3devo

MATERIALS MADE **SIMPLE**.

RECYCED PLA

Shredding and Extrusion Walkthrough

Our experiences with the recycling of 3D-printed ‘Natureworks 4043D’, which is a common grade of Polylactic acid (PLA). The material will be referred to as “PLA” in this report.

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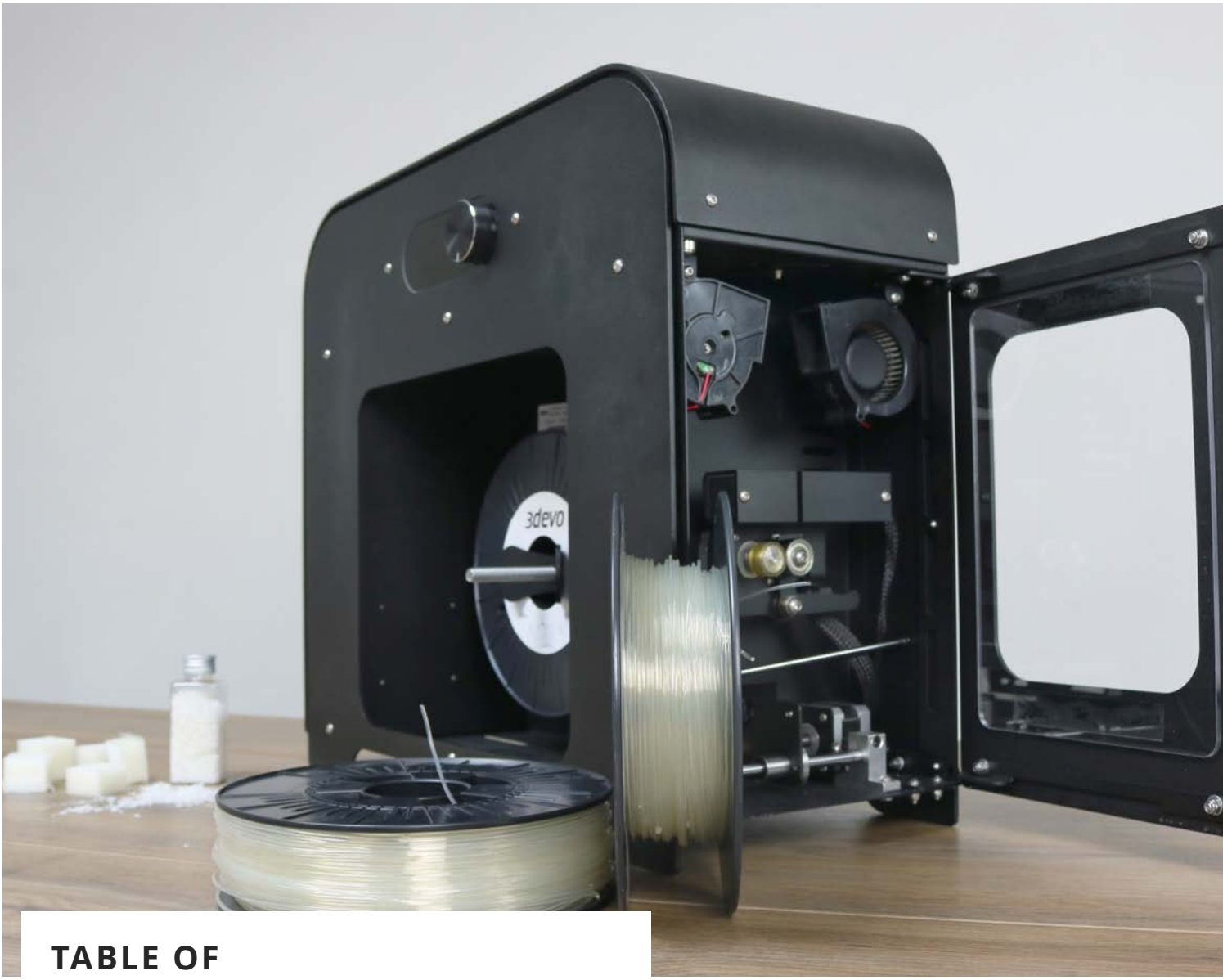

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PLA IN A NUTSHELL

- *Easiest 3D-printing material on the market*
- *Biodegradable*
- *Low processing temperature*
- *Fairly rigid but brittle, and has a low thermal resistance. That's why it is often not very suitable for end-use parts, but more fit for rapid prototyping, art, or decoration.*
- *Since it is a hygroscopic polymer, drying can increase the processing stability and product quality*

Figure 1 - *Products within the recycling process (Virgin PLA > Filament > 3D-prints > Regrind > Filament)*

1. INTRODUCTION AND CONTEXT OF THIS REPORT

This document guides the reader through the recycling extrusion process of PLA, performed in our test lab at 3devo. This process starts with virgin PLA pellets which are formed into 3D-printing filament using the 3devo Filament Maker. Then this filament was used to 3D-print small cubes (3x3cm). These 3D-printed cubes were recycled into new filament, by first shredding them and then extruding again. The products within this process can be seen in Figure 1.

The goal of the test was to show the entire recycling process with PLA using 3devo equipment. In this case 3D-printed cubes are recycled and made into **1.75mm filament**. This document describes the experimental process that led to the optimal settings and the best product quality. Please be aware that every material behaves differently, so this process might not be 100% applicable to all materials.

Chapter 2 describes the shredding step prior to extrusion. Chapters 3 to 6 explain more in detail the main experimental steps of the extrusion test itself, which consisted in a series of adjustments. It is crucial to note that the extrusion test was performed on a **Precision** machine equipped with a **4mm nozzle.** Chapter 7 gives an overall conclusion regarding the recyclability of PLA, and summarizes the entire report.

Figure 2 - *Picture of the SHR3D IT - Shredder in action*

2. SHREDDING

The shredding step was performed on the SHR3D IT (shown in Figure 2) equipped with a 4mm particle filter. This operation was rather straightforward.

In Figure 3 a close-up of the 3D-prints can be seen. Since these objects were fairly small (3x3cm), they fed into the shredder easily. The same figure also shows the regrind. This is the output product of the shredder. For this regrind it is important that the particle size is a maximum of 4 mm.

Figure 3 - *The 3D-printed blocks and the resulting regrind after shredding*

In some cases it might occur that the particle size distribution is very wide, and some particles exceed the maximum size of 4mm. A good way to fix this is by reshredding the regind (multiple times if necessary) so it has to pass through the 4mm particle filter once more. There is also an option of installing different filter screens in the shredder, for example a 3mm filter. This reduces the overall particle size, which could be benificial for some materials when feeding it into the filament extruder.

3. PREPARATION AND PRE-PROCESSING

PLA is a hygroscopic material, which means that it absorbs moisture from the air. When PLA contains too much moisture during extrusion this can cause hydrolysis, which means degradation under the influence of moisture and heat. This can cause output instability, bubbles, and an overall lower quality of the produced filament. To prevent this the material must be dried before extrusion. The **drying** was performed at **80°C for 4h** in the Airid Polymer Dryer, as shown in Figure 4.

Before the extrusion test of PLA regrind, there was still Devoclean Mid-temp left inside the machine from purging after the previous test. Transitioning from Devoclean to PLA regrind is possible since they have overlapping processing temperatures, but it can take a very long time since Devoclean has a much higher melt viscosity than the PLA regrind. That is when HDPE is used as a transitioning material. The transition between Devoclean and HDPE is fairly quick, as well as the transition from HDPE to PLA. This way less material is wasted in total.

The extrusion test here is started with virgin PLA pellets, to make the transition to PLA regrind even smoother. If you have the possibility to do this (you have access to the virgin pellets), it is always recommended to do this.

Normally when experimenting with a new polymer type we would set all heaters evenly around 10% above the melting point. Since the machine already contains good presets for this type of PLA, we will start using the PLA 1.75mm preset as a starting point.

WARNING **When experimenting with a new grade of plastic, it is of the utmost importance to introduce said plastic at temperatures high enough to ensure sufficient melting and to avoid the clogging of the machine.**

In Figure 5 is a picture of feeding the regrind in the hopper, after the hopper was completely empty and the screw was visible (this can also be done by cleaning out the hopper with a vacuum cleaner). When starting with a new material, it is always recommended to first put in a small portion (+/- 30 grams), so if anything goes wrong you won't waste a lot of material. Also the hopper grid has been removed here for better access, and the hopper empty check has been turned off in the settings menu. This will allow for smaller portions to be extruded without disrupting the process.

Figure 4 - *The Airid Polymer Dryer in action*

Figure 5 - *Feeding PLA regrind into the hopper*

Figure 6 - *Ratholing of PLA regrind in the machines' hopper*

4. EXTRUSION (1): STARTING POINT AND FIRST OBSERVATIONS

The following settings were used as a starting point during the extrusion test:

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	170°C	185 °C	190 °C	170 °C	3.5 RPM	80%

As mentioned before, the starting point here is the PLA 1.75mm material preset. This is done because these presets give very good results with PLA 4043D pellets. Since the regrind is the same material, the settings should not be far away from these presets.

THE FIRST RESULTS: The transition between PLA pellets and PLA regrind was almost invisible, because it is exactly the same material. The first produced filament looks perfect, but immediately the output flow started decreasing.

RATHOLING: Another phenomenon was observed, this time affecting the feeding. This phenomenon is known as rat holing: it generally affects powders and regrinds, it occurs when the formulation forms cohesive structures in the hopper, which do not flow properly down in the throat and therefore reduce the flow. This can clearly be seen in Figure 6. Carefully using a stick every few minutes to break the structure, or a continuously stirring device, can improve the feeding.

Figure 7 - *Better feeding using vibration and agitation*

5. EXTRUSION (2): AJUSTMENT STEPS

The objective was to find the optimal extrusion settings with the help of the filament sensor. The main issue was in this case proper and constant feeding of the regrind into the extruder. Ratholing prevents material from entering the screw, which causes a very low and inconsistent output, which makes it very difficult to create high quality filament.

3devo's R&D department is constantly researching the possibilities in order to improve the quality of its machines. For example for this phenomenon of bad feeding behaviour of regrind material. A first prototype has been designed which uses agitation and vibration to ensure proper and consistent feeding of regrind. In Figure 7 can be seen that with the help of the prototype, the ratholing disappears. At the same time the output flow of filament increases again. This prototype will in the future be further engineered so all our clients will have access to a better feeding mechanism for these type of input materials. Until then you will have to manually check every few minutes and break up the formed structure in the hopper.

Figure 8 is a picture taken during the adjustment phase, before the filament was of sufficient quality to be spooled.

FILAMENT FAN SPEED: Because the output of the filament was still slightly lower than with regular PLA pellets, it cooled down faster. This made the filament more rigid and more difficult for the puller mechanism to adjust the thickness. This is why the filament fan speed was decreased to 50%. This was just enough cooling to ensure sufficient solidifying, but maintains the stretchable nature of the soft molten material so the puller mechanism can do all the necessary filament thickness stabilizing work.

SCREW RPM: The screw rotation speed was eventually increased from 3.5 up to 4 RPM. This seemed to be the point where the melting process was stable, which also caused a stable output. Higher speeds such as 5 RPM seemed to be too fast to ensure a stable melting process, as the output was also fairly unstable.

TEMPERATURES: Heater 1 was increased with 5°C to increase output stability and melt homogeneity a bit.

CONTAMINATION: After taking a closer look at the produced filament, another major issue was found. In Figure 9 you can clearly see contamination in the microscope shot of the filament. This is caused by poor material handling prior to the extrusion. Tiny little dark spots indicate dust formulation inside the filament, and the big lump in the middle is a completely different material which did not melt at the PLA processing temperature. The lump in the middle is a piece of PET which ended up in the mix of regrind. This is probably due to improper cleaning of the shredder that was used. The test should be continued with clean material, which at least does not contain particles of different polymers, since these lumps can cause issues when printing with the filament.

Figure 8 - *Filament flowing freely during the adjustment phase, since the filament quality was not of sufficient quality yet to spool at this point*

Figure 9 - *Microscope shot of contamination in the PLA filament*

6. EXTRUSION (3): SPOOLING

The filament was spooled using the final settings found during the adjustment phase:

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	170°C	185 °C	190 °C	180 °C	4 RPM	50%

Figure 10 is the graphical representation of the datalog which corresponds to the produced spool. It shows that the filament thickness was very stable during the entire spooling process (which in this case only starts around 3000 since we did not shred that much regrind), rather well kept within the usual industry tolerance (1.75 ± 0.05mm). The beginning of the log is very unstable. This is the point where ratholing occurred.

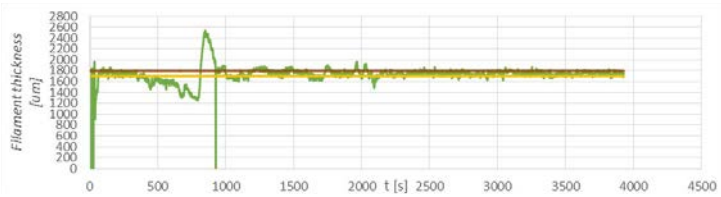

Figure 10 - *Datalog: filament thickness (set value : 1.75mm, red line : 1.80mm, yellow line : 1.70mm)*

Figure 11 - *Half a spool of recycled PLA, with some contamination*

7. CONCLUSION AND RECOMMENDATIONS

The conclusion of this test is that very good quality filament can be obtained if certain things are taken into account. It is very important to keep the batch of PLA clean, and free from contamination such as dust or pieces of different polymer. To increase the quality of the produced filament, it is also important to dry the material to prevent hydrolysis (degradation), and ratholing in the hopper has to be broken up or prevented, to ensure consistent feeding. While taking these things into account, 1.75mm filament of good quality was obtained using a Precision equipped with a 4mm nozzle. Even though the 3D printing of this filament remains to be investigated in order to close the loop and print parts of good quality, it can be said that the material can be extruded quite easily when the right parameters are found, and that the resulting filament's thickness is well kept within industry tolerance standards (+/- 50 microns). In Figure 11 the produced half spool can be seen, this contains a bit of contamination. For the next spool this can be prevented by cleaning the shredder more properly.

REPORT SUMMARY:

TO DOs:

- Transition using raw PLA pellets
- Dry the material at 80°C for at least 4h in a dryer or an oven
- When having to transition to PLA from another material, it is recommended to use HDPE as a sub-transition

WARNINGS:

- Use the shredder and the extruder with great care : blades and heat are involved
- Watch out for impurities (dust mostly) during shredding and storage, impurities will lower the quality of the final product
- It might be necessary to adjust the fan speed depending on the room conditions
- Rat holing must be taken care of regularly by stirring in the hopper manually or with the help of a continuously stirring device

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	170 °C	185 °C	190 °C	180 °C	4 RPM	50%