   B. Re-saturating filament in water for 1.75 hrs (both new and recycled) improved printing outcomes
   C. Further testing is necessary to pinpoint the ideal moisture content for PLA
3. Given the projected cost of 550 kg of filament reclaimed via the Filabot to pay for all equipment, and the much smaller scale of filament waste available (we collected 5.7 kg over two years) on our campus, this study would recommend:
   A. The quality discrepancy between reclaimed filament and new filament (significant strength difference) must be addressed before it could be market ready.
   B. The reclaimed filament might be useful even with reduced quality for draft printing and other inhouse uses.
   C. At the present rate of consumption at SUNY Canton it is more cost effective to continue purchasing new filament rather then reprocessing used filament.
   D. The institution could expand to encompass filament reclaiming for more institutions in the region in order to reach profitability. The cost benefit analysis suggests that an increased production x96 (547.2 kg)would cover equipment costs.
   E. If reprocessing could be extended to more types of plastic (ABS, PTEG, other post consumer plastics) then more market potential could be achieved. This is at least technically possible with the Filabot EX6, although quality and scalability of this has not been examined in this study.

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