3devo

MATERIALS MADE **SIMPLE**.

RECYCLING **PP** INJECTED WASTE

Shredding and Extrusion Walkthrough

3devo's experience with the shredding and extrusion of Polypropylene (PP) injected waste.

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PP IN A NUTSHELL

- *Transparent to white*
- *Highly crystalline unless the process is specifically designed to manufacture amorphous parts*
- *Drying is typically not required because PP is not hygroscopic*
- *Rather low heat resistance (Typical glass transition temperature = 0°C, Typical melting point = 160°C)*

1. INTRODUCTION AND CONTEXT OF THIS REPORT

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

The goal of the test was to recycle deep well plates made of injected PP for genomics applications, into several spools of **1.75mm filament**. Figure 1 is a picture of the initial batch of injected parts (the colored parts and most of the large deep well plates were set aside because they were found to be quite complex to shred, as explained later).

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 **2mm nozzle**. Chapter 7 gives an overall conclusion regarding the recyclability of the PP injected waste, and summarizes the entire report.

Figure 1 - *Batch of injected waste, some of which was already precut (as explained in Chapter 2)*

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

2. SHREDDING

The shredding step was performed on the SHR3D IT (shown in Figure 2) equipped with a 4mm particle filter. The initial injected parts being too wide in size to be properly fed in the shredder. Feeding the initial parts was found to be possible but time-consuming and troublesome. The solution to speed up the shredding process was to manually cut the bigger parts into smaller pieces using conventional office scissors, this operation took approximately 15min.

Figure 3 - *Feeding the SHR3D IT*

Figure 4 - *First sample of regrind coming out of the SHR3D IT*

Using this method, the feeding of the shredder was then very easy, and the shredding process quickly gave good results. Figure 3 is a picture of the feeding step, which shows that pre-cutting the parts into smaller pieces results in the good filling of the hopper.

Figure 4 is a picture of the first sample of regrind that was obtained after a few moments of shredding. It is known by experience that shredding a regrind again into even smaller bits can improve the feeding step during extrusion. In addition to being beneficial for the stability of extrusion, re-shredding a regrind can be done extremely quickly because the regrind flows much better than the initial parts into the throat of the shredder. Figure 5 shows that re-filling the hopper with the first regrind can be done easily, Figure 6 is a picture of the partially fed hopper. This second shredding step only took a few minutes.

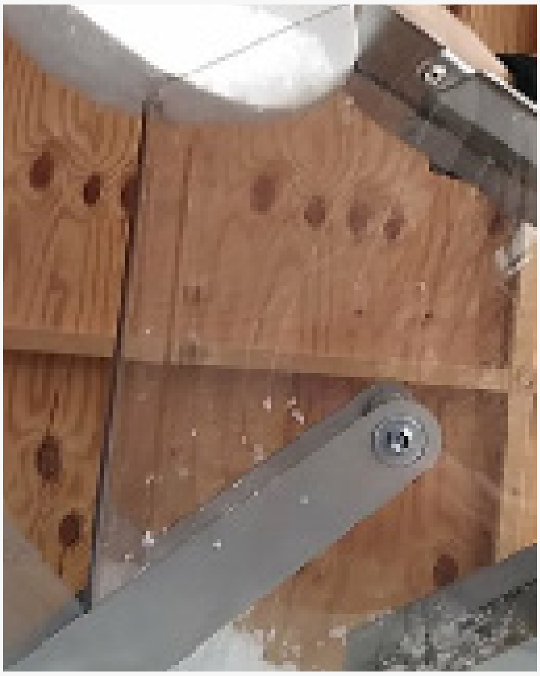

Figure 5 - *Easy feeding of the regrind for a second shredding step*

Figure 6 - *Hopper partially full of regrind*

Figure 7 - *Size and shape comparison between regrind (left), second regrind (center), standard PLA pellets (right)*

Figure 7 is a picture meant to compare the shape and size of the first regrind, the second regrind (after a second shredding step), and standard Polylactic Acid (PLA) pellets commonly used in extrusion for good quality results. It can be seen that the particle size distribution is narrower in the second regrind, and that the particle size is inferior to standard PLA pellets, which is a first indication that the plastic will melt easily.

3. PREPARATION AND PRE-PROCESSING

The material was supplied in a cardboard box. PP being a non-hygroscopic material, it typically does not need to be dried prior to extrusion.

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

- Devoclean MidTemp to clean the barrel thoroughly
- HDPE to transition more easily into PLA
- PLA to transition more easily into PP

This purging process was done at 200˚C (all four heaters).

PP was then introduced at 200˚C.

Figure 8 is a picture of the feeding, Figure 9 illustrates the transition from PLA to PP. The transition results in a rather white and opaque extrudate, which then becomes more transparent and colorless.

Figure 8 - *Feeding the second regrind into the hopper of the extruder*

Figure 9 - *Transition between purging PLA (transparent extrudate at the bottom) and PP (semi white and opaque extrudate above PLA)*

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	200 °C	200 °C	200 °C	200 °C	5.0 RPM	50%

Why 200°C ? In the case of PP, a typical melting temperature would be around 160°C. It is not uncommon for regrinds to require a processing temperature slightly inferior to the processing temperature of their virgin counterpart. However, the strategy is to start at a higher temperature (200°C) to ensure a fully melted flow during the transition. It is indeed important to prevent the clogging of the machine before starting to adjust the settings.

Figure 10 - Rat holing occurring in the hopper

The resulting flow seemed to be sufficient and quite consistent, but a phenomenon called rat holing was noticed in the hopper, and the very fast crystallization of the material was found to be a minor issue.

RAT-HOLING? As shown in Figure 10, rat holing (or tunneling) describes a situation where the material does not flow homogeneously into the throat of the extruder. This is due to the jagged shape of the regrind and to its tendency to adhere electrostatically. This phenomenon can be fixed temporarily and with great care by stirring in the hopper using a stick.

WARNING: no fix has been found to prevent rat holing permanently, which means that it occurs repeatedly every few minutes. This issue is extremely common when dealing with any kind of regrind, and may lead to flow inconsistencies if left unchecked.

PP CRYSTALLIZATION? The molecular structure of PP makes it a highly crystalline polymer, unless it is processed specifically to obtain highly amorphous parts. During this extrusion test, two filament fans were cooling down the extrudate by blowing air on it from two sides. PP crystallized too fast and anisotropically, because it was being cooled down from two opposites sides only, not isotropically, as shown in Figure 11. The result of anisotropic crystallization is that the filament becomes oval. The solution was to mount a special cooling accessory which made the airflow circular. This prevented the anisotropic crystallization. Figure 12 is a picture of the final setup with the circular cooling device.

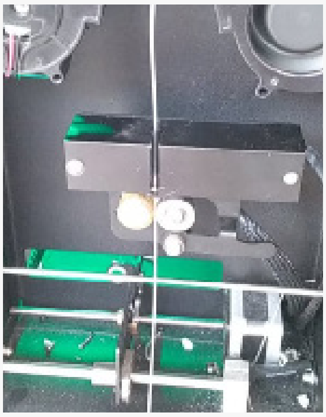

Figure 11 - Setup by default, the filament fans blow on the extrudate from two opposite sides

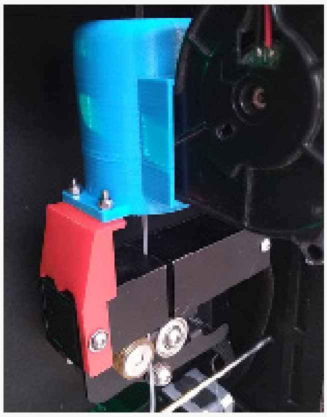

Figure 12 - 3D printed device mounted for circular cooling, only one fan is then being used

5. EXTRUSION (2): AJUSTMENT STEPS

The objective was to find the optimal extrusion settings.

SCREW RPM: The screw rotation speed was kept at **5.0RPM.** This is by default a usually appropriate value to extrude 1.75mm filament out of a 2mm nozzle. One trial was attempted at 4.5RPM but the flow was found to be more inconsistent.

FILAMENT FAN SPEED: As described before, circular cooling was required in order to avoid anisotropic crystallization. The Precision being equipped with two fans, the fan speed (%) applies to both fans, but only one of them blows into the circular cooling device. The optimal window of fan cooling percentage was found to be **10% to 20%**:

- More fan cooling (>20%) led to the early solidification of the extrudate, which could therefore not be kept straight (vertical) enough, making the pulling highly unstable.
- Less cooling (<10%) did not allow the filament to solidify before reaching the puller. This resulted in the flattening of the filament by the force of the puller wheels.

TEMPERATURES: Starting from 200˚C (all heaters), the temperatures were then gradually decreased down to 160˚C in order to get the complete overview of the window of operation. The following series of settings was used:

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value (1)	200 °C	200 °C	200 °C	200 °C	5.0 RPM	50%
Set value (2)	190 °C	190 °C	190 °C	190 °C	5.0 RPM	25%
Set value (3)	180 °C	180 °C	180 °C	180 °C	5.0 RPM	25%

During these trials, the extrudate was slightly too liquid to be pulled properly, and it contained bubbles, as shown in Figure 13. The presence of bubbles in a non-hygroscopic plastic often indicates that air is being trapped inside the plastic. In that case, the explanation is that the polymer melts too soon in the barrel, preventing some of the air from traveling “backwards” and out of the hopper. To fix this issue, the usual solution is to decrease the temperature in the first half of the extruder, especially the first heater (H4).

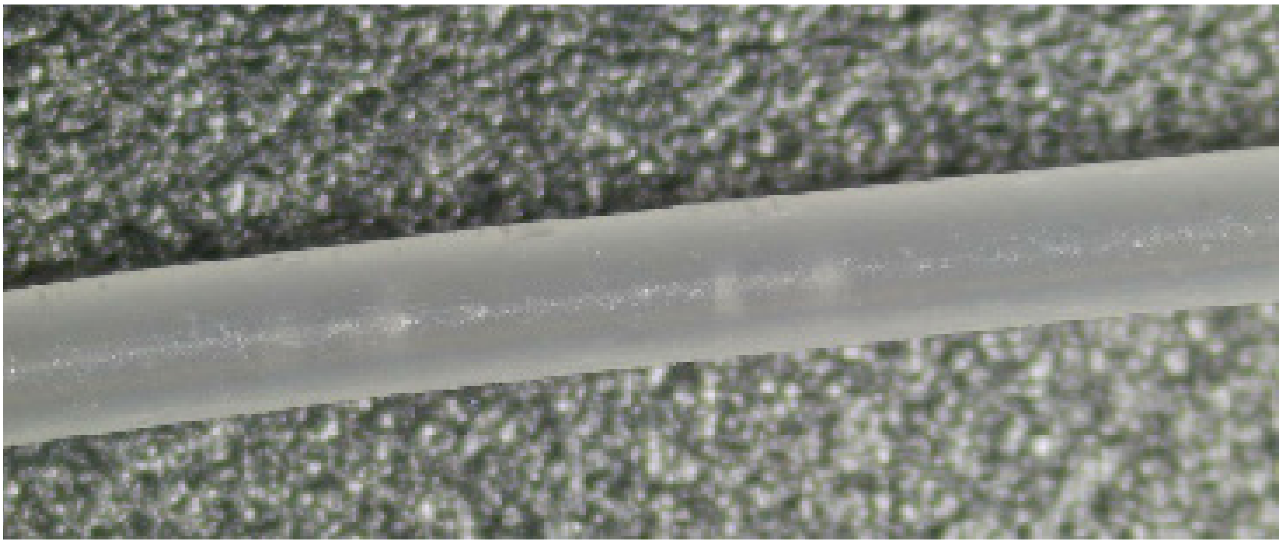

Figure 13- *View of the filament when temperatures were set too high*

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	160 °C	170 °C	170 °C	170 °C	5.0 RPM	20%

At these temperatures, it seemed like the filament did not contain any bubbles, but a few unmelted particles, as shown in Figure 14. The nature of these minor solid plugs was not clear: they could consist of:

- PP unmelted particles, in that case the obvious solution was to increase the temperatures
- Impurities (such as PP of a different grade, or foreign bits of plastic which contaminated the formulation during the storage), in that case the solution of increasing the temperatures could also work, with less certainty

Figure 14 - *Microscope shot: view of the filament when temperatures were set too low*

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	170 °C	175 °C	175 °C	170 °C	5.0 RPM	15%

These settings seemed to be optimal: the filament thickness was quite consistent, its cross-section was rather round, it did not contain bubbles. However, it contained fine dust, as shown in Figure 15, but this issue could not be solved. Regarding the dust, more will be said in Chapter 7.

Figure 15 - *Microscope shot: view of the filament of good quality, only the dust remains*

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	175 °C	175 °C	170 °C	5.0 RPM	20%

Several spools were successfully manufactured using these settings. Figure 16 is a picture taken during the spooling step.

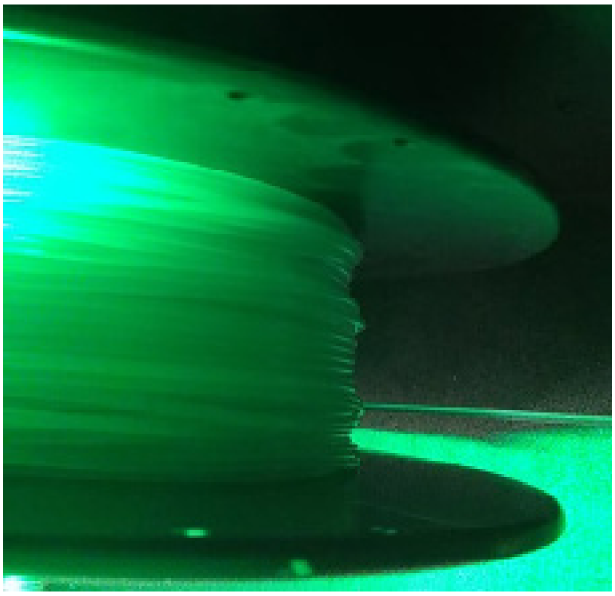

Figure 16 - *Close-up view of the spooling process*

Figure 17 is the graphical representation of a datalog which corresponds to one of the extruded spools. It shows that the filament thickness was very stable during the entire spooling process, well kept within the usual industry tolerance (1.75±0.05mm). The small bumps in the curve can be explained by the presence of impurities in the regrind: dust and occasional unmelting plastic particles, both coming from the recycling loop (shredding step, storage). No solution was found to solve this contamination problem. It can be said that the settings were very well adjusted for the shredded PP, but that the quality of the filament was limited by the presence of impurities.

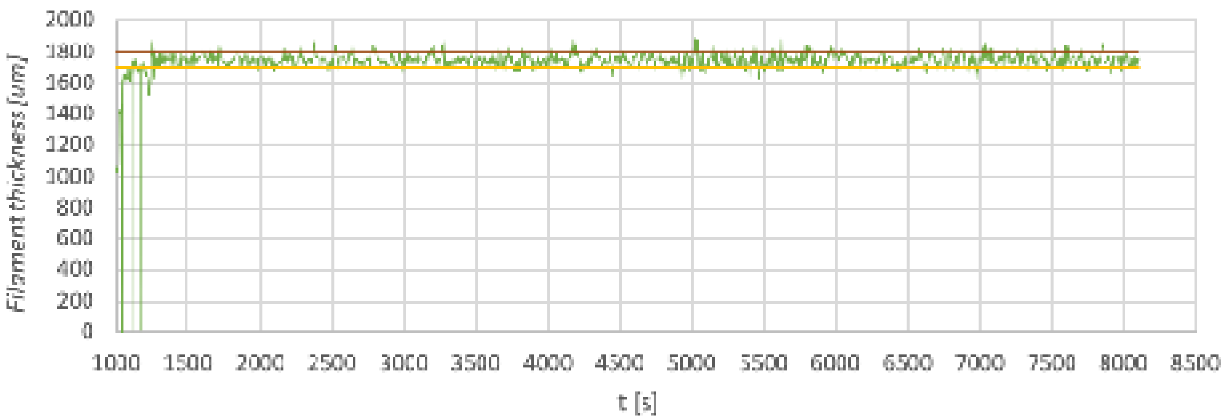

Figure 17 - *Datalog: filament thickness (set value: 1.75mm, red line: 1.80mm, yellow line: 1.70mm)*

Figure 18 - *Final spools of recycled PP*

7. CONCLUSION AND RECOMMENDATIONS

This extrusion experiment was extremely promising. Indeed, 1.75mm filament of great quality and was obtained using a Precision equipped with a 2mm nozzle and a circular cooling device. Even though the actual 3D printability of these filaments remains to be tested, it can be said that the material can be processed very easily, without facing any major issue. It was found that shredding the material twice was a rather easy task which gave good results. The fact that the material could be processed at relatively low temperatures made the launching of the process and the purging steps fast operations. Figure 18 is a picture of the three spools which were obtained at 3devo out of the first batch of injected waste.

The two limiting factors were:

- Impurities which found their way into the regrind during the recycling loop, decreasing a bit the quality of the final product. Better storage conditions would probably prevent this contamination, at least partially.
- The shape of the regrind, which can be described as flakes and jagged bits, led to rat holing, a phenomenon that systematically occurs with regrinds and for which no permanent fix has been found. It is necessary to manually stir the formulation in the hopper quite regularly.

REPORT SUMMARY:

TO DOs:

- Shred the material twice, precutting the parts speeds up the process greatly
- Keep temperatures between 160°C and 200°C (around 170°C for optimal quality)
- Keep fan speed between 10% and 20%, use circular cooling device
- Regularly stir the formulation in the hopper to prevent rat holing

WARNINGS:

- Watch out for impurities (dust mostly) during shredding and storage
- Purge after extrusion using Devoclean MidTemp at 190°C (all heaters)
- Transition back to PP with HDPE, then PLA (at 190°C)

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	170 °C	175 °C	175 °C	170 °C	5.0 RPM	20%