Caverna™ PP

USER GUIDE

Microporous Build Material for Additive Manufacturing

Rev 1: 1/12/22

infinite™

infinitematerialsolutions.com

Table of Contents

1 Introduction

Meet Caverna™ PP. Infinite's microporous build material derived from a co-continuous blend morphology that enables the printing of porous, polypropylene parts on Fused Filament Fabrication (FFF) 3D printers. Caverna PP is composed of both a soluble and insoluble phase and is compatible with both Bowden and direct drive extruders.

This unique microporous 3D printed foam has applications in a variety of fields including filtration, separators, footwear, personal protective equipment, and whatever else your imagination can think up. The possibilities are truly infinite.

This is a special guide to the ins and outs of Caverna PP, featuring new tips for current Caverna users or 10,000-foot views for potential customers. It can also help inspire you to come up with the next big thing in additive manufacturing.

We can't wait to see what you do.

2 Overview

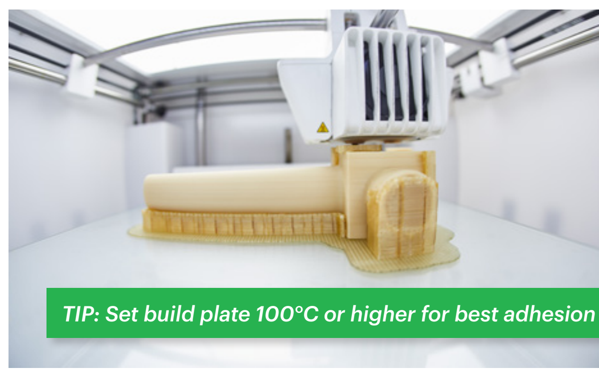
The porous network of Caverna PP is attained through a water-soak post-processing method. Follow specific post-processing instructions to obtain the desired 3D-printed, porous part.

To obtain the porous part, the as-printed part must have the soluble phase dissolved. Achieve this by submerging the as-printed part in hot water for an extended period of time (typically several hours). This allows the soluble phase to dissolve and vacate, leaving behind a uniform pore structure within the final part.

3 Prep

3.1 Build plate

We recommend using a printer with a heated build plate capable of reaching 100°C for printing Caverna PP. Printing with build plate temperatures as low as 80°C is possible, though large parts may have difficulty adhering to the plate at that temperature. We also recommend using a fixative adhesive (such Dimafix) to aid adhesion to the build plate.

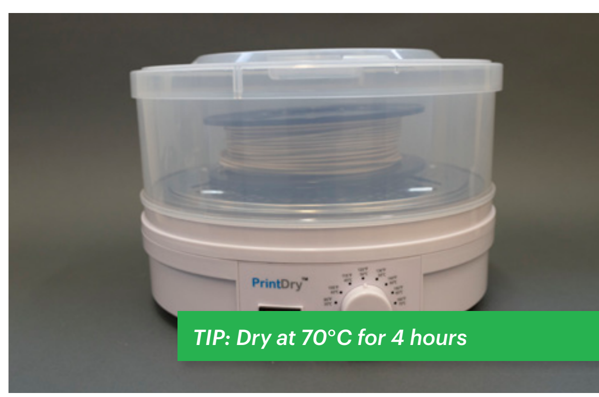


TIP: Set build plate 100°C or higher for best adhesion

4 Material handling

4.1 Moisture control and drying

Caverna PP filament is moisture-sensitive and should be stored properly when not in use to avoid moisture uptake. Store unused filament in a sealed bag in a cool, dry location. If filament has been exposed to humid air for more than 2 weeks, we recommend drying the filament at 70°C for 4 hours before use. Decreased print quality or popping sounds from the print nozzle are signs that Caverna PP may have absorbed too much moisture.



TIP: Dry at 70°C for 4 hours

Part design

5.1 Part design

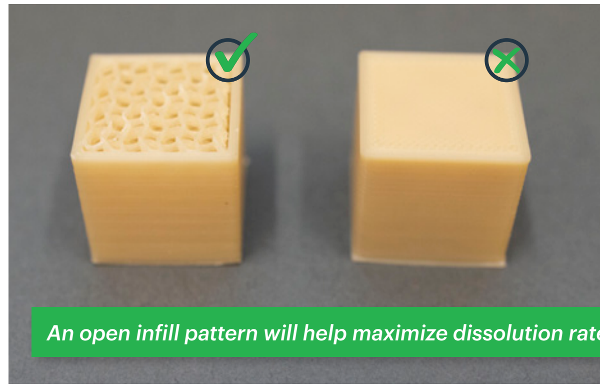
Part design has a significant impact on dissolution speed. The fastest dissolving parts will have a design where water easily contacts the majority of print lines. A part containing thick walls or closed internal areas will still dissolve, but will take longer.

Parts designed with an open infill pattern, such as a gyroid, and a relatively low infill percentage will maximize water flow and allow dissolution to occur quickly. For parts designed this way, water will only need to penetrate the outer walls and then will be able to flow freely throughout the interior.

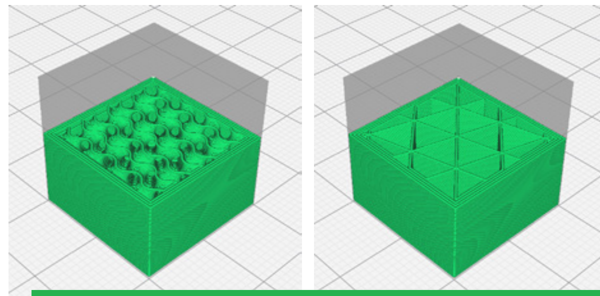
Some applications may require a high infill percentage in order to maximize mechanical properties. These parts still undergo dissolution, but it will take longer than parts composed of a lower infill percentage.

A comparison of dissolution time for several design variations is included in the dissolution section (7.1). For fastest dissolution, use the following design parameters and include a drain hole, if possible:

SETTING	RECOMMENDED
Exterior wall/top/bottom layers	3
Infill pattern	gyroid
Infill density	20



An open infill pattern will help maximize dissolution rate



A Gyroid infill (left) dissolves faster than other open infills, such as Triangle (right)

5.2 Drain holes

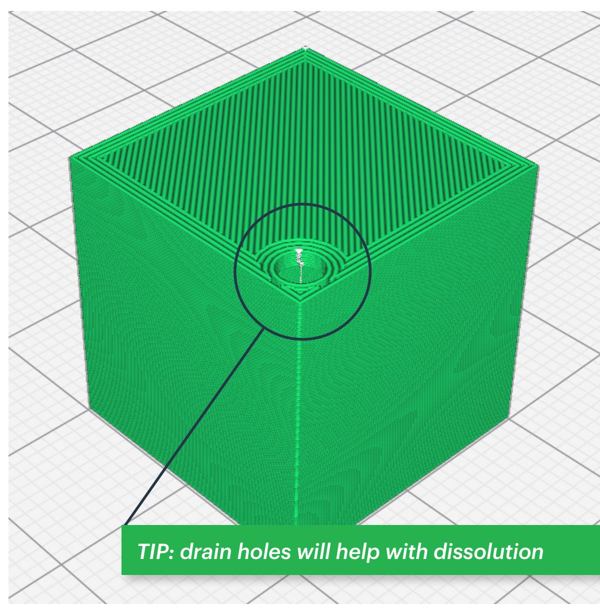
Add drain holes to a design to allow water an easier pathway to the interior of a part. Though not required, drain holes – when combined with a gyroid infill – significantly speed up dissolution.

Add drain holes in a CAD program through the following process:

- Shell the part, keeping a shell thickness equal to the number of desired exterior wall layer widths
- Cut out one or more drain holes in a noncritical region

If using Cura as the slicer, generate an infill-like structure within the shell by using the following support settings:

- Support Pattern = gyroid
- Support Density = 20%
- Support X/Y Distance = 0

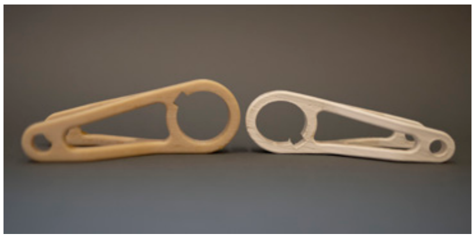


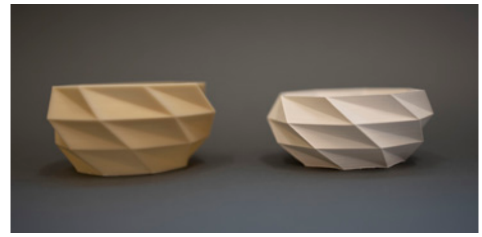
TIP: drain holes will help with dissolution

5.3 Scaling

After dissolution and drying, a final part will shrink slightly in the direction of the Z-axis. Scaling the part prior to printing can compensate for this dimension change. The compensation amount will depend on the layer height that is used, as shown in the table below. Scaling in the X- and Y-direction is not necessary.

PRINT LAYER HEIGHT	X-SCALE	Y-SCALE	Z-SCALE
0.1 mm	100%	100%	118-120%
0.2 mm	100%	100%	112-114%





Examples of printed part shrinkage after drying.

5.4 Suggested printing parameters

Caverna PP has a wide processing window for printing. When starting off, we suggest the print settings below for best results.

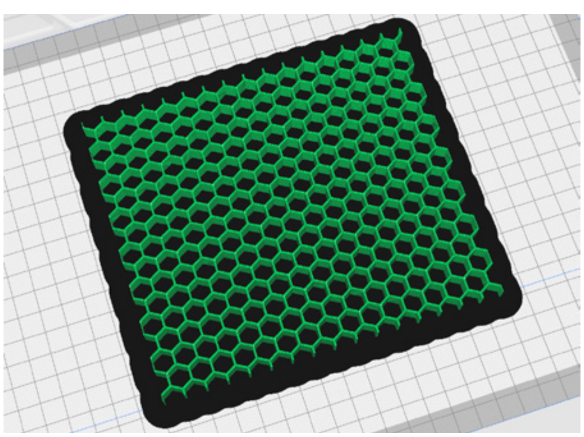
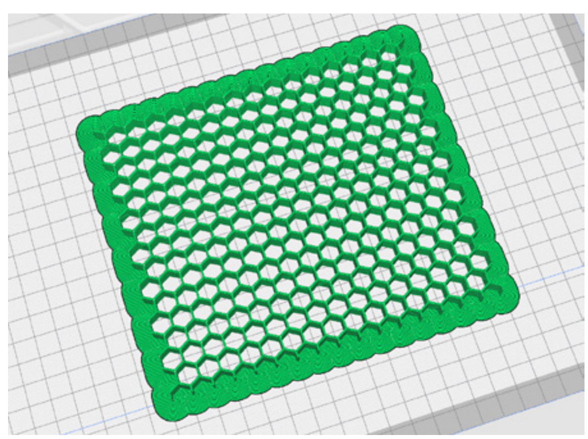
SETTING	RECOMMENDED	POTENTIAL RANGE
Nozzle Temperature (°C)	245	190 - 250
Build Plate Temperature(°C)	120	95 - 125
Print Speed (mm/s)	25	10 - 50
Layer Height (mm)	0.2	0.1 - 0.2
Infill Type	gyroid	Any infill
Infill Percent (%)	20	5 - 100

Caverna PP processes best when printed with a 0.2 mm layer height. These parts will exhibit less shrinkage than parts printed with 0.1 mm layer heights.

5.5 Rafts and brims

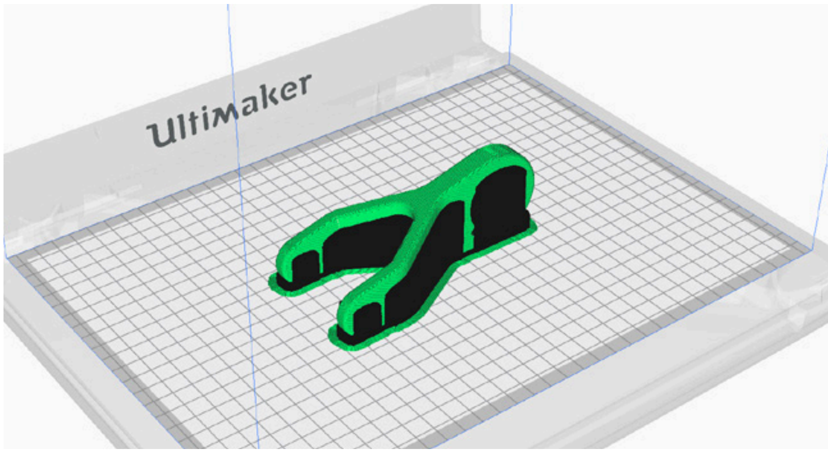
We recommend using one of two typical options to aid build plate adhesion when preparing your print:

- **Raft:** Adds a thick grid with a roof beneath the model. A raft of AquaSys® 120 soluble support works well for especially long prints.
- **Brim:** Increases the surface area contacting the build plate and will help prevent sharp corners of a print from curling upwards.

5.6 Support

Printed support is necessary anywhere your print has significant overhangs. Due to the water-soak post-processing phase, it is the most convenient to use a water-soluble support material. AquaSys 120 pairs perfectly with Caverna PP.



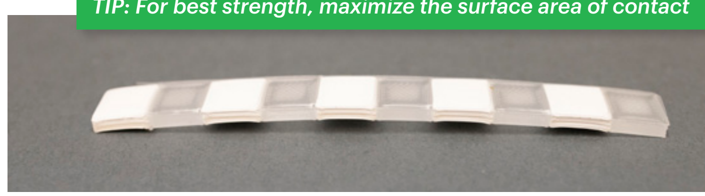
An example of using AquaSys 120 as a suitable support material

5.7 Multi-material prints

Caverna PP pairs well with polypropylene filaments as a second build material in multi-material prints. When pairing two different materials in a single print, the interface between materials will typically be a weak point. Maximizing the surface area of contact will make the interface as strong as possible.

If using Cura slicer, overlap the two STLs slightly. Cura will alternate the materials each layer in the overlapped section. This is the best way to attain a strong bond between two materials.

TIP: For best strength, maximize the surface area of contact



Printing

6.1 Build plate adhesion

Caverna PP adheres well to a hot build plate. However, very large and lengthy prints can be susceptible to plate pull-off. A build plate fixative (such as Dimafix) used on a glass build plate maximizes Caverna PP's adhesion to the build plate.

TIP: A build plate fixative will help adhesion

6.2 Warping

Caverna PP should not warp if properly adhered to the build plate during printing. If a part exhibits warping, ensure that the build plate is heated and use a fixative to increase plate adhesion. Additionally, modify the part design or orientation to increase the surface area contacting the build plate.

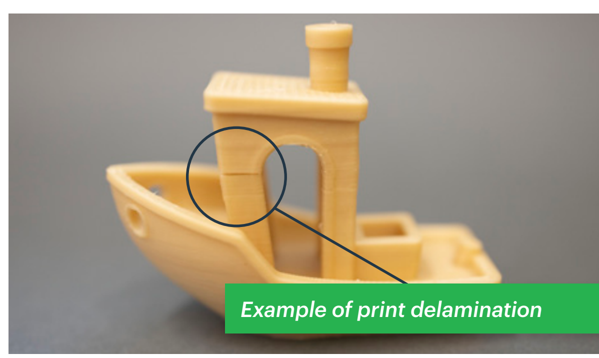
TIP: A heated build plate will help prevent warping

6.3 Print removal

Allow the build plate to fully cool before removing parts from the printer, especially if using a plate adhesive. If parts are removed from a hot build plate, there is a greater likelihood a part may fracture.

6.4 Part finish

After printing is complete, inspect all parts for defects. If delamination occurs during printing, the defect may intensify during post-processing.



Example of print delamination

7 Post-Processing

7.1 Dissolution

Caverna PP is composed of a blend of water-soluble and water-insoluble components. The final, porous structure of Caverna PP is formed when the soluble component is removed through dissolution.

7.2 Methods

Several different dissolution methods can be used to create the final porous part, though some methods can expedite the process:

- **Hot water bath:** Submerge parts in a water bath of 80°C water. If possible, stir or agitate the water bath to increase dissolution speed.
- **Pressure cooker:** A multicooker appliance with pressure cooking capabilities is the best tool to attain rapid dissolution. Using a setting which heats the part – while submerged in boiling water - under pressure is the fastest method of dissolution.

TIP: Maintain water at 80°C or greater for fastest dissolution

For all methods, use a volume of water equal to at least twice your part volume. As the soluble component dissolves, the water may begin to turn slightly yellow. If this occurs, refresh with clean water. The used water is drain safe.

7.3 Mass loss

The following sub-sections show plot comparisons of dissolution time for different heating methods and part design parameters. All samples were allowed to dissolve for 8 hours and were subsequently dried. Sample mass loss (post-dissolution dry weight/ initial weight) is plotted in each comparison. Complete dissolution is ~ 55% mass loss.

7.3.1 Water temperature and heating method

Fastest dissolution occurs when the water bath is greater than 80°C. This is most easily achieved using a pressure cooker to heat the water.

Figure 1 – Comparison of mass loss from dissolution.

Heating method: water baths heated in oven (no agitation). Samples were 20 mm cubes with 3 exterior layers and a 20% gyroid infill.

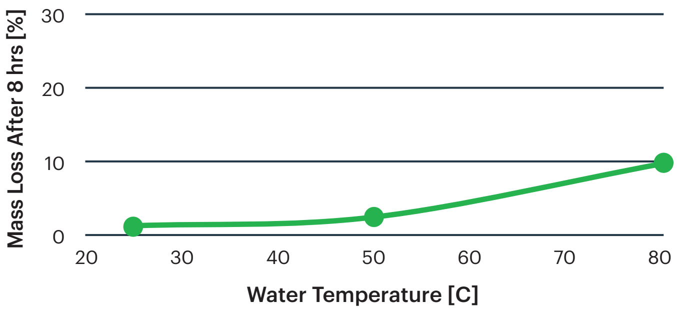
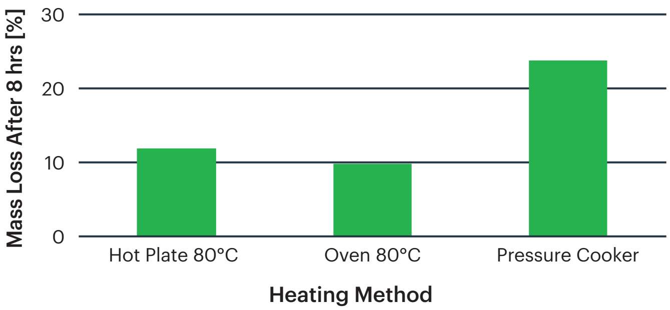


Figure 2 - Comparison of mass loss from dissolution.

Heating methods: differing. Samples were 20 mm cubes with 3 exterior layers and a 20% gyroid infill.



7.3.2 Number of exterior walls

Dissolution time decreases when fewer exterior walls are used. Additional walls create additional thickness which takes longer to dissolve.

Figure 3 – Comparison of mass loss from dissolution.

Heating method: pressure cooker. Parts containing different numbers of exterior layers.

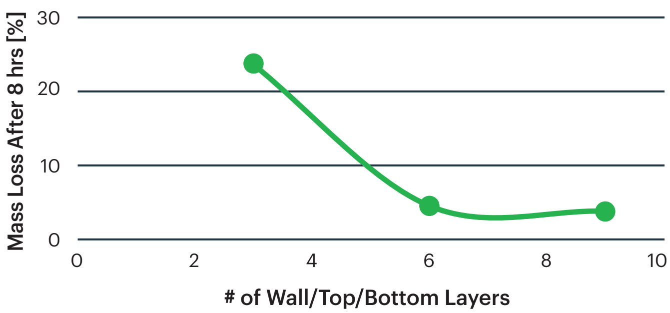
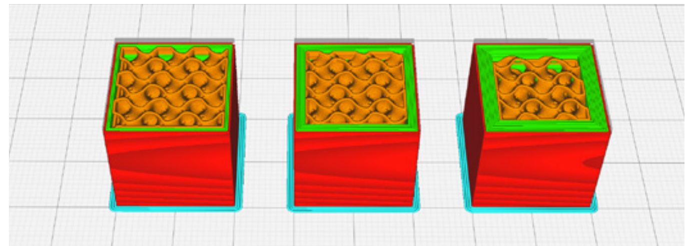


Figure 4 – Sample shapes compared in Figure 3. 20mm cubes designed with 3, 6, and 9 exterior layers (left to right).



7.3.3 Infill pattern

Dissolution occurs fastest when using an open infill, such as gyroid. Open infills allow water to reach and dissolve all surfaces of the part.

Figure 5 - Comparison of mass loss from dissolution

Samples with different infill patterns. Samples were 20 mm cubes with 3 exterior layers and a 20% infill density.

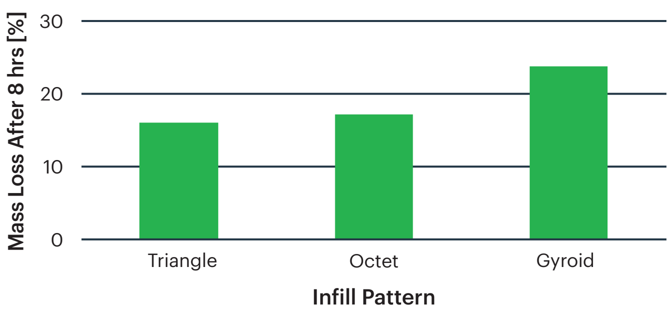
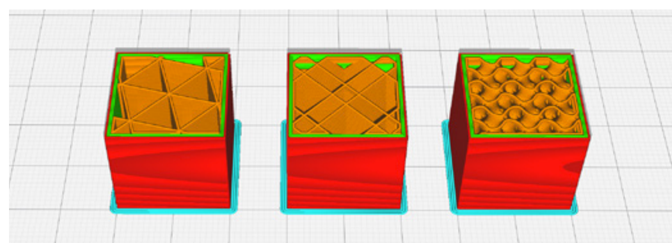


Figure 6 - Sample shapes compared in Figure 5. 20mm cubes designed with 20% triangle, octet, and gyroid infill patterns (left to right).



7.3.4 Infill percent

Dissolution occurs fastest when a low infill percent is used. This forms open passages for water to reach all surfaces. Low infill percent, however, can reduce the part's overall strength, so a higher percent may be necessary for certain applications.

Figure 7 - Comparison of mass loss from dissolution

Samples with different infill densities. Samples were 20 mm cubes with 3 exterior layers and a gyroid infill.

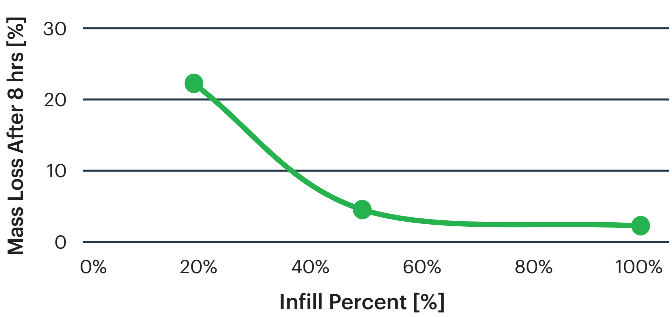
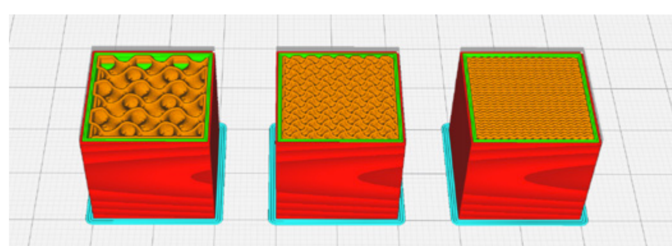


Figure 8 – Sample shapes compared in Figure 7. 20mm cubes designed with 20%, 50%, and 100% infill percent (left to right).



7.3.5 Enclosed vs. Open geometry

Enclosed parts (with walls on all surfaces) take longer for water to reach the interior, which increases overall dissolution time. Adding openness - through drain holes or removing surface walls - greatly increases dissolution speed.

Figure 9 - Comparison of mass loss from dissolution

Different degrees of enclosed samples.
Heating method: pressure cooker.

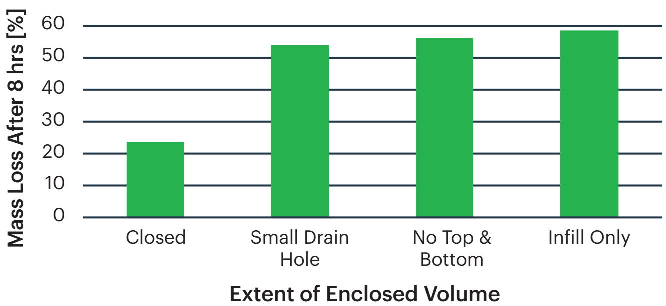
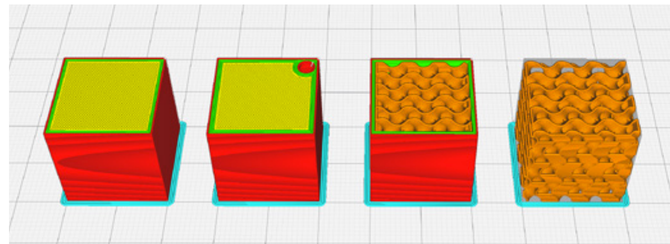


Figure 10 - Sample shapes compared in Figure 9. 20mm cubes designed with complete enclosure, a single drain hole, open top and bottom, and no exterior walls (left to right).

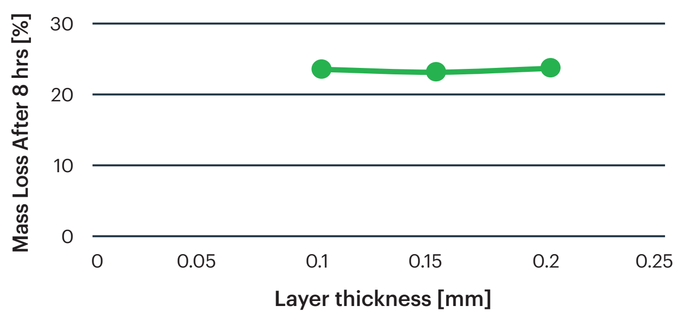


7.3.6 Print layer thickness

While different layer heights can impact the shrinkage of the dried part, dissolution time is not affected by layer height.

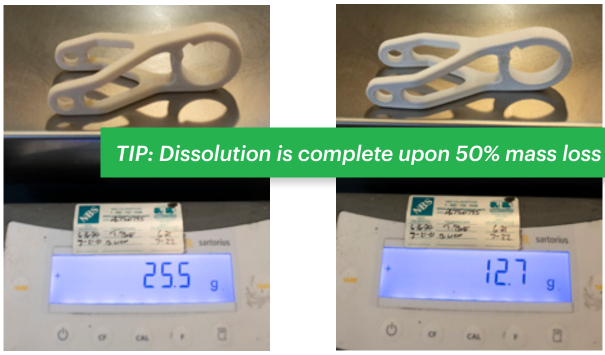
Figure 11 - Comparison of mass loss from dissolution

Differing layer heights during printing. Heating method: pressure cooker. Samples were 20 mm cubes with 3 exterior layers and a 20% gyroid infill.



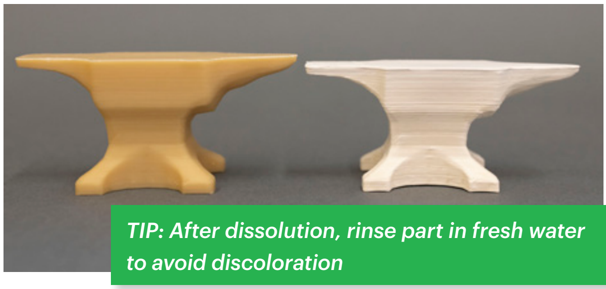
7.4 How to tell when dissolution is complete

- The best way to determine when dissolution is complete is by comparing the pre- and post-dissolution mass of the part. Dissolution is complete when the part has about half the mass as the pre-dissolution mass. Dry the part before weighing to ensure the mass is not influenced by water retained from dissolution.



TIP: Dissolution is complete upon 50% mass loss

- For thin-walled parts, a change in color can also be used to indicate dissolution. This should only be used if the print is sufficiently thin and open for water to contact most of the print lines. As dissolution occurs, the part will change from a tan color to white. Be cautious if using this method. The surface of thick parts will turn white long before the interior has fully dissolved.



TIP: After dissolution, rinse part in fresh water to avoid discoloration

7.5 Drying

After removing the part from the dissolution bath, water will be retained in its micropores. It is important to dry your part before use to remove the retained water.

Drying time will vary depending on several factors including part size, surface area, and access to interior features. Observing mass loss is the best way to determine when a part is completely dry.

For many parts, drying at 60 - 80°C for 8 hours will be sufficient.

If tan spots appear on the surface of your print during drying and your part has reached full mass loss, this is an indication that soluble material was on the part surface prior to drying. Rinsing and wiping the part surface with fresh water prior to drying will prevent these spots from forming.

TIP: Make sure to rinse your part off after dissolution is complete

7.6 Swell and shrinkage

During dissolution, the part will swell slightly in the Z-axis direction. After dissolution, the part will shrink in the Z-Axis direction. As described in the Part Design section, it is important to scale your prints accordingly so that the desired dimensionally accurate part is obtained.

With the help of this guide, we hope your understanding of Caverna PP has grown. Now it's up to you to make the most of this innovative build material. Enjoy.

infinite™

Infinite is an innovation house dedicated to disruptive materials, by design. In other words, we create unique, highly differentiated materials for the additive manufacturing industry. Our company is the joint venture of Nagase America, a leader in specialty material manufacturing, and Interfacial Consultants, a leader in developing material science-based technology platforms.

Our proprietary materials can be found in the simplest parts and the most complex solutions. They solve previously unsolvable problems across industries, from the far reaches of space to the soles of running shoes. Infinite products work with FFF and pellet-based extrusion printers — and this is just the beginning.

Talk to one of our experts about how Caverna PP can work for your applications:

Contact us at **info@infinitematerialsolutions.com**.

Or visit **infinitematerialsolutions.com** to learn more.

Caverna™ PP

Infinite Material Solutions™ | N4660 1165th St. | Prescott, WI 54021 | 1 (347) 487-8880 | info@infinitematerialsolutions.com