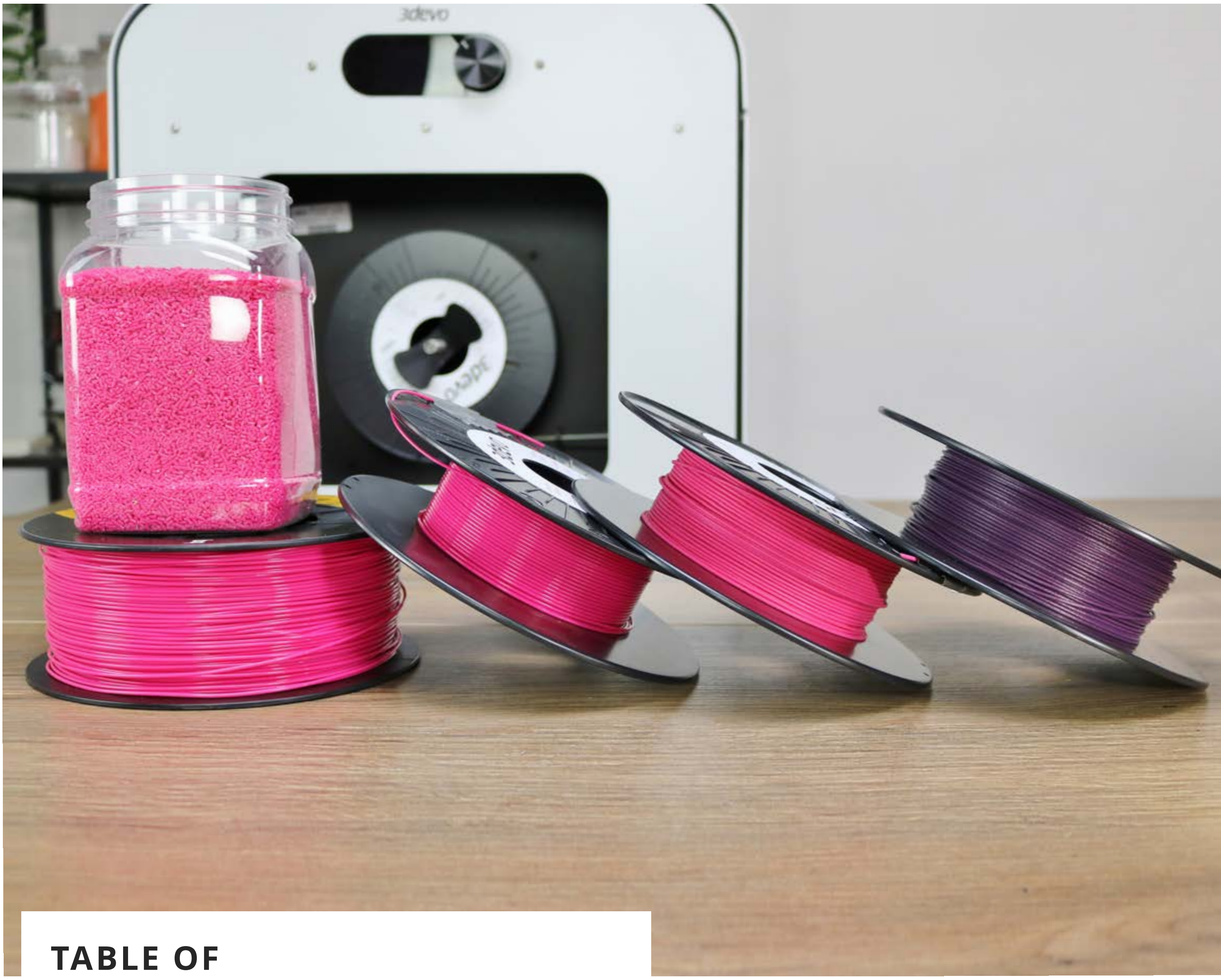
3devo

MATERIALS MADE **SIMPLE**.

RECYCLING **PLA** WITH GLASS POWDER / CARBON FIBER

Shredding and Extrusion Walkthrough

Our experiences with the shredding and extrusion of bq PLA 3D-printer filament, a grade of Polyactic Acid (PLA). The material will be referred to as “PLA” in this report. The material is to be recycled virgin, with glass powder (“GP”), and with carbon fiber (“CF”).



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PLA IN A NUTSHELL

- *Pink color (This one specifically)*
- *Commodity thermoplastic for generic 3D printing applications*
- *Low thermal range (typically below 200°C)*

1. INTRODUCTION AND CONTEXT OF THIS REPORT

This document guides the reader through the shredding process and extrusion process of PLA, performed in our test lab at 3devo. It describes the experimental process that led to the optimal settings and the best product quality.

The goals of the test were to:

- Recycle spooled filament of virgin PLA into 1.75mm recycled filament
- Add two different fillers: GP (glass powder) and CF (carbon fiber)
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Figure 1 is a picture of the original spools provided in a cardboard box.

Chapter 2 describes the shredding step prior to extrusion. Chapters 3 to 7 explain more in detail the main experimental steps of the extrusion tests themselves, with and without additives. This phase 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**. The results are analyzed in Chapter 8; and Chapter 9 gives an overall conclusion regarding the recyclability of PLA, and summarizes the entire report.

Figure 1 - *Batch of bq PLA 3D-printer filament spools*

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. The filament was unspooled from its original spools, as shown in Figure 3, and fed in the shredder.


Figure 3 - *Spool of bq PLA 3D-printer filament being unspooled manually*

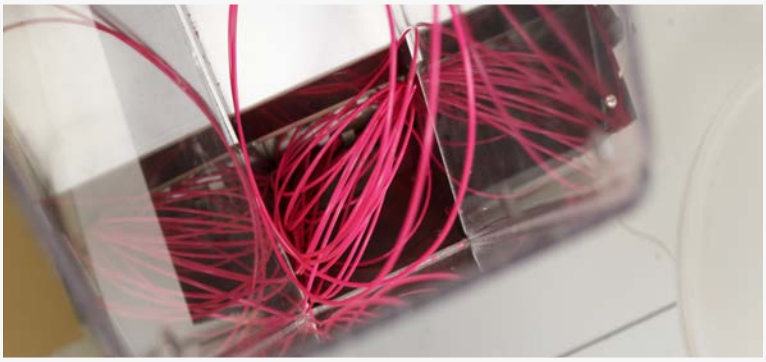
Figure 4 - *Feeding the SHR3D IT*


Figure 5 - *First sample of regrind coming out of the SHR3D IT*


Figure 6 - *Size and shape comparison between PLA regrind (left), PLA regrind after a second shredding step (center), and standard pellets (right)*


Figure 7 - *Overview of the regrind*

Figure 5 is a picture of the first sample of regrind that was obtained after a few moments of shredding. It shows that the quality (homogeneity) of the regrind was good except for a few notable particles which managed to exit the shredder despite their size bigger than 4mm. The reason is that these bits of filaments were longer than 4mm in length, but smaller than 4mm in diameter, which is why the filter screen could not stop all of them.

RESHREDDING PLA: *When plastic bits bigger than the filter size remain, it is possible to shred the regrind again in order to increase the homogeneity of the particle size. This step is extremely easy and straightforward since the first regrind flows fast down the hopper of the shredder. Shredding a batch of material a second time usually only takes a few minutes. A second shredding step can be very beneficial : a more homogeneous regrind will result in a more stable flow during the extrusion step, and subsequently in a better filament quality.*

Figure 6 is a picture meant to compare the shape and size of the PLA regrind to standard pellets commonly used in extrusion for good quality results. It can be seen that the particle size distribution of the regrind is rather narrow, and that the particle size is similar or inferior to standard PLA pellets, which is a first indication that the plastic will feed and melt easily in the extruder. Figure 7 shows that the whole batch of regrind looks homogeneous, but it contains several significant impurities (dust). Shredding the material several times and/or installing a 3mm filter on the shredder can help the user obtain the desired quality of regrind.

3. PREPARATION AND PRE-PROCESSING

The material was supplied in a cardboard box, unprotected from moisture. Drying is typically not a crucial step when trying to process PLA-based formulations, but is sometimes recommended. As explained below, good results were obtained without drying the material. If the user faces moisture-related issues, a drying step can be implemented: 65°C for 2h in our Dryer Airid.

Before the extrusion test, the machine was purged with the following compounds:

- Devoclean MidTemp to clean the barrel thoroughly
- HDPE to transition more easily to PLA
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This purging/transitioning process was performed at 200˚C (all four heaters). PLA was then introduced at 200˚C.

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.

Figure 8 illustrates the transition from HDPE to PLA. The transition only took a few moments, it was sudden and clearly visible.

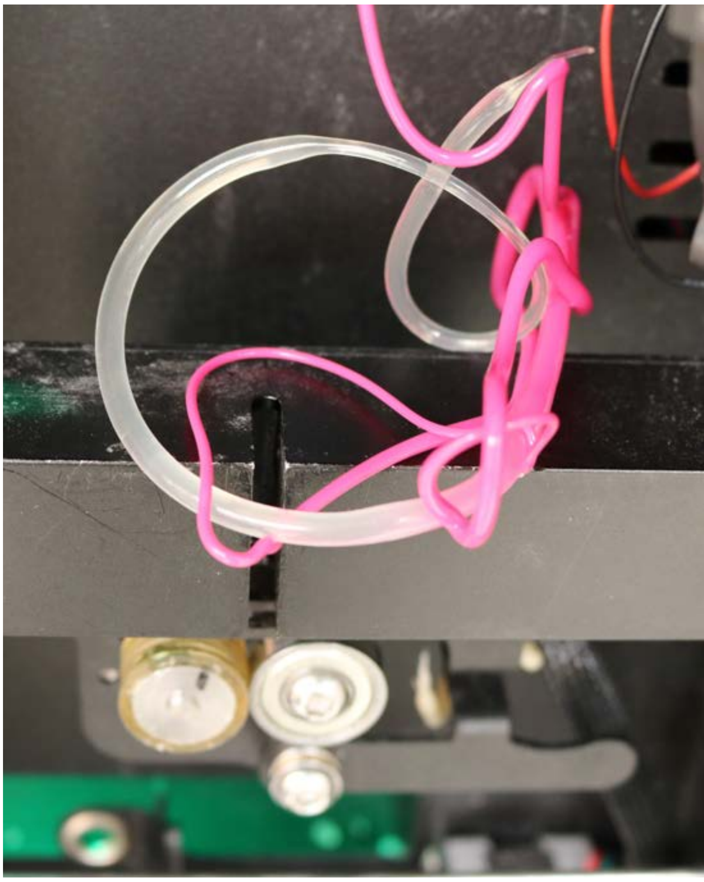

Figure 8 - *Transition from purging HDPE (transparent) to PLA (pink)*

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

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

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	200 °C	200 °C	200 °C	200 °C	5.0 RPM	50%

WHY 200°C? As mentioned earlier, it is wiser to start at a temperature that is too high, to avoid the clogging of the machine. For most grades of PLA, 200°C is on the high end of the thermal window of operation.

WHY 5.0RPM AND 50% FAN SPEED? These values are very often appropriate values to start experimenting with a new material. In order to extrude stable filament of 1.75mm thickness, the best rotation speed is usually found between 3.0 and 7.0 RPM, which is why the starting value of 5.0RPM is always a good start. As far as the fan speed is concerned, it is harder to define an ideal percentage that works by default, because this parameter can vary a lot; it is good to start with a medium value and be ready to make quick adjustments.

THE FIRST RESULTS: The transition from HDPE was smooth and fast, the flow did not seem to be much disturbed. The flow appeared to be rather stable but the extrudate was slightly too liquid : it was hard to pull it properly because it was wobbly and flattened by the puller. The surface of the filament was smooth, and only a few bumps could be seen, probably caused by the presence of impurities in the regrind.

5. EXTRUSION (2): AJUSTMENT STEPS AND SPOOLING (VIRGIN PLA)

The objective was to find the optimal extrusion settings with the help of the filament sensor. The main issue was that the extrudate was too hot, resulting in the flattening of the filament by the puller wheels.

FILAMENT FAN SPEED: Because the extrudate was too hot when reaching the puller, the correct approach was to increase the fan cooling percentage. Several options were tested and seemed to work **between 80% and 100%.**

SCREW RPM: The screw rotation speed was kept on **5.0RPM** in order to achieve a steady flow, maintain just enough pressure inside the barrel, and process recycled filament reasonably fast

TEMPERATURES: All temperatures were decreased gradually, 5°C by 5°C, down to **190°C,** point at which the quality of the filament looked sufficient for it to be spooled: the material seemed to melt neither too soon nor too late inside the barrel (this is the optimal situation to obtain a stable flow).

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

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	190 °C	190 °C	190 °C	190 °C	5.0 RPM	100%

A spool was successfully manufactured using these settings, as shown in Figure 9.

Figure 9 - Final spool of recycled virgin PLA

6. EXTRUSION (3): EXPERIMENTING WITH GLASS POWDER (PLA+GP)

2.5% (weight) of GP were added to the batch of PLA regrind. A new experiment was performed, applying the same method as previously. This time the extrudate seemed a bit more fluid than when PLA was virgin. The most likely reason is that the glass powder present in the melt is mechanically tougher than the plastic, it therefore concentrates the stretching in the weak points of the extrudate. The right strategy was to decrease the temperatures more than previously, and decrease the screw speed slightly, in order to give more time to the extrudate to cool down.

The surface of the resulting filament was slightly rougher than the virgin PLA, but the overall quality and flow stability were very good.

The following settings were used to spool PLA+GP :

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	180 °C	185 °C	185 °C	185 °C	4.8 RPM	100%

Figure 10 shows the PLA+GP blend in the hopper of the extruder; Figure 11 is a picture of the PLA+GP spool.

Figure 10 - *Feeding the PLA+GP blend in the hopper of the extruder*

Figure 11 - *Final spool of GP-filled recycled PLA*

7. EXTRUSION (4) : EXPERIMENTING WITH CARBON FIBER (PLA+CF)

3.0% (weight) of CF were added to the batch of PLA regrind. The same experimental approach was applied. The behavior of the blend was very similar to the PLA+GP. The surface of the resulting filament was slightly smoother, but the color clearly turned to purple.

PLA+CF was spooled using the following settings:

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	185 °C	187 °C	187 °C	187 °C	4.7 RPM	100%

Figure 12 shows the PLA regrind and 3%w of CF in a jar before they were mixed; Figure 13 is a picture of the PLA+CF spool.

Figure 12 - *PLA regrind and 3%w CF in a jar, before they were mixed*

Figure 13 - *Final spool of CF-filled recycled PLA*

8. ANALYSIS OF THE RESULTS

Figure 14 is a microscope shot which shows the surface quality of the obtained filaments. It can be said that the filament of recycled virgin PLA is smooth and homogeneous. The two filled filaments have a rougher texture which should not disturb the printing. All three samples contain a few particles of dust that make the surfaces slightly bumpy in certain minor areas (spots on the surface).

Figure 14 - *Microscope shot of (top to bottom): recycled virgin PLA, recycled PLA+GP, recycled PLA+CF*

Figure 15 is the graphical representation of the datalog which corresponds to the produced spool of recycled PLA + GP. It shows that the filament thickness was rather stable during the entire spooling process, well kept within the usual industry tolerance (1.75±0.05mm). The turbulence around 3200s corresponds to a user action which disturbed the spooling process momentarily.

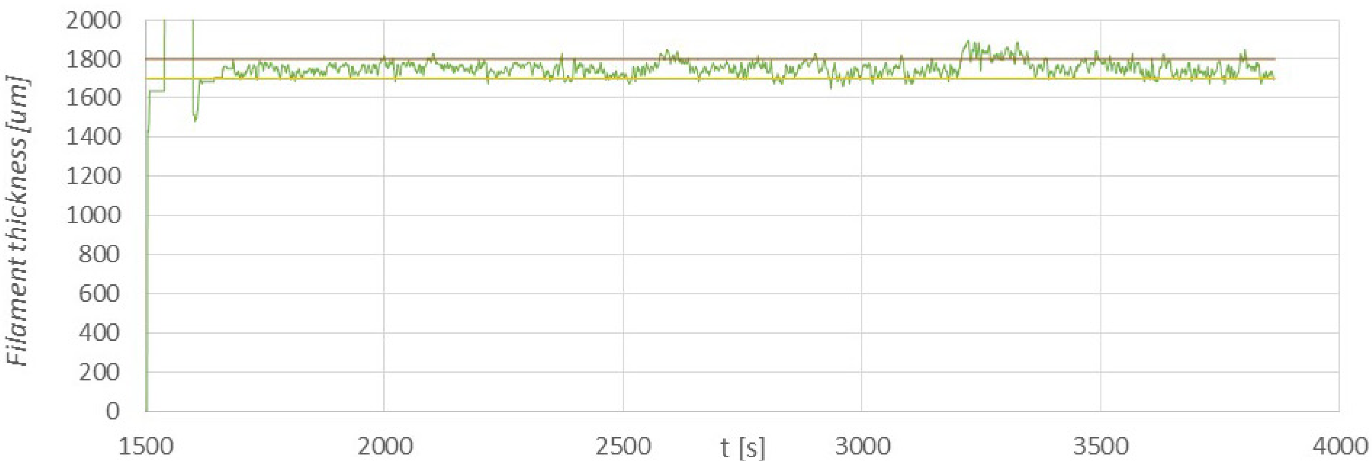

Figure 15 - *Datalog: Screw rotation speed (RPM*100) (set value: 7.0RPM)*

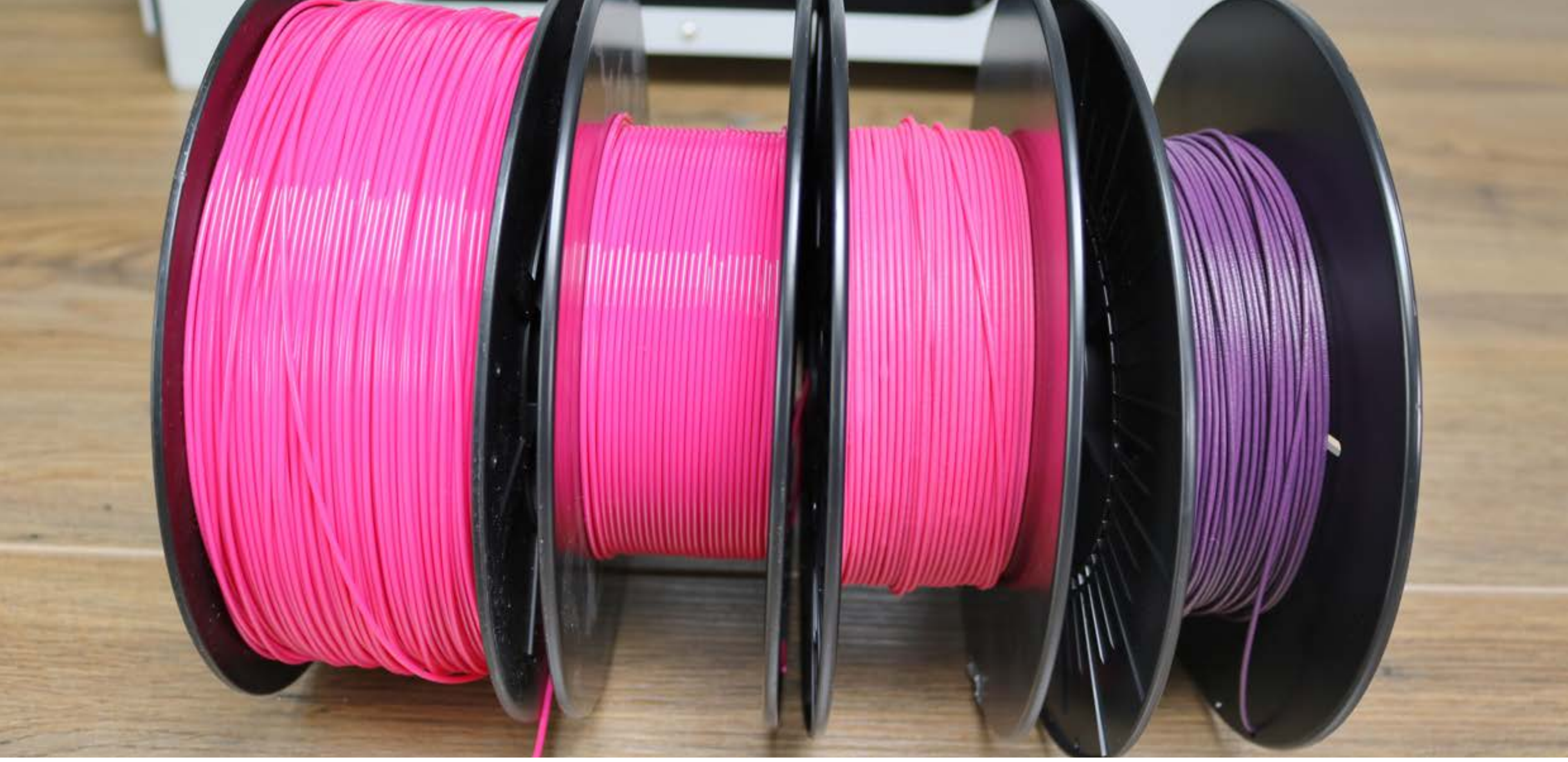

Figure 16 - *Left to right: original spool of bq PLA 3D-printer filament, recycled virgin PLA filament, recycled GP-filled PLA filament, recycled CF-filled PLA filament*

9. CONCLUSION AND RECOMMENDATIONS

This extrusion experiment was extremely positive. Indeed, 1.75mm filament of great 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 excellent quality, it can be said that the material can be shredded and extruded very easily, without facing any major issue, and that the resulting filament's thickness is well-kept within industry tolerance standards (+/- 50 microns). Moreover, fillers were successfully added to the recycled matter: glass powder and carbon fiber. The fact that the material could be processed at relatively low temperatures made the launching of the process a fast operation. Figure 16 is a picture of several spools which were obtained at 3devo in several days of testing.

REPORT SUMMARY:

TO DOs:

- Keep temperatures around 190°C for optimal quality
- Drying is not mandatory, but can be implemented if moisture-related are faced at one point during the experiments
- Purge thoroughly after extrusion using Devoclean MidTemp (at the processing temperatures)
- Transition back to PLA with HDPE first. This is not mandatory but will save some PLA

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
- Be careful when working with fine particles like powders and carbon fibers