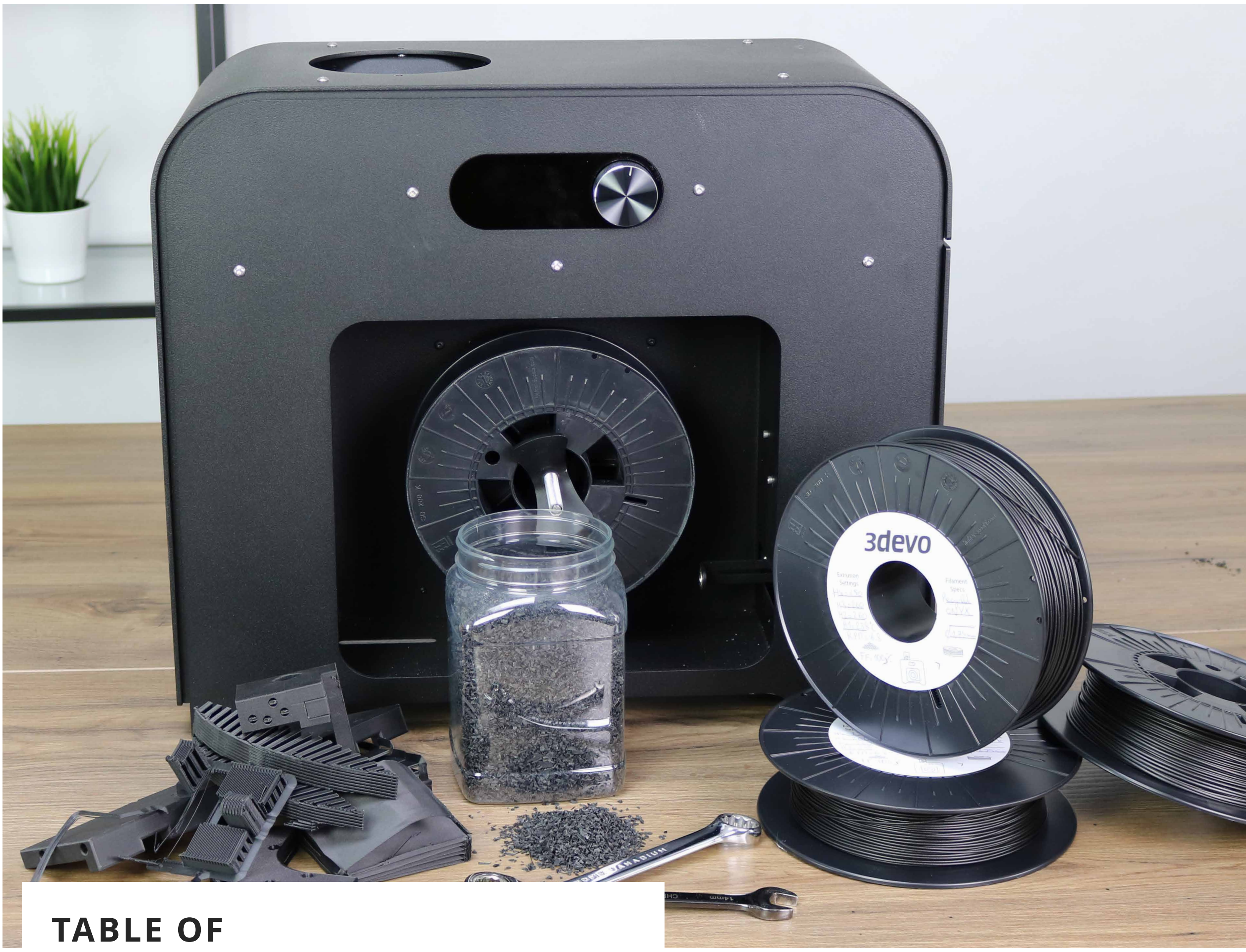
RECYCLING MARKFORGED **ONYX**

Shredding and Extrusion Walkthrough with Carbon Fiber Reinforced Material

Our experiences with the shredding and extrusion of Onyx 3D printed waste. The material will be referred to as “Onyx” in this report.



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ONYX IN A NUTSHELL

- *Opaque and black, smooth surface finish*
- *Formulation containing nylon and chopped carbon fibers*
- *High strength (including flexural strength) and good durability make Onyx a highly performant material for structural applications*
- *When 3D printed with a continuous carbon fiber reinforcement, Onyx becomes comparable to Aluminum*
- *Rather high heat resistance (typical processing temperatures around 285°C)*

1. INTRODUCTION AND CONTEXT OF THIS REPORT

This document guides the reader through the shredding process and extrusion process of Onyx 3D printed 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 parts of various shapes made of 3D printed Onyx into **1.75mm filament**. Figure 1 is a picture of the original printed 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 **2mm nozzle**. Chapter 7 gives an overall conclusion regarding the recyclability of Onyx, and summarizes the entire report.

Figure 1 - *Batch of Onyx printed 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. Some of the printed parts were quite flexible and easily fed in the shredder, while other parts were more voluminous.

The shredding process quickly gave good results. Figure 3 is a picture of the feeding step, which shows that some of the waste was quite flexible. Manual force-feeding, using the handle of the machine, was applied to speed up the shredding process.

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 except for a few notable particles which managed to exit the shredder despite their size bigger than 4mm.

Figure 3 - *Feeding the SHR3D IT*


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

Figure 5 is a picture meant to compare the shape and size of the Onyx 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.

RESHREDDING ONYX : 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 5 - *Size and shape comparison between Onyx regrind (left) and standard PLA pellets (right)*


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

Figure 7 - *Picture of the Dryer and a jar of Onyx regrind*

3. PREPARATION AND PRE-PROCESSING

The material was supplied in a cardboard box, unprotected from moisture. Drying is typically a crucial step when trying to process nylon-based formulations. The drying was performed at 80°C for 4h in our Dryer, as shown in Figure 7.

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 Onyx

This purging/transitioning process was performed at 285˚C (all four heaters).

Onyx was then introduced at 285˚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 Onyx. The transition only took a few moments, it was sudden and clearly visible.

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

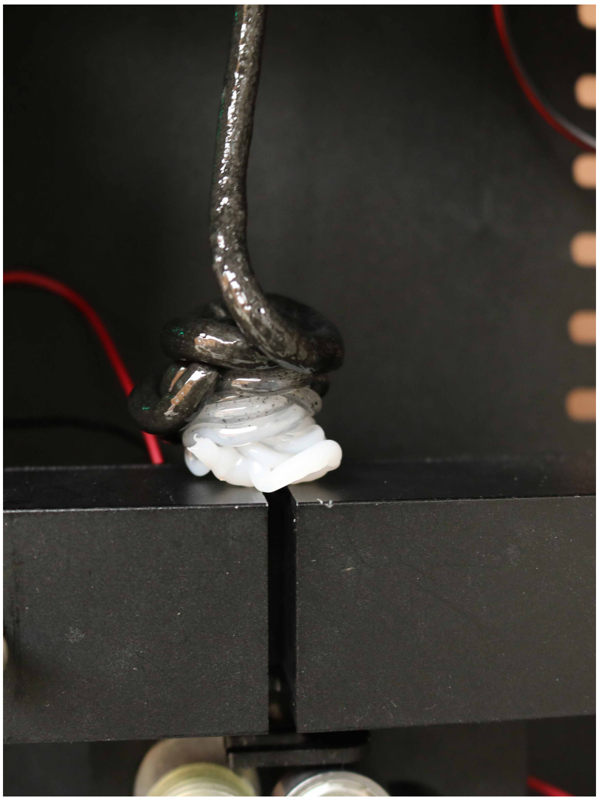

Figure 9 - *Transition from purging HDPE (white extrudate at the bottom) to Onyx (black extrudate at the top)*

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	285 °C	285 °C	285 °C	285 °C	5.0 RPM	50%

WHY 285°C? This temperature is the recommended printing temperature of Onyx. Thermoplastics are usually extruded below their printing temperature because the residence time is longer in the case of extrusion, and a significant fraction of the heat is produced by friction. However, as mentioned earlier, it is wiser to start at a temperature that is too high, to avoid the clogging of the machine.

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 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 rough, as if the material was degrading, or as if air had been trapped inside the melt.

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

RAT HOLING: Another phenomenon was observed, this time affecting the feeding. This phenomenon is known as rat holing : it generally affects powders and 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 10. Carefully using a stick every few minutes to break the structure, or a continuously stirring device, can improve the feeding.

5. 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. Figure 11 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 correct and obvious approach was to increase the fan cooling percentage. Several options were tested **between 70% and 100%.**

SCREW RPM: The screw rotation speed was increased gradually up to **7.0 RPM**. Despite the need for high filament fan speed, it was found that screw speeds of 6.0RPM to 7.0RPM resulted in a stable flow. Further investigation might reveal that it is possible to increase the stability of the flow by decreasing the production rate.

TEMPERATURES: All temperatures were decreased gradually, 5°C by 5°C, down to 250°C, point at which the analysis showed an increase in the RPM fluctuation which suggested that the material was not being melted easily enough. It was found that a “low-high-low bell” curve was the optimal temperature profile : 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 IMPORTANCE OF DRYING: It is known that nylons are troublesome to process when they have not been dried prior to the extrusion. The experiment confirmed that moisture can have a very negative effect on the extrusion process and the quality of the filament (see Chapter 6 for illustrations). Drying the material before extruding it results in a smoother surface. It is also important to know that moisture can also cause the presence of “void” inside the filament : moisture trapped in the material forms bubbles at the core of the filament, the shrinkage is then uneven, the surface becomes rough, and the filament cannot be printed since matter is “missing” inside it.

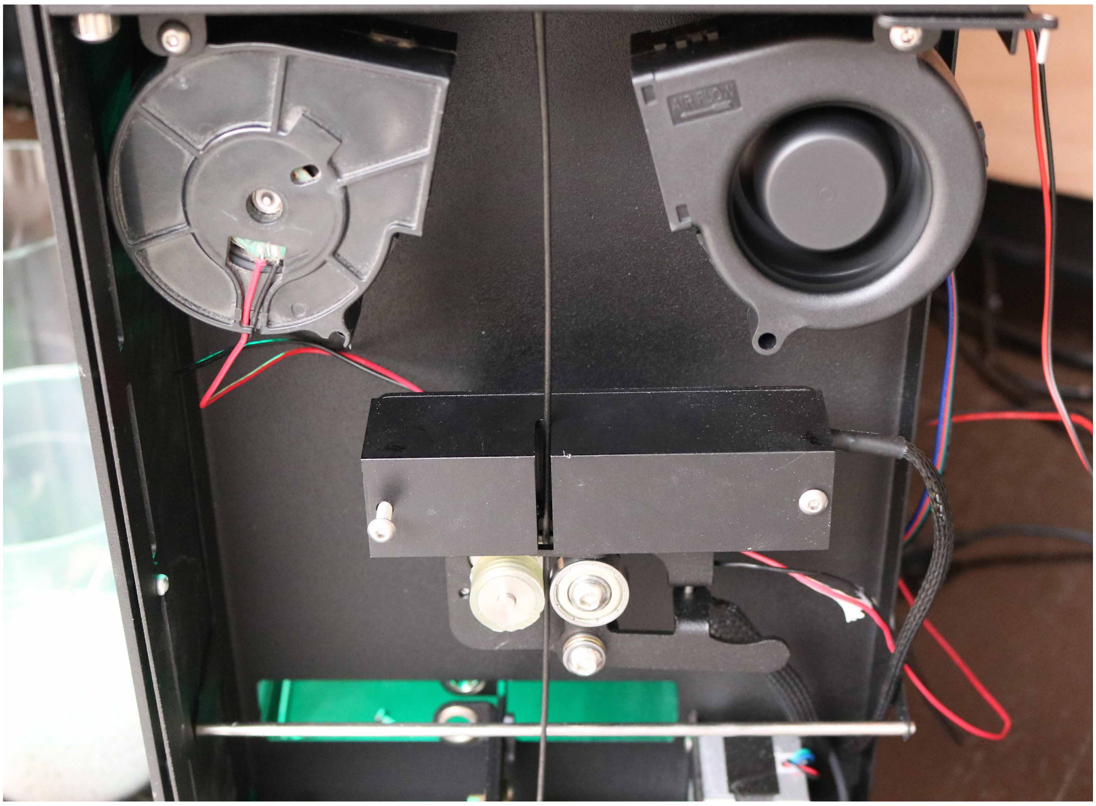

Figure 11- *Filament flowing freely during the adjustment phase*

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	250 °C	260 °C	260 °C	238 °C	6.8 RPM	100%

Several spools were successfully manufactured using these settings. Figure 12 and 13 are microscope shots of three different products : recycled Onyx filament obtained with the wrong settings, recycled Onyx filament obtained with good settings, original commercial Onyx filament. Using the wrong settings such as excessively high temperatures, or not drying the material before extruding it, lowers the quality of the surface finish. Obtaining a surface smoothness similar to the one of the original filament was achieved by finding the right settings. As a side note, this made the search for correct settings somewhat easier, by defining the target product quality.

Figure 14 is the graphical representation of the datalog which corresponds to one of the produced 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).

Figure 12 - *Microscope shot to compare the visual aspect and roughness of each filament : (from top to bottom) recycled Onyx when extrusion temperatures are too high and/or when the material has not been dried prior to extrusion, recycled Onyx with the correct settings, commercial unrecycled Onyx filament*

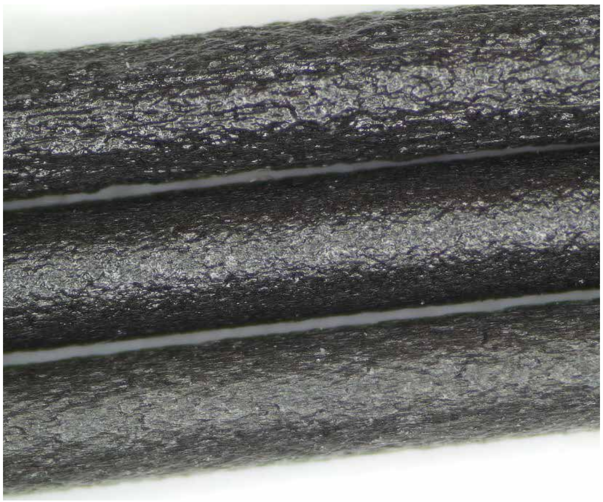

Figure 13 - *Microscope shot : close-up of Figure 12*

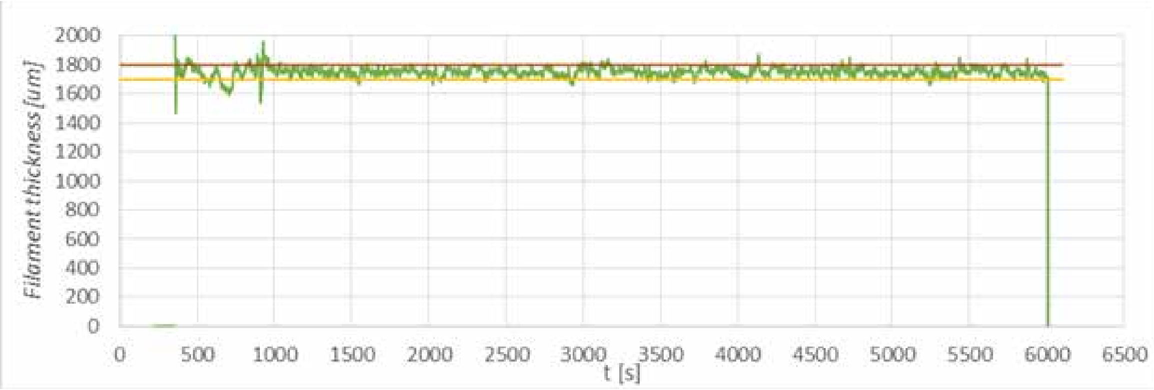

Figure 14 - *Datalog : filament thickness (set value : 1.75mm, red line : 1.80mm, yellow line : 1.70mm)*

***Figure 15 -** Spools of recycled Onyx*

7. CONCLUSION AND RECOMMENDATIONS

This extrusion experiment was extremely positive. Indeed, 1.75mm filament of great quality was obtained using a Precision equipped with a 2mm 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). The fact that the material could be processed at relatively low temperatures made the launching of the process a fast operation, but the purging was more tedious because of the strong black color of the formulation. Figure 15 is a picture of several spools which were obtained at 3devo in a few days of testing.

REPORT SUMMARY:

TO DOs:

- Keep temperatures around 250°C for optimal quality
- 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 Onyx with HDPE first. This is not mandatory but will save some Onyx

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 between 70% and 100% depending on the room conditions
- Rat holing must be taken care of regularly by stirring in the hopper manually or with the help of a continuously stirring device

Parameter	H4	H3	H2	H1	Screw speed	Fan speed
Set value	250 °C	260 °C	260 °C	238 °C	6.8 RPM	70%