3-D Printing Filament Recycling and Reuse

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Abstract:

This Module will go through the processes involved in being able to repurpose failed 3D print projects, virgin print materials and unused 3D filament spools back into useable 3D printing filaments. Throughout the Module we will discuss topics that are critical and topics that are optional. Demonstrations will be shown for what acceptable finished processes would be for Part 1, Part 2 and Part 3 of this Module. When this Module is complete you will be able to extrude acceptable 3D printing filaments for use in standard fused filament fabrication (FFF), formerly known as fused deposition modeling (FDM), type 3D printers.

Objectives:

- To demonstrate how to recycle failed 3D print projects, created with fused filament fabrication (FFF), into standard filament sizes for use in FFF 3D printers.
- To demonstrate how to use virgin filament pellets to create standard sized filament for use in FFF 3D printers.

Student learning objectives:

- Learn about the processes required to convert failed 3D prints and virgin plastic pellets into useable 3D printing filaments.

- Learn about the viability of recycling 3D printed filaments to minimize material waste.

Keywords:

3D printing

Filament recycling

Filament extruding

Module data:

Type of Module: Demonstration in the classroom

Intended grade levels: Intermediate Schools (7-9), Secondary Schools (9-12), Post-Secondary and Vocational Schools

Time Required:

Part 1: Sorting of material and gathering enough material can range in time depending on the number of sources creating needed material. Minimum amount recommended would be 1kg (2.2lbs) of failed/scrap prints.

Part 2: Approximate time is one (1) hour from shredding to extrusion. Actual demonstration times will vary depending on student load and availability of equipment and materials. Additional time is needed for adjusting extrusion rates and filling filament spools. This demonstration can also be done with virgin resin pellets of the desired material.

Pre-requisite knowledge: Familiarity with FFF processes and the range of temperatures at which different filament types melt.

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Equipment and supplies needed:

- Filament Extruder (Felfill, Protocycler+ or FilaStruder)
- Filament Spooler
- Filament Recycler/Grinder (Generic blender, food processor or paper shredder)
- Sifter/Separator (Any type of grating with holes that are no larger than 5mm)
- Dehydrator
- Storage bin
- Failed 3D prints, unwanted 3D prints or virgin filament pellets
- Measuring tool (caliper)

Categories:

Additive manufacturing

Polymers/Plastics

Recycling

Curriculum overview:

Sorting 3D print materials for filament recycling purposes.

Preparing failed print and virgin filament materials for repurposing.

Adjusting filament extrusion to meet 3D print machine standards.

Cause and effect of filament recycling failures.

Instructor notes

- Before using this demonstration, make sure that all equipment and materials are in satisfactory working condition by prior to. Make sure that all scrap to be used is dried for a minimum of 12 hours prior to turning back into filament. Make sure

that all scrap has been properly sorted as mix-ins of different materials will cause filament failure when used in a 3D printing machine or during extrusion.

- This demonstration will primarily focus on reusing PLA filaments as it is the most common print material.
- Filament extruders and spooler setups vary across the manufacturers for process and price and will cost around $600 total for the two (2) pieces of equipment. There are DIY alternatives, but require a good deal of ingenuity and resources. This demonstration will show the general process of turning 3D scrap material back into useable filaments.
- Grinders or shredders can be used. An old paper shredder can be used on thin failed/scrap 3D prints or rafts and brims. Larger parts can be broken down using an old pillow case or bag that won't fall apart when hit with a dead blow (sand filled and soft faced) hammer or metal hammer. Please note that in using this method all proper PPE should be used such as protective eyewear and gloves. Blenders and food processors work well to turn larger pieces into smaller pieces. Blenders generally have a larger volume compared to food processors, but food processors have shown a more consistent breakdown of pieces to smaller sizes. When using a blender or food processor, make sure not to run the machine for too long or the material inside will begin to melt due to heat buildup in the material from being processed.
- Sifters/separators can be made or purchased. Household colanders with different mesh sizes can be used. 1" × 2" wood from a home improvement store with wire mesh can be used to create the necessary sifters. It is recommended to have at

least two (2) different sizes with the smallest mesh size being a maximum of 5 mm^2 or less than 0.25 in^2 openings. Shredded or ground materials larger than the smallest separating size mentioned before will need to be reground or shredded to get to the smallest required size. For sorting, you can stack the sifters/separators on top of each other from largest mesh (top) to smallest mesh (bottom) with all material reaching the bottom being of acceptable for use in the extrusion process. Any pieces of material that don't make it to the last separator will need to go through the appropriate shredder/grinder one more time to be reduced in size.

- Prior to the demonstration, you will want to set aside material that has been properly dried for a minimum of 12 hours in a food dehydrator. One of the other methods available is using a portable dehumidifier. However, drying times may vary greatly depending on the atmosphere, the amount of material being dried, the drying volume, dehumidifier capacity and electricity. If a dehydrator is not available, most classrooms are acceptable drying environments as long as there are no doors that lead directly outside or windows that are regularly left open for air circulation. Materials can be left in the classroom to air dry and achieve acceptable dryness. Other alternatives for drying are ovens, but most ovens do not offer temperatures below 100°C (212°F) and can cause the material to melt during drying. If the oven has a warm setting it will be warm enough to facilitate drying of the material without bringing the material to its melting point. Ideal temperatures will range between 49°C (120°F) and 60°C (140°F) for drying the material. If drying multiple layers of material, make sure to leave at least 4 cm

(1.5 in.) between the layers for air circulation. Drying times will vary for all setups and in most cases longer is better.

- Making sure that all the material is separated, dried, and properly sized to obtain the best results possible while re-extruding.
- This demonstration is best done once for an individual cohort to allow for a sufficient buildup of material for use. A standard spool of 1.75 mm and 2.85 mm filament weighs 1 kg (2.2 lbs.). Recycling and reuse of these materials yields approximately the same with differences in the yield from contaminants, humidity or inconsistent extrusion.

Module process

You will be going through the process of sorting, separating and recycling failed or unwanted 3D print projects back into usable filament for use in 3D filament printers. The topics that will be discussed are intentionally left open, for instructor to student discussion, through this handout as to why certain things happen with different materials or why a certain outcome happens. This is to encourage participation and to clarify topics that may be confusing or misunderstood to the students. Some of the stages of this demonstration should be completed prior to the actual demonstration of using your recycled 3D projects and/or virgin material pellets, but during this demonstration the instructor will go through the various stages of sorting and separating. This will lead to ideal results when creating your new recycled filament. Since there are several manufacturers of filament recyclers available and we can't demonstrate all of them, the general terms will be used. The reason for that is because the process of extruding

filament is similar for all manufacturers, but each manufacturer may have their own niche in the process that makes their process different from the rest.

Module procedures:

Abstract

This Module will go through the processes involved in being able to repurpose failed 3D print projects, virgin print materials and unused 3D filament spools back into useable 3D printing filaments. Throughout the Module we will discuss topics that are critical and topics that are optional. Demonstrations will be shown for what acceptable finished processes would be for Part 1, Part 2 and Part 3 of this Module. When this Module is complete you will be able to extrude acceptable 3D printing filaments for use in standard fused filament fabrication (FFF), formerly known as fused deposition modeling (FDM), type 3D printers.

List of supplies and equipment

- Failed or unwanted scrap 3D prints
- Virgin material (i.e. PLA, ABS or etc.) pellets
- Separators (i.e. mesh bottom containers, colanders or etc.)
- Storage bins
- Shredder/Grinder (i.e. Paper shredder, food processor, blender or industrial grinder)
- Dehydrator (i.e. desiccant, food dehydrator, oven or filament specific dryer)
- Filament Spooler
- Filament Extruder

- Dial/Digital/Vernier Caliper

PART 1: Sorting 3D print materials before filament recycling.

- In a general classroom environment, there are very few exact methods of identification possible for 3D print materials. This makes it more critical to maintain proper separation of materials. Maintaining good recycling habits with failed and scrapped 3D prints will help to make sure there are no contaminants within the different types of filaments.
- Prior to this demonstration in a class setting, materials should be gathered, separated and stored with the intention to use them as raw material. Failed 3D prints should be stored in separate containers for materials such as PLA, ABS or PETG.
    - There are subtle visual differences between common materials such as PLA and ABS. There are chemical differences between PLA and ABS that create a different smell in their molten state.
    - PLA is smoother looking and shiny while the colors are more saturated. PLA gives off a distinguishable burnt sugar smell due to its biodegradable nature when it reaches its molten state.
    - ABS colors are mostly matte with less intensive colors. ABS filaments have a chemical smell when it was molten.
- The next step after sorting the different types of filament would be to identify the size of the different pieces to determine which ones will need more processing. This process will make more sense in the next part of this Module when we start breaking down the materials to acceptable sizes for use in extruding filament.

PART 2: Breaking down the material to useable sizes for extrusion

- Gather material of different sizes, but of the same material type (i.e. PLA, ABS, PETG etc.).
    - Example: Ideally you will only be dealing with one type of filament at a time. Mixing filament types will cause issues for extrusion of the final filaments.
- Setup grinder/shredder or various sequences of machines to process the material to the desired size.
    - This is when you will be doing most of the processing of the filaments down to smaller pieces that are acceptable to use in the extrusion process.
    - If using a blender/food processor, you will want to make sure that you do not blend the materials for too long because they will generate heat and become pliable or soft and begin adhering to objects in the blender/food processor. While processing the material to smaller parts, consistency is key. Stirring up the containers to move larger objects to the bottom or pouring out the contents into strainers that have certain size openings to single out pieces that are too large to pass through is essential.
- Setup the different sizes of separators. It is ideal to setup the largest separator at the top and the smallest at the bottom. Material that reaches the bottom separator will be considered an acceptable size.
    - There are many different ways to use these separators. You can use a kitchen colander if it has the correct size openings. In most cases you will

want a minimum of two (2) different size opening colanders for this process. A larger one that allows some pieces that may only need to be broken down a little more and then a final one that has openings no larger than 5 mm or 2/10th of an inch.

- Separator alternative: you can use a few 1 in. × 2 in. wood pieces from a hardware store, cut them down to form a square frame and attach a mesh screen to the bottom. The mesh screens would be the openings that separate the pieces that can be used and the pieces that needs to be processed further into smaller pieces.
- Break down any pieces that are too large to be ground or shred. These large pieces can be broken down using a sturdy bag (i.e. pillow case or old sheet wrapped around the pieces or anything that won't break down during the hammering and leave contaminants in the final product) and smashed inside with a hammer. This is a crude method of bringing down these pieces to size, but it is one of the most effective methods that are available.
- It is a subjective opinion as to which pieces are too large to move on and need to be processed into smaller pieces, but the final goal is to have somewhat uniform ground pieces that are no larger than 5 mm or 2/10th of an inch in any given dimension (i.e. length, width and height). Refer to Figures 2.1, 2.2 and 2.3 for pictures of acceptable sizes of materials.
- After the pieces have reached their acceptable size of 5 mm or 2/10th of an inch they will need to be dried before reaching the extruding step.

Drying will help to prevent any excess moisture build-up from affecting the finished filament.

- There are several methods of drying that can be used. A food dehydrator is one of the most practical for the temperatures that are needed to dry the filaments. If the material doesn't need to be used right away it can be stored in a plastic box that has a locking lid with a seal and place reusable desiccant packs inside the plastic box with the material. The reusable desiccant packs passively absorb excess moisture. You can also use standard ovens, but it is advised to not put the filament into the oven until it has reached the appropriate temperature. However, most standard kitchen ovens are not able to consistently hold the low temperatures that are needed for drying filament and materials.
- Drying times will vary depending on the environment that the material will be able to dry in.
  - PLA should be dried at 122°F (50°C) for more than 3 hours.
  - ABS should be dried at 149°F (65°C) for more than 3 hours.
- Making sure that your material is dry prior to extrusion and use in a 3D printer makes for the most ideal scenarios, but just because the material was dry when it was made doesn't mean that it remained dry while it sat around. With each step in the process to making it to the 3D printer there are more chances for the filament to absorb moisture.

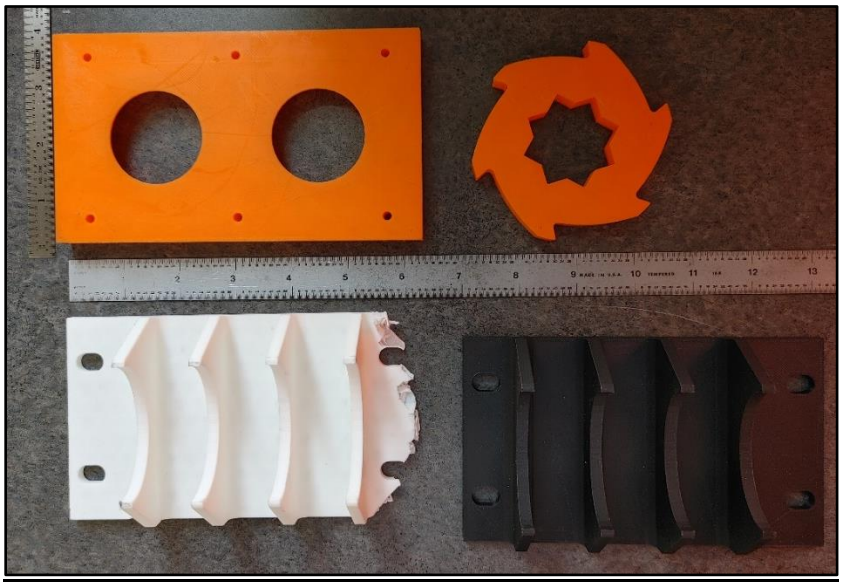


Figure 2.1: These failed prints are too large to be used for extrusion. The pieces are greater than 5 mm or 2/10ths of an inch in all dimensions of Length × Width × Height.

Figure 2.2: These previously shredded materials are still too large to be used for extrusion. Again, the pieces are greater than 5mm or 2/10ths of an inch in all dimensions of Length x Width x Height.

Figure 2.3:(Left) These previously shredded materials are acceptable for use in the extruding process. The pieces are under 5mm or 2/10 in. in all dimensions and are consistent in sizes.

(Right) These pieces are virgin pellets from a manufacturer, have never been extruded and are ideal for use in the extrusion process. You'll notice that the pieces are cylindrical in shape that has a diameter less 5mm or 2/10ths of an inch and an overall length that is less than 5mm or 2/10ths of an inch. As they are solid pieces, they make for a very uniform compression of material through the extrusion process.

PART 3: Setup and demonstration of filament extrusion and filament spooling

- This is the stage of the extrusion process to turn dried and shredded materials back into useable filament in 3D filament printers.
- Each setup will have its own unique method, but in most cases you have two (2) different orientations for these setups.
    - Vertical orientation
        - This setup will have the nozzle of the extruder pointing down to allow gravity to control the stretch of the material being extruded.
        - An example of this can be found at FilaStruder (https://www.filastruder.com/)
    - Horizontal orientation
        - This setup will have the nozzle of the extruder pointed to the side, with a slight sag to where the filament will be spooled. This method is more common because it doesn't not require a vertical mounting to a wall or framed structure and can be placed on any flat surface.
        - An example of this can be found at Felfill (https://felfil.com/?v=5ea34fa833a1) or Protocycler+ (https://redetec.com/)
- You will want to make sure that you have the correct nozzle in your extrusion setup prior to starting the extruding process.
    - 1.75 mm filament is the most common filament used in 3D printers with smaller build volumes.

- 2.85 mm filament is used with larger build volumes that exceed 250 mm × 150 mm × 150 mm.

  NOTE: depending on your specific setup, sometimes nozzles that are oversized or undersized are required to make the desired finished filament. In most cases, the default setup that the filament extruder was setup with is capable of making the correct filament size.

- With setup of the filament spooler or winder you will want to make sure that it is the appropriate distance away from the extruder that is specified by the manufacturer.
  - Too great of a distance and the filament will stretch to thinner sizes.
  - Too short of a distance and the filament won't have enough stretch and will be bigger than the desired size.
- With most spoolers or winders, you can use any old filament spools that you have from previous filament purchases because the spooler or winder will have an adapter to hold most common sized filament spools.
  - A filament spooler isn't necessary, but it does make the job easier in the end. You can have your extruder direct print to the floor or into a storage container if you decide to spool the filament at a later time.
    - If you decide to store the filament into a storage bin, don't forget to place a dehydrator within the storage bin. Remember that just because it was dry when you made it doesn't mean that it can't get wet before you use it.

- Within the previous two (2) pieces of equipment there may be a laser that measures the finished diameter of the filament being extruded and based on what size the laser reads during extrusion you can increase or decrease variable inputs to control the finish size of the filament. If your equipment doesn't have a laser to measure the size of the filament being extruded, you can use the caliper to measure the filament at its solid state. This is not ideal and may require you to snip and make much needed manual adjustments.
- Once you have your materials and equipment, we can start with the different parts of the filament extruder.
- **Figure 3.1** shows the general parts of a filament extruder.

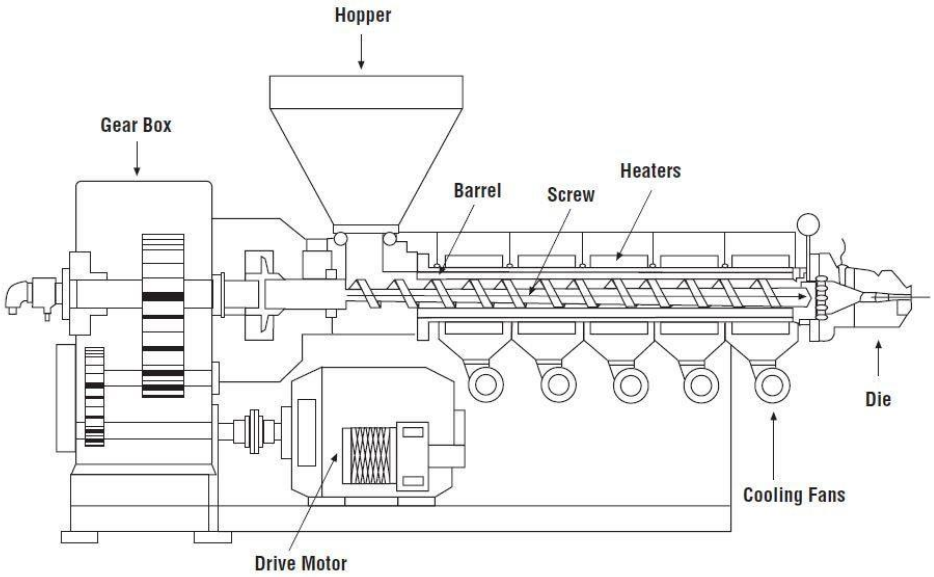
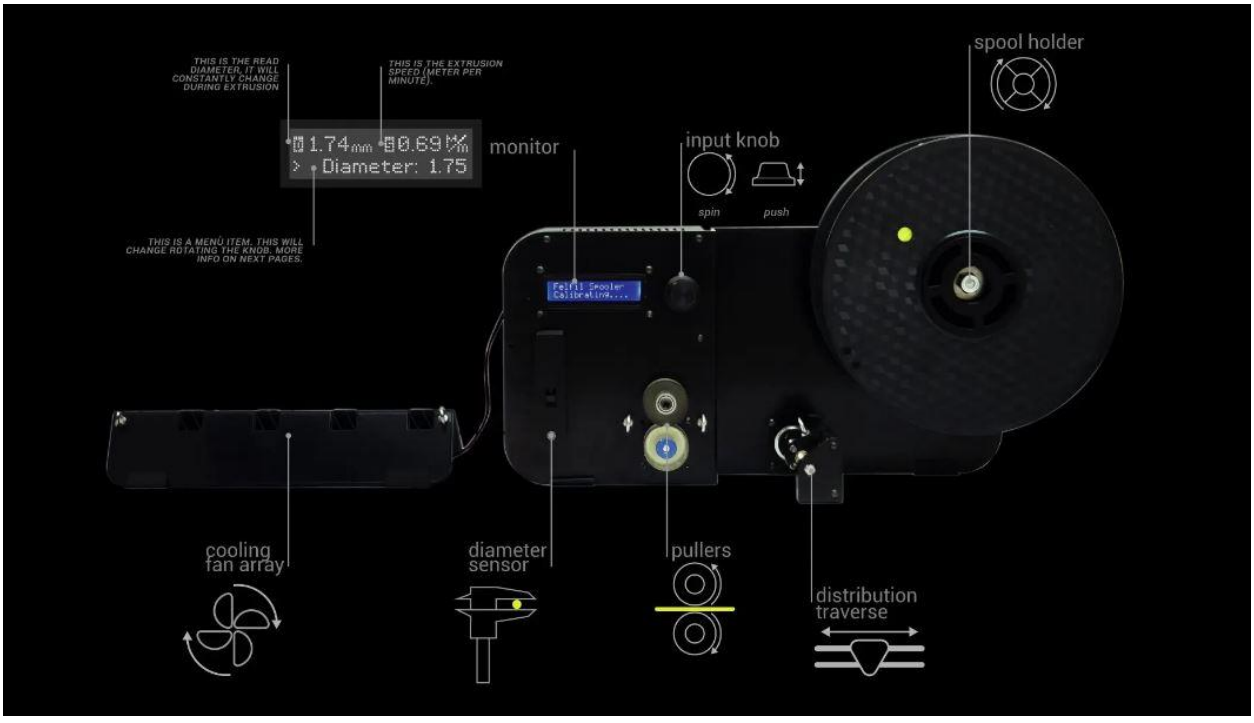


Figure 3.1:

- **Hopper**: the open mouth that you add/pour shredded material or virgin pellets.
- **Drive motor**: the engine that drives the screw to rotate and extrude.

- **Gearbox**: ability to multiply the power of the drive motor and reduce overall RPM's to a safe and manageable parameter.
- **Barrel**: the housing around the screw that retains the rotational pressure inside created by the screw.
- **Screw**: the part that rotates at a controlled speed to feed shredded material or virgin pellets through the heated section of the barrel where it meets the nozzle.
- **Heaters**: a small electric heating blanket that raises the temperature of the barrel so that the material inside can reach its molten state before it is compressed into the back of the nozzle.
- **Nozzle/Die**: the part that has a specific size hole in the center with a conical taper opposite of the hole to allow for the material to be fed.

- **Figure 3.2** shows the parts of a filament spooler manufactured by Felfill.



- **Figure 3.2:**
  - **Cooling fan array**: this is used to cool the filament being extruded back into a solid state to be measured by calipers or the diameter laser sensor.
  - **Diameter sensor**: measures the diameter of the filament being extruded as it passes by. With some machines this will also be used in determining how quick the spooler should turn the empty spool for the finished filament to wind on properly.
  - **Pullers**: adds tension to the filament to create the necessary slack in the filament to maintain a consistent size.
  - **Distribution traverse**: (optional) used to feed the filament across the opening of the spool instead of it spooling all in one place on the empty spool.
  - **Spool holder**: loaded with your empty spool to wind your recently extruded filament onto.
- With all parts setup, you will start by turning on the filament extruder and allowing it to warm up the heaters around the barrel. If you try to extrude too quickly before the barrel has enough time to heat up, there will be excess pressure going into the nozzle/die or air pockets from the material not being compressed together before being extruded. Below is a table of extrusion temperatures for the most common filament types provided from the manufacturer Felfill.

Material Type	Extrusion Temperature Range °C (°F)
PLA	187 °C (369 °F) – 210 °C (410 °F)
ABS	205 °C (401 °F)
PETG	210 °C (410 °F)

- Once the extruder has reached the required temperature, check to make sure that the motor, gear box and screw are operating. Most extruders have a common ON switch. Once the machine is ON and everything is running, you only need to adjust the RPM's of the screw and the temperature of the heaters.
- If everything is working properly, you can add/pour your material into the hopper.
    - Be careful not to flood the hopper and cause a jam in the mouth before the material even reaches the screw. This can cause air pockets during the extrusion process.
- After a short while of feeding the material into the barrel, filament should begin extruding from the nozzle/die.
    - If filament is not extruding, it may be because the barrel has not reached the appropriate temperature to melt the material. This is why it is important to have the extruder preheated and to have consistently shredded material.
    - Large sized material requires more heating time in the barrel to melt.
- Once the filament begins extruding, you will then feed the filament through a cooling fan array to bring the filament's temperature down to become solid.
    - Sometimes it is necessary to clip the first few inches of the extrusion due to contamination elements inside the nozzle/die. After you clip the end you should have more consistent filament being extruded to feed onto the spooler.

- During the extrusion process, your extruder may adjust the screw's RPM to increase or decrease the extrusion rate out of the nozzle. This adjustment would be determined by the laser sensor on the filament spooler that reads the current diameter of the filament being extruded.
  - If the filament coming out is too large than the RPM of the screw must be reduced because too much material is being forced through the nozzle/die.
  - If the filament coming out is too small than the RPM of the screw must be increased because too little material is being forced through the nozzle/die.

- When you have enough filament being extruded to feed through the cooling fan array, it will then have to be fed through the laser sensor for measurement, through the pullers and onto the empty spool.
  - When there is enough filament to attach to the empty spool, you can manually wrap the filament on the spool, tape it to the center of the spool or tuck the end of the filament into one of the holes that exists on most filament spools that is used to retain the ends of the filament during storage.
  - Make sure, whichever method you choose to attach the filament to the empty spool that it is secure because if it does not hold then the spooler will end up creating a loose and unmanageable spool of filament.

- If your equipment does not have a control to increase or decrease the RPM of the screw, it is possible to adjust the diameter of the filament by using the pullers on the spooler or gravity along the line of extrusion.
- Once you have adjusted all the necessary settings to get the correct size filament, all that is left is to continue feeding the hopper with shredded/virgin materials and keep an eye on the spooler to make sure that the filament continues to spool onto what was an empty filament spool.

References:

Filastruder (DIY setup of filament extruder and spooler)

www.filastruder.com

Felfil (Felfill EVO extruder and spooler setup)

https://felfil.com/

ReDeTec (Protocycler+)

https://redetec.com/

Green River College (Manufacturing Technology and Additive Manufacturing)

www.greenriver.edu

Student evaluation

1. Through all of the processes required in this demonstration, what do you think was the most important part to ensure a quality extrusion?
    a. ANSWER: acceptable answers will be the separation/sorting of materials, keeping the material dry before-during-after and consistent shredded/virgin materials.
2. Describe the process during the extrusion of the filament.
    a. ANSWER: shredded/virgin materials into the hopper, rotating screw feeds the material down the barrel into a heat zone that brings the material to a molten state. That is then forced through a nozzle/die.
3. What factors can cause separation in the filament during the extrusion process? (i.e. breaking in the filament or gaps)
    a. ANSWER: inconsistent feeding of material into the hopper, jamming of material in the screw and barrel, mixing of materials that have require different molten temperatures or the temperature of the heat zone is incorrect for the material being extruded.
4. Do different materials require different temperatures and different extrusion rates?
    a. ANSWER: Yes

Instructor evaluation

1. Were there any complications during the demonstration that **couldn't** be prevented?

2. Were there any complications during the demonstration that **could** be prevented
3. Is there any information that you feel would have been helpful to this demonstration?

Demonstration evaluation:

1. How would you rate the clarity of the professor? Did he/she seem knowledgeable?
2. How would you rate the content of this demonstration? Was it informative or practical?
3. Is there anything you would add to make this demonstration better?
4. Would you recommend this demonstration to a friend?
5. How would you rate the difficulty of this demonstration? In regards to understanding the process and terminology.

Acknowledgements:

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