3devo

MATERIALS MADE **SIMPLE**.

PP COPOLYMERIZED WITH ETHYLENE

Extrusion Walkthrough

Our experiences with the extrusion of polypropylene copolymerized with ethylene. The material will be referred to as “PP” in this report.

DATE: NOV 12TH, 2019

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PP IN A NUTSHELL

- *Visual white, opaque, slightly shiny*
- *Medium temperature range (recommended processing temperatures 220-230°C)*

1. INTRODUCTION AND CONTEXT OF THIS REPORT

This document guides the reader through the extrusion process of PP, 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 pellets of PP into **2.85mm filament.** Figure 1 is a picture of the original batch of pellets provided in a plastic bag.

Chapters 2 to 5 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 6 gives an overall conclusion regarding the processability of PP, and summarizes the entire report.

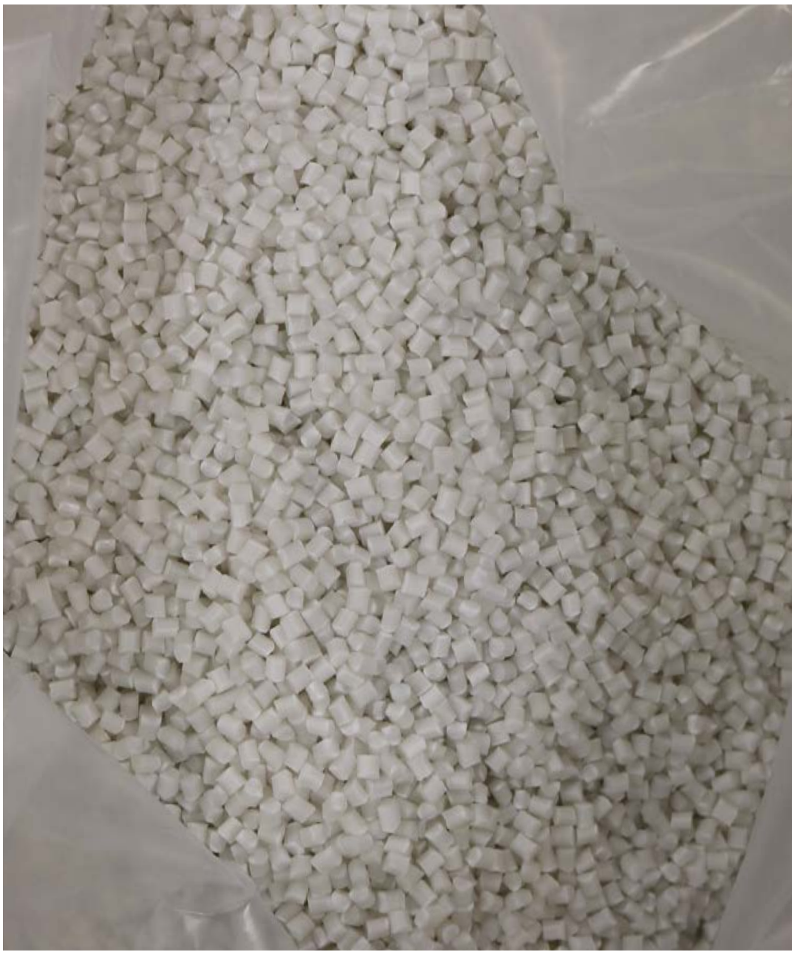

Figure 1 - *Batch of PP pellets*

Figure 2 - *Feeding PP pellets into the hopper of the extruder*

2. PREPARATION AND PRE-PROCESSING

The material was supplied in a plastic bag, unprotected from moisture. Drying is typically not needed when trying to process PP-based formulations.

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 PP

This purging/transitioning process was performed at 230˚C (all four heaters).

PP was then introduced at 230˚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 2 is a picture of the feeding.

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	230 °C	230 °C	230 °C	230 °C	5.0 RPM	50%

WHY 230°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 PP, 230°C is on the high end of the recommended thermal window of operation (220-230°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 2.85mm 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, Figure 3 illustrates this transition. The transition only took a few moments, it was sudden and clearly visible, even though both plastics look alike in the picture. The flow did not seem to be much disturbed. The flow appeared to be rather stable but the extrudate was too liquid : it was hard to pull it properly because it was wobbly and flattened by the puller. The surface of the filament was quite smooth, the material did not show any sign of degradation nor did it contain any bubbles.

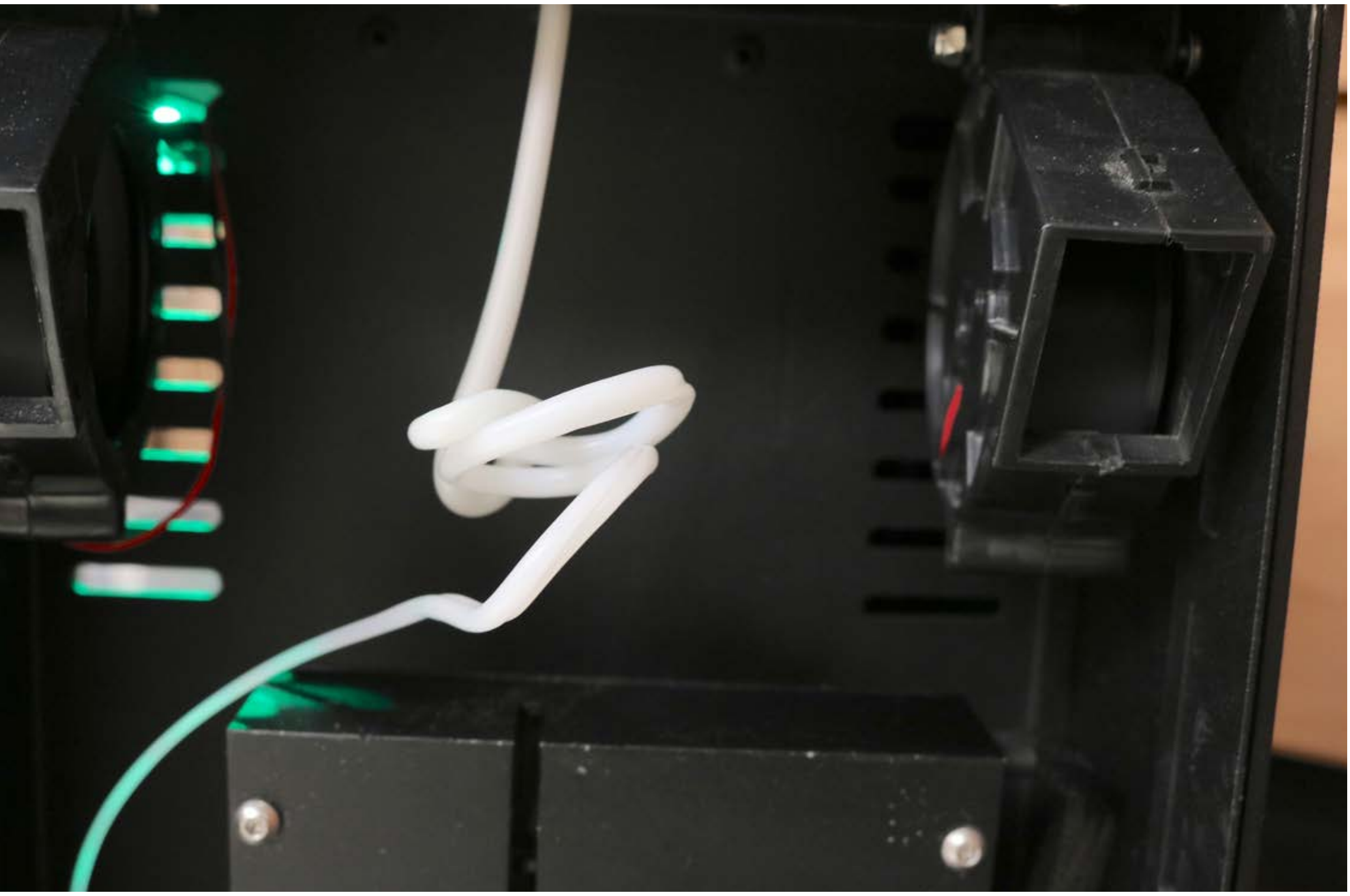

Figure 3 - *Transition from purging HDPE (white extrudate at the bottom) to PP (white extrudate at the top); the difference is hard to notice, but in reality PP is more shiny, and HDPE was transparent right after coming out and before becoming white.*

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 extrudate was too hot, resulting in the flattening of the filament by the puller wheels. In addition to this, as explained in detail below, the material was crystallizing anisotropically, producing a filament of oval cross-section. Figure 4 is a picture taken during the adjustment phase, before the filament was of sufficient quality to be spooled.

FILAMENT FAN SPEED: Because the extrudate was too hot when reaching the puller, the approach was to increase the fan cooling percentage. Several options were tested ***between 70% and 100%.*** This ensured that the filament was solid enough before reaching the puller. However, anisotropic crystallization was caused.

ANISOTROPIC CRYSTALLIZATION: The molecular structure of PP makes it a highly crystalline polymer, unless it is processed specifically to obtain highly amorphous parts (with rapid cooling). 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 from “all around”. The result of anisotropic crystallization is that the filament becomes oval in cross-section.
In such a case, the solution is usually to mount a special 3D-printed cooling accessory which makes the airflow circular (depicted in Figure 5). However, this option did not work: no method was found to cool down the filament properly into a round cross-section.

SCREW RPM: The screw rotation speed was decreased gradually down to 4.0RPM. The purpose was to reduce the need for cooling by giving more time to the extrudate to cool down. It was found that, at all the screw speeds that were tried, ***the flow was never stable for more than 10min.***

TEMPERATURES: All temperatures were decreased gradually, 5°C by 5°C, down to 190°, in order to make the flow more stable and decrease the need for cooling. At lower temperatures, the flow seemed more unstable: it was impossible to have a constant output for more than 5-10min. The low motor current (1500mA) measured during these experiments indicated that the screw was turning “too easily”. This usually is a sign of early melting in the feed zone. As a consequence, an ascending profile was tested (lower temperature on H4 in the feed zone then gradually increasing temperatures up to the nozzle), but the flow was not more stable. In a nutshell, the temperatures did not allow for a stable flow and little need for cooling.

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

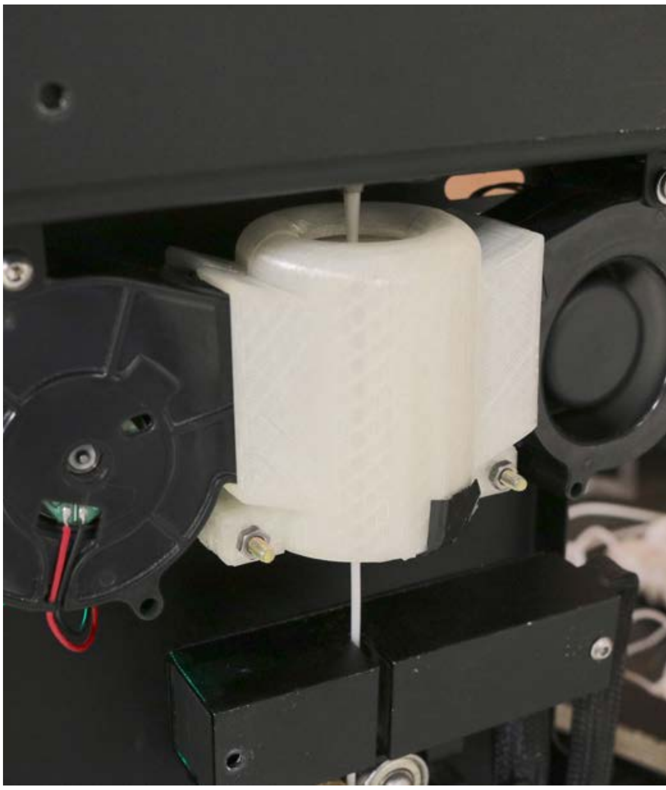

Figure 5 - *Circular cooling device (two versions were experimented with: this one allows for both fans to be plugged in, the other version was used with one fan only)*

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	220 °C	220 °C	220 °C	210 °C	4.8 RPM	100%

Four very small spools were successfully manufactured using these settings. They were rather constant in tolerance but every time the flow became unstable and decreased significantly.

Figure 6 is the graphical representation of the datalog which corresponds to three of the incomplete produced spools. It shows that the filament thickness was rather stable during certain phases of the spooling process, being well kept within the usual tolerance (2.85±0.05mm). However, the overall process was obviously not stable: it was necessary to stop spooling every 10min approximately because the flow was becoming too weak.

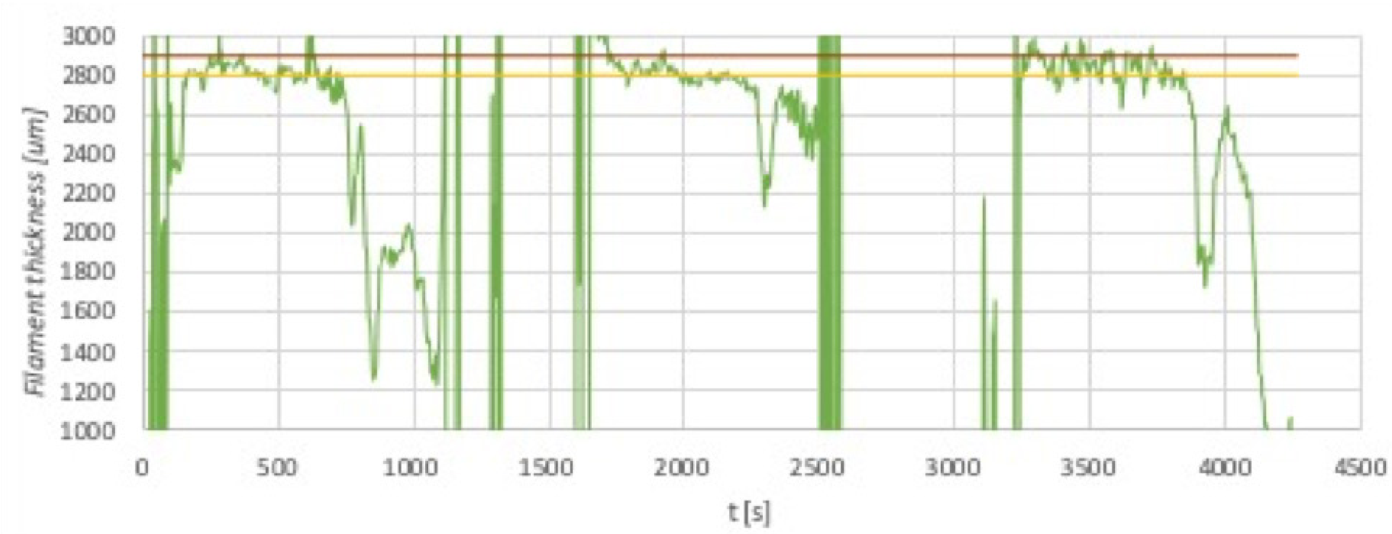

Figure 6 - *Datalog : filament thickness (set value : 2.85mm, red line : 2.90mm, yellow line : 2.80mm)*

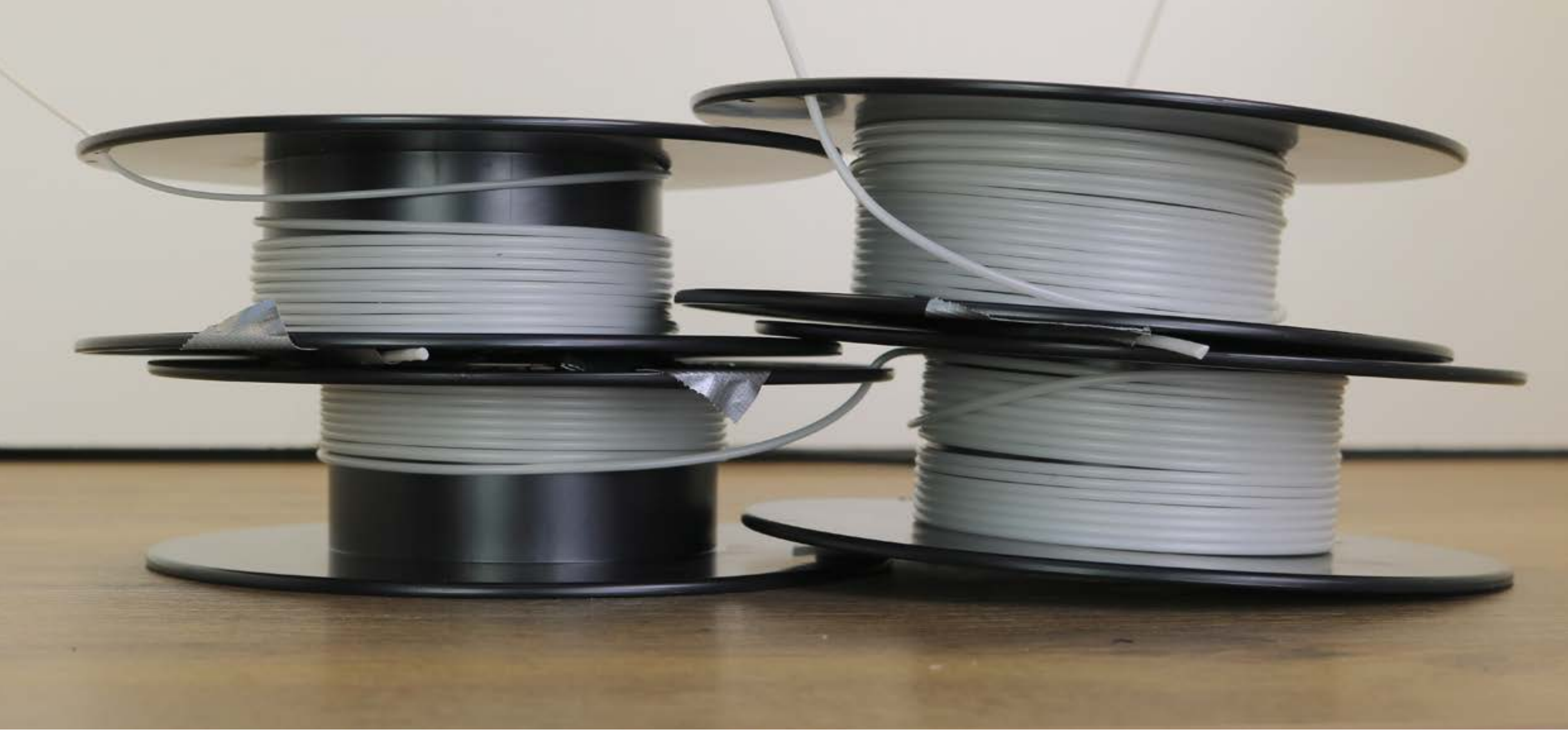

Figure 7 - *Four incomplete spools of PP*

6. CONCLUSION AND RECOMMENDATIONS

REPORT SUMMARY:

TO DOs:

- Keep temperatures around 215-220°C for optimal quality (there is still room for improving the results, by making small temperature adjustment
- Use a circular cooling device for a more isotropic crystallization

WARNINGS:

- It might be necessary to adjust the fan speed depending on the room conditions
- Oval crystallization is the main obstacle to good filament (in order to fix this, one must limit the need for cooling, and apply circular cooling if possible)
- 1.75mm filament is easier to cool down than 2.85mm filament: it would work better with the machine
- After each extrusion session, purge the machine thoroughly with HDPE (it only takes a few minutes)
- The following “final” settings still need to be improved:

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	220 °C	220 °C	220 °C	210 °C	4.8 RPM	100%