Investment Casting with PolyCast™

1. Overview

PolyCast™ is an entirely new 3D printing filament designed specifically for investment casting applications. This document provides the basic information regarding the printing and post-processing of the material, as well as a practice guide for investment casting processes using 3D printed PolyCast™ patterns.

2. Brief introduction

Investment casting produces metal parts with excellent surface finish and dimensional accuracy. This manufacturing process is compatible with a large number of metals & alloys, such as steel, stainless steel, aluminum alloy, bronze, etc.

Figure 1. Rapid production of metal parts using PolyCast™ and 3D printing

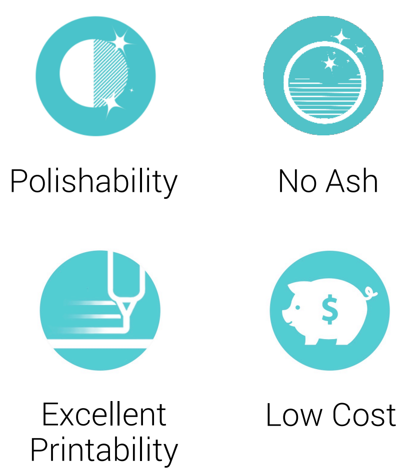
Traditional investment casting processes utilize injection molded wax patterns. The tooling required is both time- and cost-intensive.

3D printing has been increasingly used as an alternative method to produce investment casting patterns, especially for small-volume production runs, as it cuts down both the cost and lead time significantly by eliminating the tooling process. In addition, 3D printing enables a larger design freedom as the technology can afford much greater geometric complexities than the injection molding process.

PolyCast™ is an entirely new 3D printing filament, designed specifically for investment casting applications. It enables the use of widely available filament-extrusion based 3D printing technologies (e.g. FDM/FFF) to produce investment patterns.

The key advantages of PolyCast™ include:

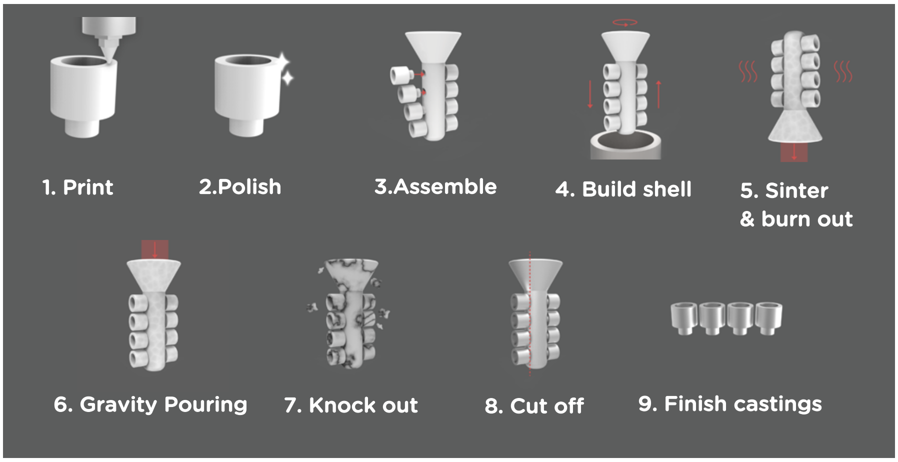
- Compatible with Polymaker's Layer-Free™ technology, delivering superior surface quality while minimizing the need for post-processing after casting;
- PolyCast™ burns off cleanly without any residue, enabling defect-free metal parts;
- Can be used on any FDM/FFF printer with excellent printability;
- Lower cost compared to other 3D printing technologies (e.g. SLA/DLP/SLS).



Comparison between conventional wax-based investment casting and PolyCast™

	Conventional investment casting	Investment casting with PolyCast™
Tooling cost	$ 10,000 – 1000,000	$ 0
Lead time	> 5 weeks	< 2 weeks

3. Process Overview



The video of PolyCast™ can also help you understand this process. (https://www.youtube.com/watch?v=Un3dpy9Og5Q)

4. 3D printing with PolyCast™

PolyCast™ (available in both 1.75 and 2.85 mm diameters) can be used on almost any filament-extrusion based 3D printer that allows 3rd party materials. The material is engineered to offer excellent printability with easy support removal. Below is a quick guide to get you started with printing PolyCast™.

4.1. Prepare your 3D printer

PolyCast™ patterns can be produced on the vast majority of the filament-extrusion based 3D printers in the market. Any printer compatible with printing PLA is expected to work with PolyCast™. The following printers are some examples which have also passed Polymaker's long-term test:

- Makerbot Replicator+ / Mini+ / Z18 / 2 / 5th generation / Mini
- Ultimaker 3 / 2+ / 2 GO / Original+
- LULZBOT TAZ 6 / TAZ 5 / MINI

- MakerGear M3 / M3 independent Dual / M2 / M2 Dual
- BCN3D Sigma / +
- Zortrax M300 / M200
- Raise3D N2 / N2 Plus
- CEL Robox
- MASS PORTAL Pharaoh XD 20 / Pharaoh XD 30 / Pharaoh XD 40
- FLASHFORGE Creator pro / Dreamer
- XYZPrinting da vinci Pro
- 3D Platform

4.2. Slicer settings

Below are recommended slicer settings for printers with standard 0.4 mm nozzles. The parameters can be modified to suit any particular printer set up.

Parameter	Recommended Setting
Nozzle temperature (°C)	200 – 230
Build surface material	Glass, Blue Tape, BuildTak®
Build surface treatment	Not required if heated to 60-70 °C; Or apply PVA glue to the build surface
Build plate temperature (°C)	0 - 70
Model cooling fan	Turned on
Printing speed (mm/s)	40 – 90
Raft separation distance (mm)	0.1 - 0.14
Retraction distance (mm)	1 – 3
Retraction speed (mm/s)	30 – 40
Recommended environmental temperature (°C)	20 – 30
Threshold overhang angle (°)	60
Recommended support materials	S02N (PI), or PVA

Other comments：

- Print patterns with minimal infill (e.g. 10%) and number of shells (2-3). This facilitates the pattern burnout process, and can prevent potential damage to the ceramic shell.

- Apply shrinkage compensation to the STL file. The dimensional change of printed PolyCast™ patterns during the casting process is negligible, so you only need to consider the shrinkage of metal from the molten to solid state. Modify the size of the model by the metal/alloy-dependent compensation factor, which is typically between 1.007-1.030. For example, the compensation factor for steal is 1.025-1.030. Therefore if the expected dimension of the metal part is 1 m, the dimension of printed patterns should be 1.025-1.030 m.

- Pattern designs for traditional wax processes may be used directly for 3D printing, and it is ideal for producing small numbers of prototypes of parts that will eventually be mass manufactured using the wax process. However for making end-use parts, users are encouraged to "design for 3D printing", i.e. take advantage of 3D printing and optimize the part geometry to improve both printing quality and efficiency. For a complete guide, check out this article by 3D Hubs: https://www.3dhubs.com/knowledge-base/how-design-parts-fdm-3d-printing

- Choose a suitable orientation to place the model on the printer platform, to minimize support structure as much as possible. It is helpful to improve both printing efficiency and surface finish.

- Use a typical layer height of 0.1-0.2 mm. This ensures a reasonable spatial resolution and facilitates the post-processing.

4.3. Handling and storage

PolyCast™ is sensitive to moisture. Please keep filament under dry conditions (relative humidity of no more than 20%) during storage and utility. One good solution is to use Polymaker's PolyBox™ (purchased separately).

Figure 2. PolyBox™ - the perfect solution for storing 3D printing filaments

Moisture within the patterns is not acceptable because it will affect the pattern burnout process, which increases the possibility of failure from shell cracking. To dry the printed patterns, expose the patterns to well-circulated hot air at 50 °C for at least 1 hour.

5. Post-processing of 3D printed patterns

The surface finish of patterns will have a strong effect on the casting process as well as the surface finish of final metal parts, so it is very important to polish the surfaces of patterns through post-processing.

5.1. Layer-Free™

PolyCast™ is compatible with Polymaker's Layer-Free™ technology, which is the recommended technology for post-processing 3D printed patterns. The technology works by exposing the printed model to a dense mist of tiny (< 10 μm) alcohol droplets, which are absorbed locally onto the surfaces of the printed model and subsequently make them smooth (with layer lines no longer visible), while preserving macroscopic dimensional accuracy. The process can be done seamlessly using Polymaker's desktop machine, the Polysher™ (purchased separately).

Figure 3. Polish the PolyCast™ pattern by Polysher™

The polished part will exhibit fully sealed surfaces with a smooth and glossy finish. This is critical for the success of investment casting, for a number of reasons:

- The porous surfaces on many FDM/FFF parts can result in penetration of the slurry that leads to defects in final metal parts. Fully sealing the surface eliminates this problem.
- A smooth surface finish facilitates the slurry coating process. In contrast, a rough surface with layer lines can lead to issues such as trapped air bubbles, which in turn can cause defects in final metal parts.
- The smooth surface finish ensures high surface quality of the final metal parts and minimize the need for post-processing (e.g. surface polishing).

Follow the steps below to polish a printed PolyCast™ pattern (using the Polysher™)

STEP 1 (optional): Use sand paper (800-grit or similar) to remove any major seams or surface defects of the printed pattern. Remove dust and debris.

STEP 2: Use the Polysher™ to process the printed pattern. Follow the correct procedure when operating the Polysher™. Depending on the size, ambient temperature, alcohol concentration, etc., it may take anywhere between 20-60 minutes to polish the pattern. Place the part on the Polysher™ platform in a way that allows maximum and even exposure of all surfaces to the alcohol mist. It is recommended to “hang” the part by attaching it to a wire or similar material on a stand, or raise the bottom using a base with small contact area.

STEP 3: Allow the print to dry for 20-30 minutes. Inspect the print. Repeat STEP1-2 if more polishing is needed.

STEP 4: Place the polished pattern in a vacuum (preferred) or convection oven at 40 °C for at least 1 hour to ensure complete solvent evaporation and surface hardening.

If access to a Polysher™ is not available, or the pattern exceeds the maximum size of the Polysher™, two alternative polishing techniques can be considered: dip polishing and spray polishing. Unlike using the Polysher™ both techniques require certain extent of practice to accumulate enough experience and achieve good results.

The following are recommended steps for dip and spray polishing:

5.2. Dip Polishing

STEP1 (optional): Use sand paper (800-grit or similar) to remove any major seams or surface defects of the printed pattern. Remove dust and debris.

STEP2: Attach a wire or similar material to suspend the prints.

STEP3: Immerse the print in isopropyl alcohol or ethyl alcohol for 5-10 seconds typically. You can use multiple short immersions to get stronger polishing effect.

STEP4: Allow the print to dry for 20-30 minutes. Inspect the print. Repeat STEP1-4 if needed.

STEP5: Allow the part to rest in a vacuum(preferred) or convection oven at 40 °C for 1 hour to ensure complete solvent evaporation and surface hardening.

Figure 4. Dip the PolyCast™ pattern into isopropyl alcohol

5.3. Spray Polishing

STEP1 (optional): Use sand paper (800-grit or similar) to remove any major seams or surface defects of the printed pattern. Remove dust and debris.

STEP2: Attach a wire or similar material to suspend the print or put it on a base with small contact area.

STEP3: Spray isopropyl alcohol or ethyl alcohol on the print surface.

STEP4: Allow the print to dry for 20-30 minutes. Inspect the print. Repeat STEP1-4 if needed.

STEP5: Allow the part to rest in a vacuum(preferred) or convection oven at 40 °C for 1 hour to ensure complete solvent evaporation and surface hardening.

Figure 5. Spray isopropyl alcohol on the PolyCast™ pattern

6. Investment casting process with PolyCast™ patterns

In most cases PolyCast™ patterns can be used in a similar way as traditional wax patterns, with no or minimal modification to the casting process. However, in order to achieve high success rates and consistent results, we still recommend that you follow or at least start with the following "best practice" guide.

6.1. Build casting tree

The casting tree can be built using the same method as wax patterns. PolyCast™ patterns adhere well to the wax.

Additional vents/gates may be added to promote air flow during the burnout process. Another effective way to promote air flow is to drill through the outer shell of the pattern at the gate location.

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6.2. Make ceramic shell

Build up the ceramic shell around the casting tree by using the standard process of the foundry. Use silica sol/gel, colloidal silica, etc. as slurry systems for Polycast™ (avoid using sodium silicate). The number of coatings can be between 4-9 and varies by foundries (also by parts). We recommend 5-6 coats (no less than 5) for PolyCast™ as this has been found to produce the most consistent results. If the patterns contain some fine structures (e.g. turbine blades), we recommend 7-9 coats to prevent any potential risk of shell cracking.

6.3. De-waxing

Use high temperature steam to remove the wax tree. The PolyCast™ will still remain in the ceramic shell (the pattern may soften or deform) which is normal – it will be burned off in the sintering process. You can choose to skip the de-waxing step entirely if recycling the wax is not a priority; in this case the wax will simply be burned off in the kiln together with Polycast™.

6.4. Sinter ceramic shell and burnout

Heat the kiln to 1100-1200 °C for an extended period of time (up to 40-60 min) to simultaneously sinter the ceramic shell and burn out the PolyCast™ patterns. The optimum burnout temperature and time may be determined by each foundry for the metal/part to be produced and the specific kiln or furnace used.

Figure 6. Adhere the PolyCast™ pattern to the wax tree

Figure 7. Make the ceramic shell

Figure 8. Sinter the ceramic shell and burnout

Figure 9. Rinse the shell

6.5. Rinse shell

Rinse the ceramic shell (after cooling down to ambient temperature) by water to remove any residual ash that may still be present. We recommend the rinse step just as a "safe" option for foundries to get started, in case the burnout process is not yet optimal which can leave small amount of ash in the shell . Once the foundry is more experienced with the process they can skip the shell rinsing step upon their choice. In our experience foundries can get excellent results without this step.

Figure 10. Pour the molten stainless steel into the shell

6.6. Cast

Once the ceramic shell is fully prepared and clean, complete the casting process by following the standard practice for the designated metal/alloy. Steps may include pre-heating the shell, pouring the molten metal/alloy to the shell, allowing the shell to cool, removing the shell, cutting off gates, machining, heat treatment, etc.

7. Critical success factors

7.1. Pattern

- Use minimal infill and number of shells
- Maintain the filament dry
- Dry patterns thoroughly before making ceramic shell

7.2. Ceramic shell

- Use silica sol/gel or colloidal silica
- Use at least 4-6 slurry coats

8. Printing and casting service

You can contact 3DHubs (https://www.3dhubs.com) if you need such service.

9. Safety

Observe manufacturer's recommendations for safety, material handling and storage, before using any chemical solvent and instrument in polishing process. This information can be found in the Safety Data Sheet (SDS).

10. Contact

Please contact us through support@polymaker.com