3devo

MATERIALS MADE **SIMPLE**.

PC + PTFE

Extrusion Walkthrough

Our experiences with the extrusion of Polycarbonate (PC) filled with 20%w Polytetrafluoroethylene (PTFE, or Teflon). The material will be referred to as “PC+PTFE” in this report.

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PC+PTFE IN A NUTSHELL

- *PC is originally optically clear with very good light transmission properties, PTFE gives it a white color*
- *Amorphous*
- *Rather high strength, impact strength and toughness, wide plastic deformation range (pliability)*
- *Rather high heat resistance (typical processing temperatures around 250-300°C)*

1. INTRODUCTION AND CONTEXT OF THIS REPORT

This document guides the reader through the extrusion process of PC+PTFE, 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 extrude filament of **1.50mm** thickness out of PC pellets mixed with PTFE powder. Figure 1 is a picture of the original pellets mixed with 20%w PTFE fine powder.

Chapters 2 to 5 explain more in detail the main experimental steps of the extrusion test, which consisted in a series of adjustments. The extrusion test was performed on a **Composer** machine equipped with a **2mm nozzle.** Chapter 6 gives an overall conclusion regarding the processability of PC+PTFE, and summarizes the entire report.

Figure 1 - *Pellets of PC (transparent) mixed with PTFE powder (white)*

2. PREPARATION AND PRE-PROCESSING

The material was supplied in a plastic bag, unprotected from moisture. Drying is typically a crucial step when trying to process PC-based formulations. The **drying** was performed at **80°C for 4h** in our Dryer, as shown in Figure 2.

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 PC+PTFE

This purging/transitioning process was performed at 290˚C (all four heaters).

PC+PTFE was then introduced at 290˚C. It is recommended, but not mandatory, to introduce virgin PC before transitioning to PC+PTFE. This way, less PTFE is wasted during the transition.

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 3 is a picture of the feeding. Because the material mostly came in pelletized form, no major feeding issues were faced.

Figure 2 - *Picture of the Dryer (the picture was not taken during this specific project)*

Figure 3 - *Feeding PC+PTFE into the hopper of the extruder*

3. 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	290 °C	290 °C	290°C	290 °C	5.0 RPM	50%

WHY 290°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 PC, 290°C is on the high end of the thermal window of operation (250-300°C).

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 1.50mm thickness, the best rotation speed is usually found between 3.0 and 6.0 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 slow (it took more than 10min). Increasing the rotation speed to 10RPM can speed up the transition. The flow appeared to be rather stable but the extrudate was too liquid : it was hard to pull it properly because it was collapsing under its own weight. PTFE lumps were visible in the extrudate and made the surface rough, which indicated that segregation was happening : some of the PTFE was not well dispersed in the melt.

4. EXTRUSION (2): AJUSTMENT STEPS

The objective was to find the optimal extrusion settings with the help of the filament sensor. The main issue was that the PTFE was segregating and forming frequent small bumps in the filament. Figure 4 is a picture taken during the adjustment phase, before the filament was of sufficient quality to be spooled.

FILAMENT FAN SPEED: It was found that to achieve optimal quality, a low fan speed was preferred, around **10%**.

SCREW RPM: Several options were tested, the goal was to disperse the PTFE by shear stress (high screw speed) while maintaining a steady flow (low-medium screw speed). After experimentation between 3.0 and 7.0RPM, the conclusion was that **5.0RPM** was the best option to combine production rate and product quality.

TEMPERATURES: All temperatures were decreased gradually, 5°C by 5°C, down to 240°C. Nozzle buildup started to occur below 260°C. In order to maximize the shear stress but avoid nozzle buildup, the solution was to keep H1 above 260°C and decrease H2, H3, H4, as much as possible.

THE IMPORTANCE OF DRYING: Not drying the PC may result in the formation of bubbles in the filament, that will dramatically damage the mechanical properties of the material, and increase fluctuations and inconsistencies in the flow.

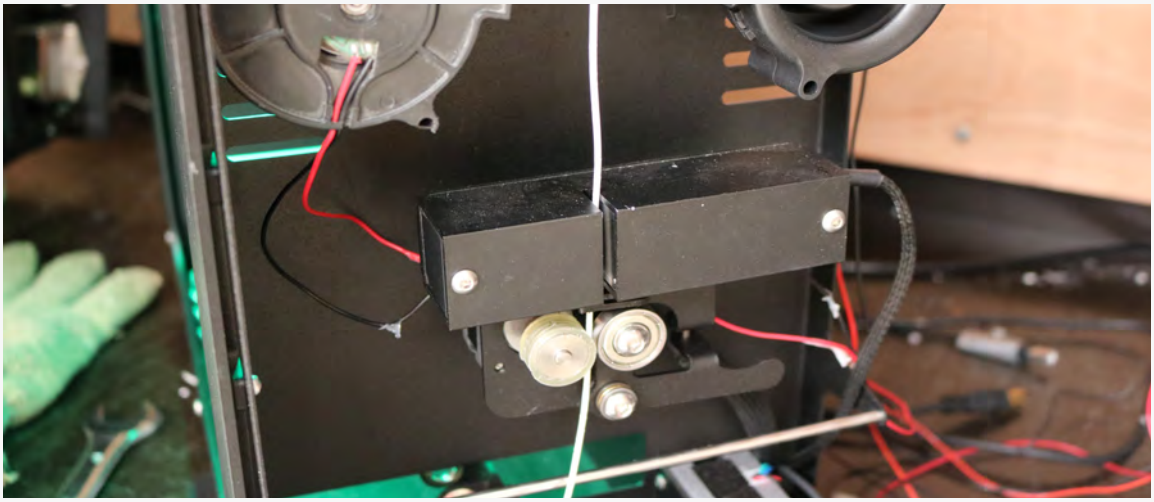

Figure 4 - *Filament flowing freely during the adjustment phase*

5. 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	240°C	245 °C	245°C	265 °C	5.0 RPM	10%

A spool was successfully manufactured using these settings. Figure 5 is a microscope shot of the product. The segregation of PTFE could not be avoided : some small PTFE inclusions remain and can be seen on the surface of the filament. However, given the overall visual aspect of the filament, and given the fact that virgin PC is colorless and transparent, it seems like most of the PTFE has been successfully dispersed in the matrix.

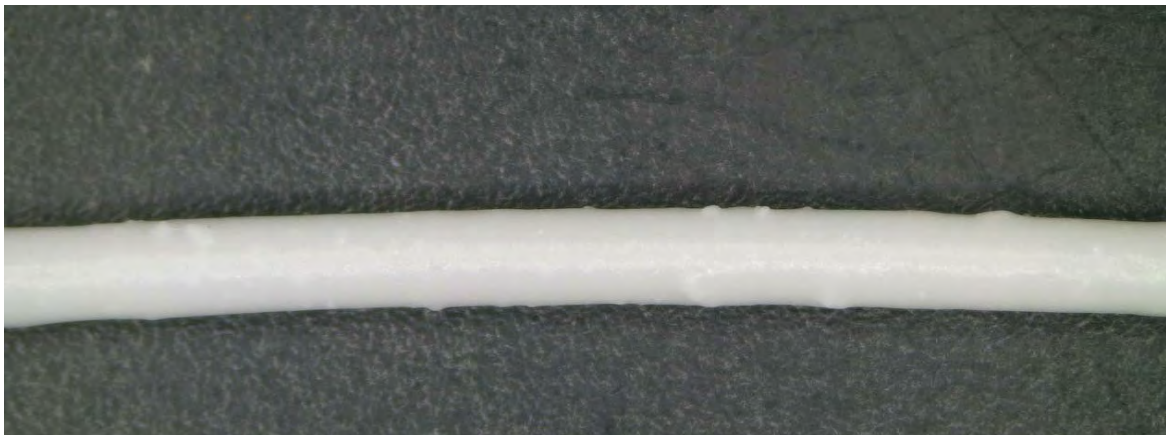

Figure 5 - *Microscope shot to show the visual aspect of the filament : PTFE undispersed lumps can be seen on the surface*

Figure 6 is the graphical representation of the datalog which corresponds to the produced spool. It shows that the filament thickness was rather stable during the entire spooling process. The filament is close to being well kept within the usual industry tolerance (1.50±0.05mm). The hypothesis is that the flow was very stable but that the remaining PTFE specks led to a significant instability in the sensor's reading. In other terms, it is probable that decreasing the weight percentage of PTFE slightly would remove the inclusions, and the flow should then appear very stable.

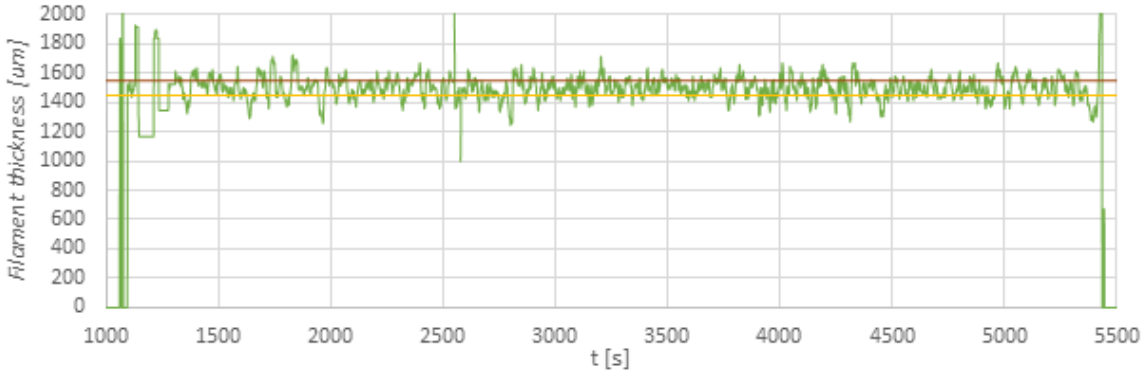

Figure 6 - *filament thickness (set value : 1.50mm, red line : 1.55mm, yellow line : 1.45mm)*

Figure 7 - *Spool of PC+PTFE*

6. CONCLUSION AND RECOMMENDATIONS

This extrusion experiment was extremely promising. Indeed, 1.50mm filament of rather good quality was obtained using a Composer equipped with a 2mm nozzle. The final spool is visible in Figure 7. Even though the 3D printing of this filament remains to be investigated, it can be said that the material could be extruded quite easily, without facing any major issue, and that the resulting filament's thickness was close to being well-kept within industry tolerance standards (+/- 50 microns). In order to achieve PC+PTFE filament of great quality, the weight percentage of PTFE must be optimized. A possible way would be to experiment with gradually lower infill percentages until segregation no longer happens, most likely between 10%w and 20%w. Another method which could be investigated in order to increase the quality of the mixed filament would be to replace the PC pellets by PC powder, for more homogeneous mixing.

REPORT SUMMARY:

TO DOs:

- Keep temperatures around 260°C for optimal quality (nozzle buildup may happen if H1 goes below)
- Dry the material for at 80°C for at least 4h in a dryer or an oven
- Purge **thoroughly** after extrusion using Devoclean MidTemp (at the processing temperatures)
- Transition back to PC or PC+PTFE with HDPE first. This is not mandatory but will save some PC and/or PTFE

WARNINGS:

- It might be necessary to adjust the fan speed around 10% depending on the room conditions
- As explained earlier, the following settings seem to work rather well but will lead to minor PTFE segregation if used with a 20%w PTFE formulation

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	245 °C	245 °C	250 °C	265 °C	5.0 RPM	10%