3devo

MATERIALS MADE **SIMPLE**.

LLDPE INJECTED PARTS

Shredding and Extrusion Walkthrough

Our experiences with the shredding and extrusion of injected parts made of Linear Low-Density Polyethylene (LLDPE). The material will be referred to as **"LLDPE"** in this report.

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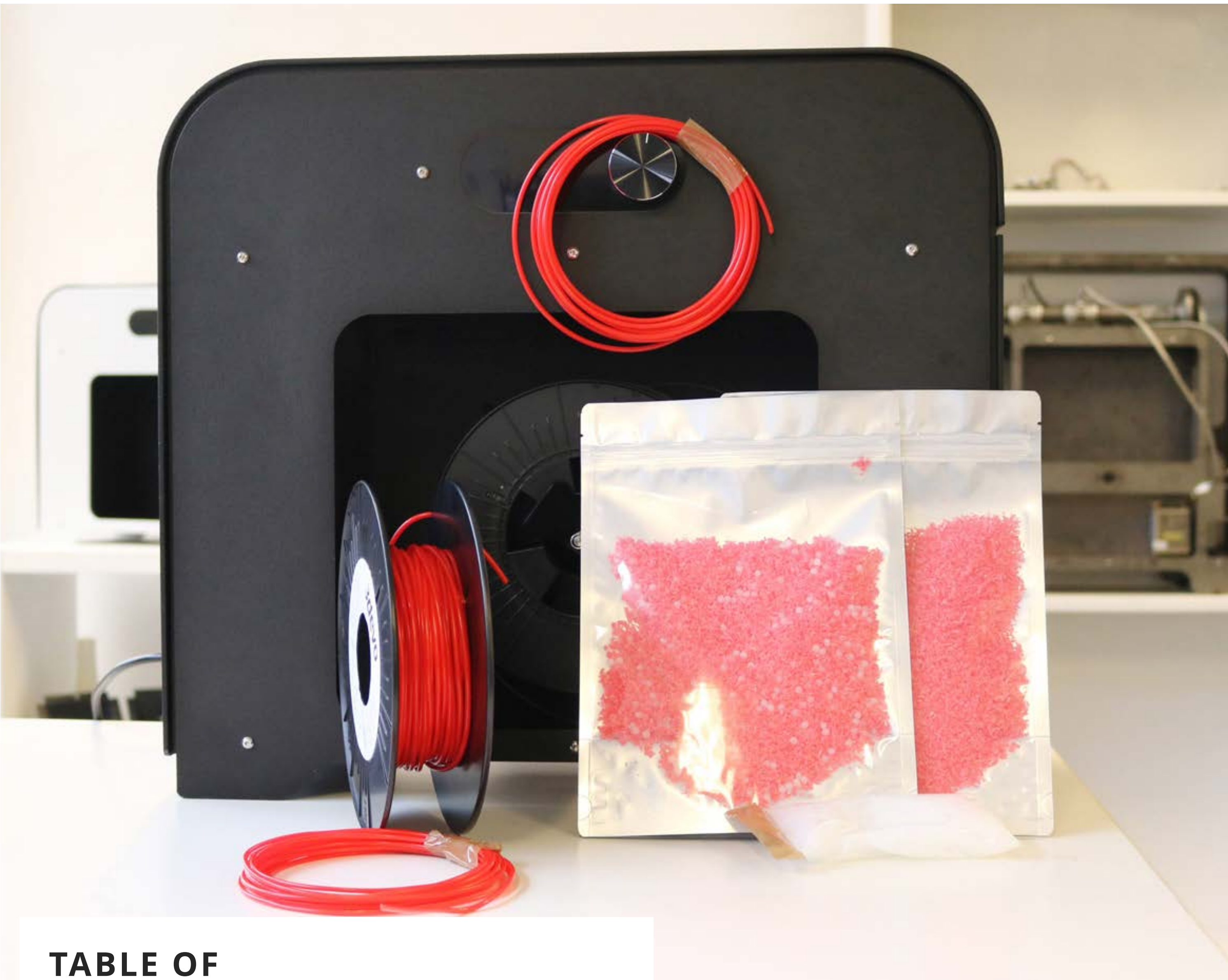

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1. INTRODUCTION AND CONTEXT OF THIS REPORT

This document guides the reader through the shredding process and extrusion process of LLDPE, 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 injected parts of various shapes made of LLDPE into **3.00mm filament**. Figure 1 is a picture of the original injected parts provided in a cardboard box.

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 LLDPE, and summarizes the entire report.

Figure 1 - *Batch of LLDPE injected parts*

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. This operation was rather straightforward. The parts had been pre-chopped so that they could fit in the hopper of the shredder.

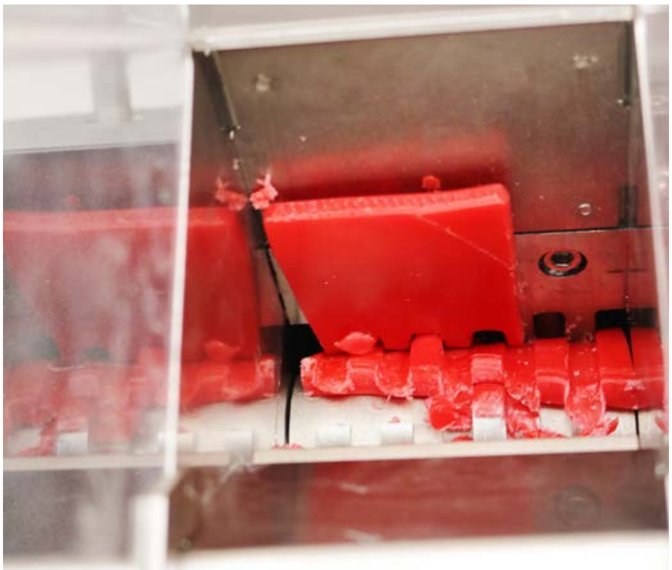

Figure 3 - *Feeding the SHR3D IT*

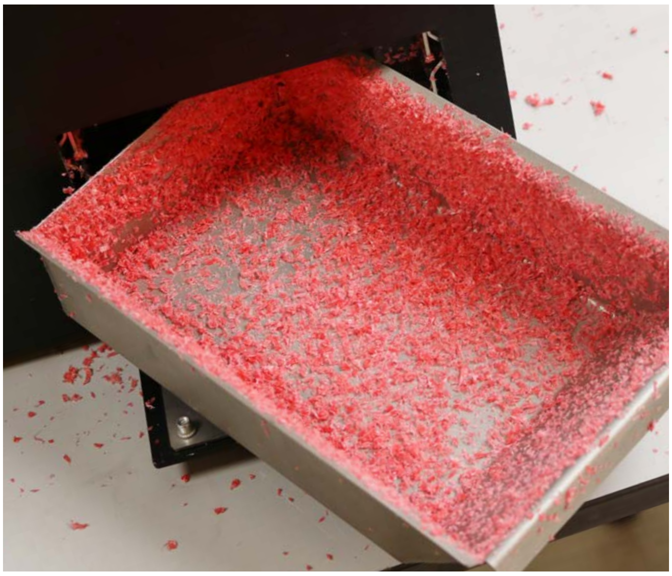

Figure 4 - *First sample of regrind coming out of the SHR3D IT*

The shredding process quickly gave good results. Figure 3 is a picture of the feeding step, which shows that some of the parts were long and tough enough to wrap themselves around the teeth of the shredder, impeding the chopping. Feeding only two parts at a time can help preventing this issue from happening. Once a good feeding rate is found, the shredding process becomes quite easy.

Figure 4 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, but that the flakes were electrostatically sticking to their environment.

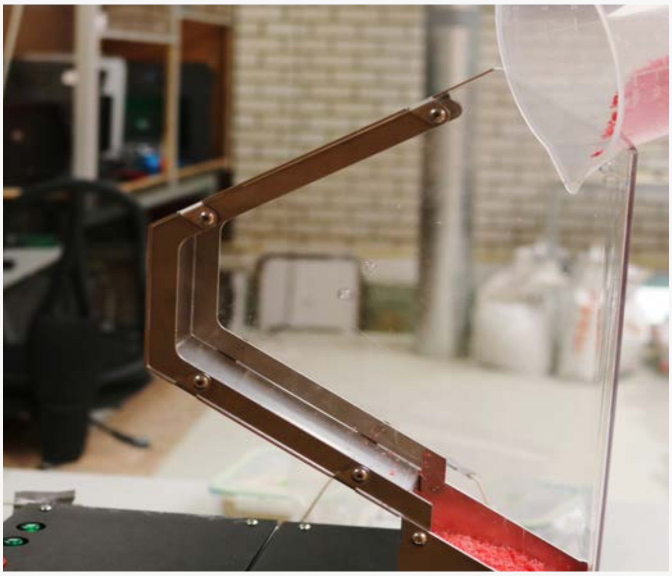

Figure 5 - *Easy feeding of the regrind for a second shredding step*

Figure 6 - *Close-up view of the regrind*

Reshredding LLDPE : 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, as shown in Figure 5. 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 7 is a picture meant to compare the shape and size of the LLDPE regrind to standard Polylactic Acid (PLA) 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 6 shows that the whole batch of regrind looks homogeneous and free of significant impurities. Shredding the material several times and/or installing a 3mm filter on the shredder can help the user obtain the desired quality of regrind.

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

3. PREPARATION AND PRE-PROCESSING

The material was supplied in a cardboard box, unprotected from moisture. Drying is typically not required when working with polyethylenes.

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

- Devoclean MidTemp to clean the barrel thoroughly
- Another grade of high density polyethylene, specifically designed for purging, referred to as “HDPE”

This purging/transitioning process was performed at 220˚C (all four heaters).

LLDPE was then introduced at 220˚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 is a picture of the feeding, Figure 9 illustrates the transition from HDPE to the shredded red LLDPE. The transition only took a few moments, it was sudden and clearly visible.

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

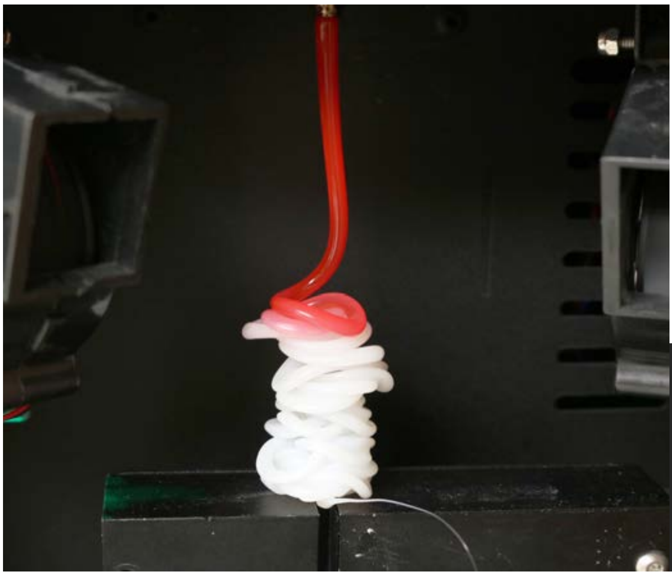

Figure 9 *- Transition from HDPE (bottom) to shredded LLDPE (top)*

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	220 °C	220 °C	220 °C	220 °C	5.0 RPM	50%

WHY 220°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 LLDPE, 220°C are sufficient to melt the matter.

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 3.00mm 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 after the purge was smooth and fast, 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. Other issues were faced, as explained below.

5. EXTRUSION (2): AJUSTMENT STEPS

The objective was to find the optimal extrusion settings with the help of the filament sensor. The main issues were the bridging in the hopper, and the anisotropic crystallization. Figure 10 is a picture taken during the adjustment phase, before the filament was of sufficient quality to be spooled.

BRIDGING : Another phenomenon was observed, this time affecting the feeding. This phenomenon is known as bridging: it usually affects regrinds, it occurs when the formulation forms cohesive structures in the hopper, which do not flow properly down in the throat and therefore diminish the flow. This can clearly be seen in Figure 11. This issue was momentarily fixed by putting a vibration motor in contact with the outside wall of the hopper.

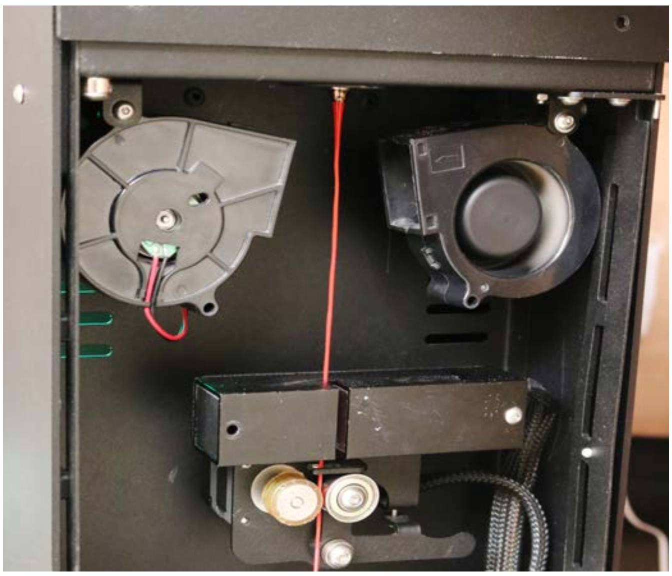

Figure 10 - *Filament flowing freely during the adjustment phase*

Figure 11 - *Bridging : the material forms a cohesive structure against the walls of the hopper, making the feeding inconsistent*

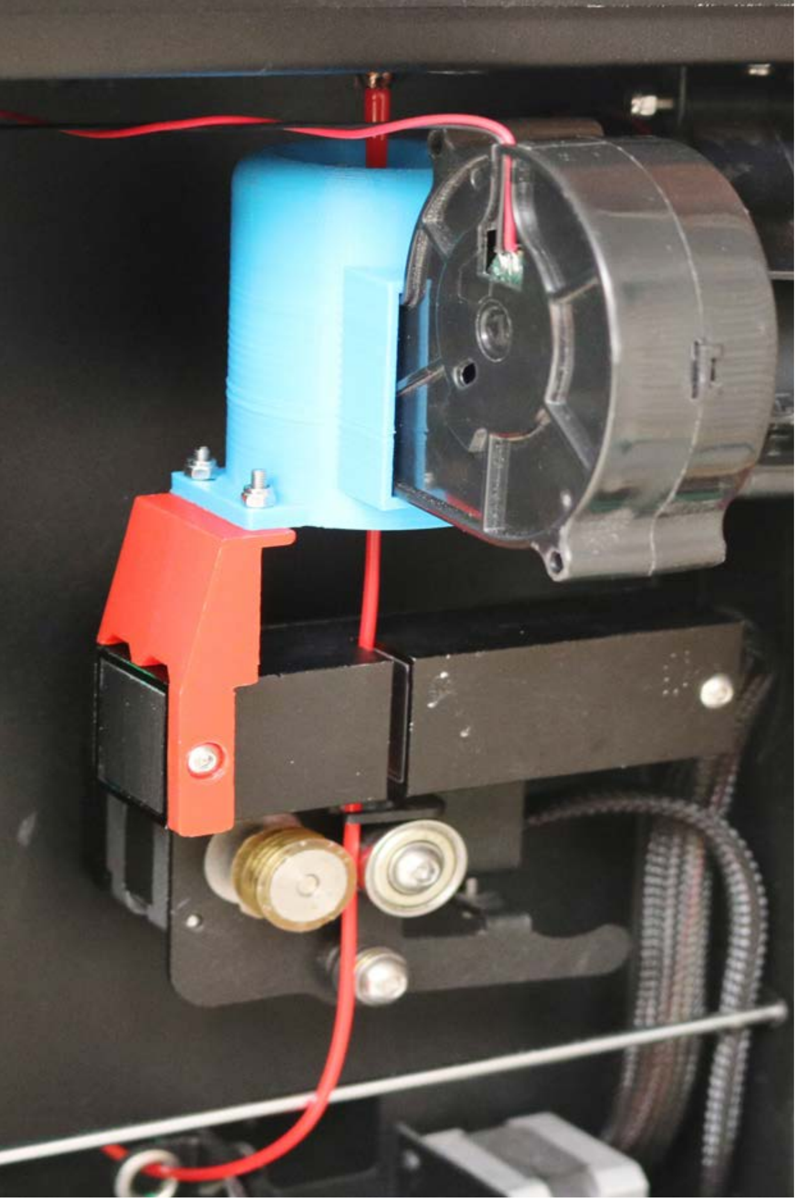

Figure 12 - Circular cooling device mounted at the front of the machine, with one fan plugged in

ANISOTROPIC CRYSTALLIZATION: The molecular structure of LLDPE makes it a highly crystalline polymer. During this extrusion test, two filament fans were cooling down the extrudate by blowing air on it from two sides. LLDPE crystallized too fast and anisotropically, because it was being cooled down from two opposites sides only, not isotropically.

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.

CONCLUSION : Despite the addition of a vibration motor for better flow in the hopper, and despite the refining of the settings, it was not possible to consistently spool filament of great quality for more than 1h. The bridging mechanism was happening repeatedly, and impeding the feeding.

The solution was to add a percentage of HDPE to the batch of LLDPE regrind.

6. EXTRUSION (3): MIXING TWO GRADES OF PE

10%w (in weight) of HDPE pellets were added to the batch of LLDPE regrind. As a result, because of the presence of pellets in the hopper, the bridging phenomenon stopped, and it was possible to spool a rather consistent filament. 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	195 °C	195 °C	100 °C	5.0 RPM	100%

Bigger portions of filament were successfully manufactured using these settings.

Figure 13 - *Samples of recycled HDPE, and LLDPE regrind (before and after mixing)*

7. CONCLUSION AND RECOMMENDATIONS

This extrusion experiment was very promising. First, 3.00mm filament of good quality was extruded using a Precision extruder. It was not possible to spool a full spool, because of bridging issues in the hopper. A way to make the process more stable over time was to add about 10% in weight of HDPE pellets, normally used for purging. The quality of the filament was still quite high and most of the filament was still made of recycled plastic. The function of the HDPE pellets is to ease the feeding. 10%w were added, but the ratio may be investigated furthermore for optimal quality. The goal is to process as much recycled matter as possible, supposedly.

The 3D-printability of the product remains to be investigated. The fact that the material could be processed at relatively low temperatures made the launching of the process a fast operation Figure 13 is a picture of several spools which were obtained at 3devo in a few days of testing.

REPORT SUMMARY:

TO DOs:

- Keep temperatures around 200°C for optimal quality
- No drying is needed
- Purge thoroughly after extrusion using Devoclean MidTemp (at the processing temperatures), or with HDPE (but the purge will take more time to get rid of all the colorant)
- Mix about 10%w of HDPE pellets, and 90%w LLDPE regrind (the ratio can be adjusted, the purpose of the pellets is to ease the flowing in the hopper)

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
- Feeding issues can be reduced by placing a small vibration motor in contact with the wall of the hopper

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	190 °C	195 °C	195 °C	190 °C	5.0 RPM	100%