SLA Best Practices

SLA Best Practices QuickCast Investment Casting Guide

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Original Instructions



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1 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE ACCURA FIDELITY AND ACCURA CASTPRO

	ACCURA FIDELITY	ACCURA CASTPRO
Applications	• Medium to large size patterns without tooling • One-off investment castings • Low production runs investment castings • Any casting materials	• Medium to large size patterns without tooling • One-off investment castings • Low production runs investment castings • Any casting materials
Benefits	• Accurate QuickCast patterns • Clean burnout with ultra-low ash content (<0.010%) • Patterns dimensional stability • Fast and effective pattern draining • Designed to eliminate bubble formation	• Accurate QuickCast patterns • Patterns dimensional stability • Fast and effective pattern draining • Surface rigidity right out of the printer • Lower cost
Features	• Antimony-free material • Ultra-low coefficient of thermal expansion • Excellent humidity/moisture resistance • Low viscosity material • Clear material	• Low coefficient of thermal expansion • Clear material
Datasheet	https://www.3dsystems.com/sites/default/files/2020-12/3d-systems-accura-fidelity-datasheet-usa4-2020-10-06-a-print.pdf	https://www.3dsystems.com/sites/default/files/2020-11/3d-systems-accura-castpro-datasheet-usen-2020-09-15-a-print.pdf

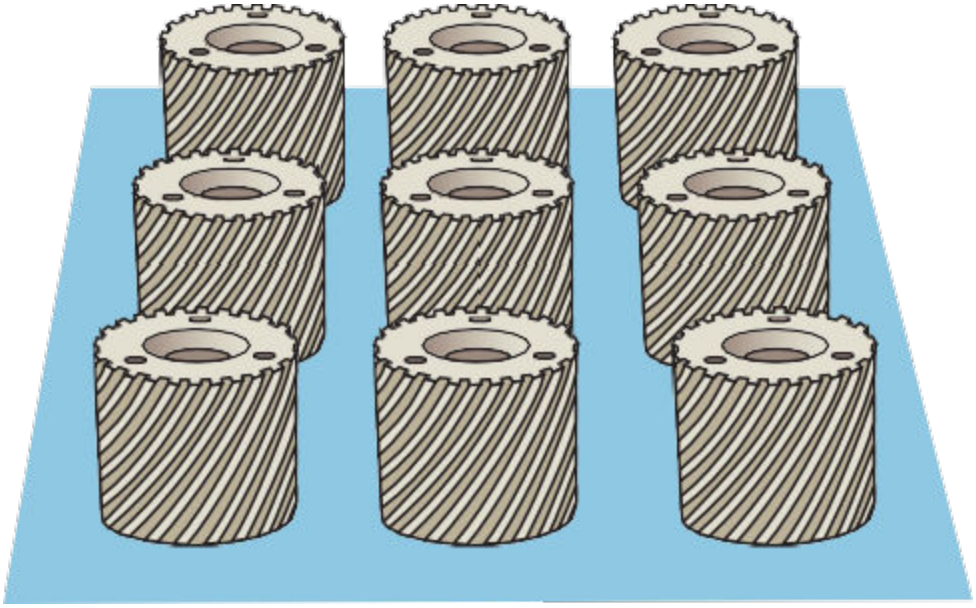
2 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE
QUICKCAST VS QUICKCAST DIAMOND

	QUICKCAST® HEX	**QUICKCAST® DIAMOND**
Description	QuickCastHex build style consists of a hollow SLA pattern with an internal **hexagonal honeycomb-like** support structure. Quickcast is available with all current and legacy 3D Systems' printers.	The QuickCast Diamond is a new build style consists of a hollow SLA pattern with an internal **diamond lattice** support structure. QuickCast Diamond is available with 3D Systems' current generation SLA printers and 3D Sprint PRO additive manufacturing software.
Benefits	• Hollow build style reduces the amount of material to burn out. • Capable of producing large assemblies. • Rapid production compared to traditional tooling. • Provides invaluable shrink and gating information prior to hard tooling. • High dimensional stability. • Create complex master patterns in hours instead of days/weeks at a fraction of the cost of traditional tooling.	• Hollow build style reduces the amount of material t burn out. • Capable of producing large assemblies. • Rapid production compared to traditional tooling. • Provides invaluable shrink and gating information prior to hard tooling. • High dimensional stability. • Create complex master patterns in hours instead of days/weeks at a fraction of the cost of traditional tooling. • Up to 30% lighter parts. • Up to 20% faster print times. • Consistent part strength across X,Y, Z geometries throughout casting. • Increase print yield through adaptive lattice structures. • Easily add drains and vents to any surface in 3D Spr

3 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE
OVERVIEW OF INVESTMENT CASTING WITH QUICKCAST STYLE PATTERNS

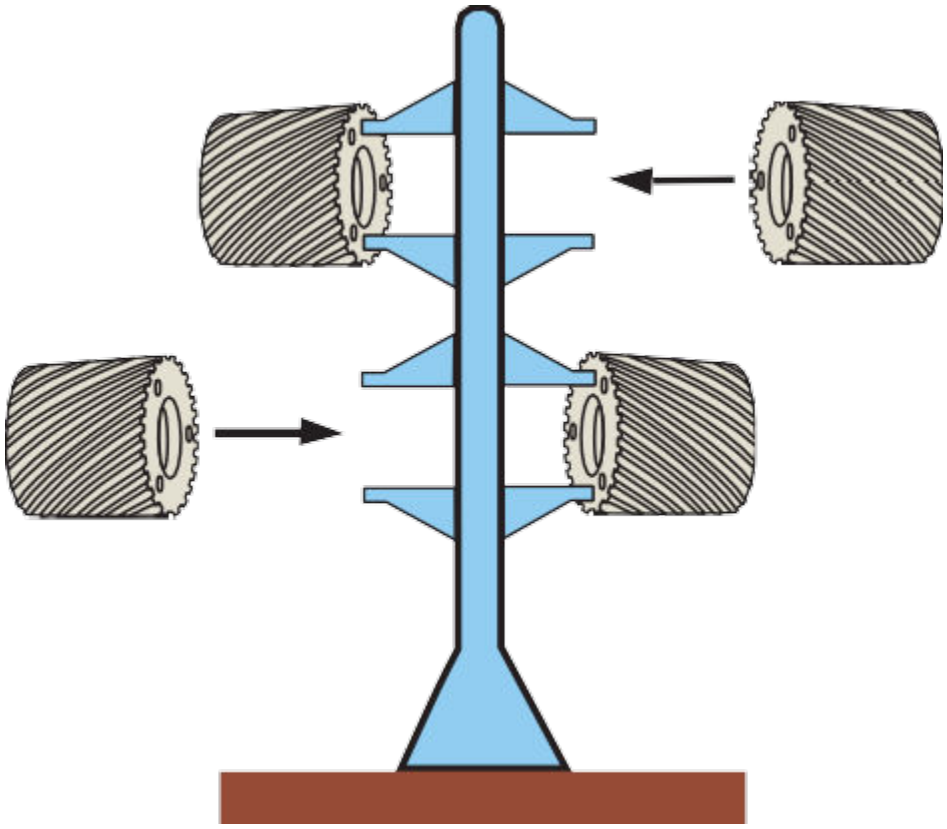
STEP 1

The QuickCast style pattern(s) are produced on a 3D Systems SLA stereolithography systems. Using QuickCast style patterns reduces cost and time by eliminating the tooling necessary to injection mold a wax pattern.



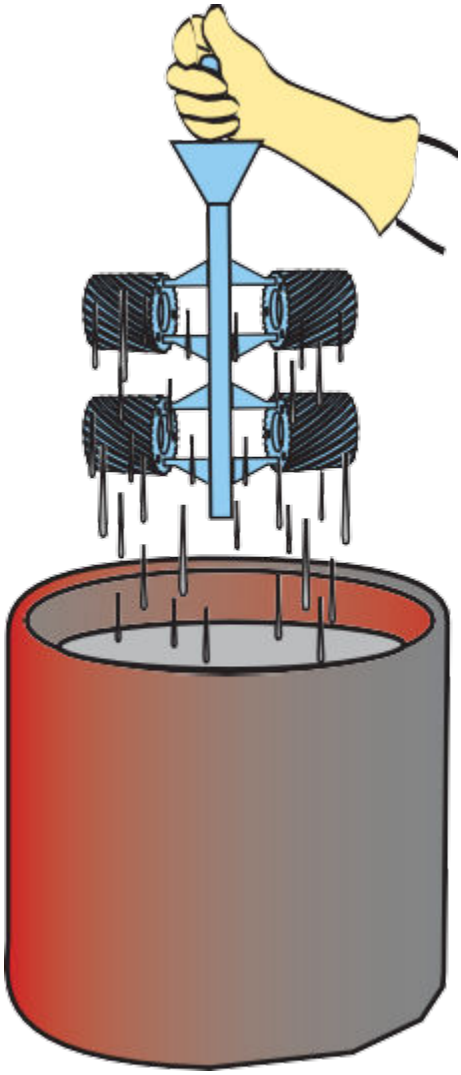
STEP 2

The QuickCast style patterns are attached to a sprue (central wax bar) with gates (wax runners) to form a cluster or tree.



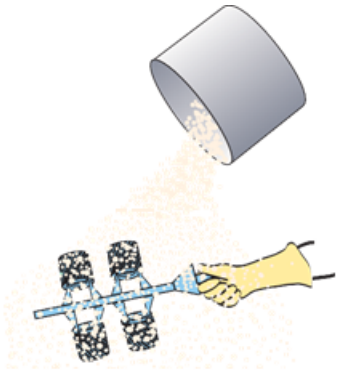
STEP 3

The shell mold is built by dipping (investing) the tree into ceramic slurry. The first layer is a "facecoat" of very fine slurry that will aid in reproducing fine, detailed features.



STEP 4

Then the shell is coated with fine ceramic refractory grains (sand). After drying, this process of dipping and coating is repeated with coarser refractory grains to obtain the desired shell or mold thickness.

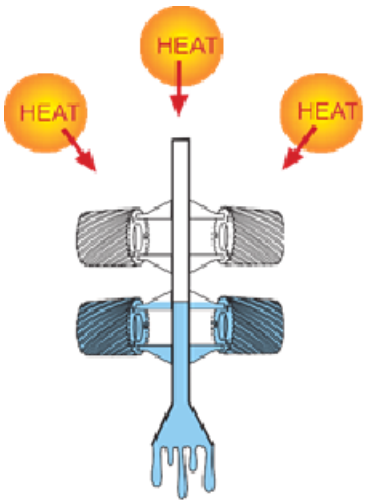


STEP 5

Once the shell mold is dry, it is heated in an Autoclave to allow the wax sprue and gates to run out. Alternatively, you may also melt out the wax sprue and gates during the next step in a flashfire furnace.

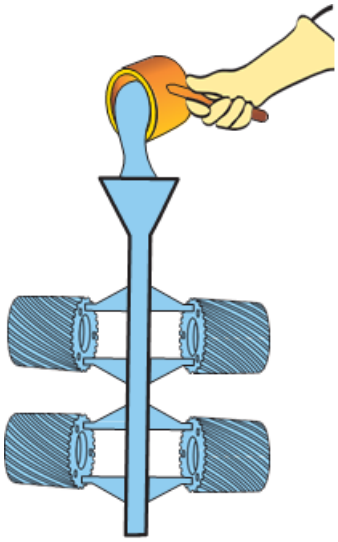
STEP 6

The tree is heated in a Flashfire furnace at high temperature to sinter the mold and remove the QuickCast pattern. Removing the wax and QuickCast pattern has now produced a negative impression of the assembly.



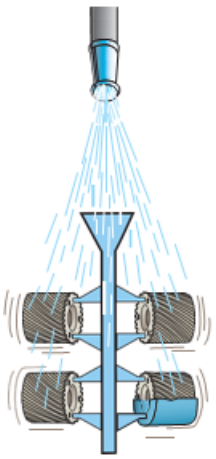
STEP 7

Molten metal is poured into the pre-heated mold by gravity, pressure, vacuum or centrifugal force. As the metal cools; the parts, gates and sprue become one solid casting.



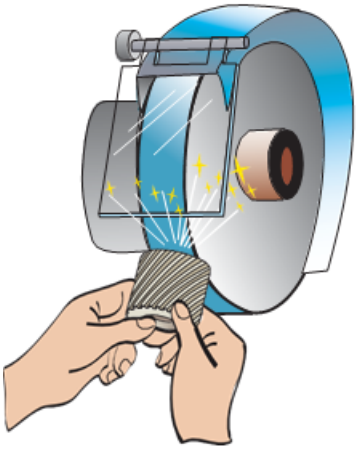
STEP 8

When the metal has cooled and solidified, the ceramic shell is removed by mechanical vibration, chemical cleaning or water blasting. The method may depend on the particular metal cast.



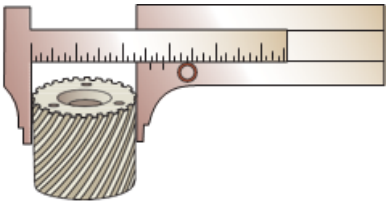
STEP 9

Parts are cut from the sprue and gate stubs and then ground smooth. Parts are now ready for straightening, tempering or additional processes.



STEP 10

Inspection for dimensional accuracy, material density, mechanical properties, etc.



4 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE RECEIVING THE QUICKCAST BUILD STYLE PATTERN

To ensure a quality cast is achieved, it is important to inspect the patterns for leaks or imperfections before you begin processing it.

Visual Inspection: Upon arrival of your pattern, you should perform a visual inspection. Carefully look over the pattern for surface flaws or cracks that may have occurred during shipping. These will cause defects, such as inclusions to the casting. The pattern should have rigid or stiff surfaces. Inspect the pattern for any solid sections. If there are solid walls over about 0.050" thick that are larger than about a ½ inch square, it may be cause expansion and shell cracking in autoclave or flashfire burnout. Of course, it will not be possible to inspect for solid sections after the pattern is shelled so it is important to do it now.

Dimensional Inspection: In order to produce a dimensionally correct casting, it is imperative to know the dimensions of the pattern. Measure and record critical dimensions. 3D Systems On Demand will provide inspection reports of extents dimensions, or at your request, any critical features/dimensions from drawings if provided or otherwise, features selected at their discretion. . Remember, however, that the pattern will include allowances for metal shrink, therefore don't compare the pattern dimensions you measure to the desired dimensions on the final metal casting. As a general rule, it is good practice to require that the pattern does not contribute more than 50% of the tolerance of the finished casting. Any unacceptable dimensions should be reviewed with the supplier to determine cause and pattern replacement if required.

Leak Inspection: It is critical that the QuickCast pattern be completely sealed and leak proof to prevent slurry from flowing into the internal structure, causing an inclusion or other casting defect. Perform this leak check upon receipt - before doing any addition of wax gates, and again just before introducing the pattern to the shelling process. The pattern should have been vacuum tested by your supplier before shipment. However, the foundry will need to verify with a vacuum test to ensure that the pattern was not damaged in shipment.

If the pattern does not have a tube or port to attach a vacuum hose, you will need to add one, or you may prefer to use a soft rubber tip on your vacuum hose that can be placed over the hole left and marked on the pattern by the supplier. If adding a tapered port to fit onto your vacuum hose, bond the port over the marked hole.

Using a hose attached to the port on the pattern and an automotive vacuum leak tester or other pump draw a vacuum on the pattern to 10 in of mercury (250 mm of Mercury). Too much vacuum may damage the pattern, crushing it. If the vacuum holds and does not leak, the pattern is indeed properly sealed. A vacuum leak will indicate there is a hole somewhere in the pattern.

To find a hole, use a low pressure regulator to blow 1-10 psi (7-70 kPa) into the port on the pattern. Too much pressure will damage the pattern, blowing it apart. Find the hole by feeling or listening for escaping air. Additionally, the part may be submerged in liquid - escaping bubbles will identify the area with a leak. Alternatively, a solution of dishwashing soap and water can be brushed onto the part.

Seal any leaks using the Checking for Holes or Leaks section found in the QuickCast Post Processing Guide. Repeat the vacuum test to verify the pattern is totally sealed.

Storing the Pattern: If the pattern will not be used immediately, store it in a cool, dry environment, away from ultraviolet sources. Continued exposure to ultraviolet (sunlight and fluorescent lights both have high UV contents) will change material properties over time and may make the pattern unusable. In addition, most SLA resins will absorb moisture over time, which can affect both dimensional accuracy and stiffness. Storing the part in a sealed black plastic bag with desiccant is recommended. Prolonged storage may require re-checking dimensions and leaks on the pattern.



Include desiccant with your QuickCast style pattern in a sealed bag.

5 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE PATTERN ASSEMBLY

As with wax patterns, QuickCast patterns must be incorporated into a system that includes the pouring cup, sprue, runners and gates.. Creating an assembly with QuickCast patterns is similar to creating an assembly with wax patterns, but there are a few areas in which care must be taken. This section covers those areas.

5.1 SLA Best Practices Quickcast Investment Casting Guide Gating - Sprues and Runner

Gates and runners can made using a QuickCast material or fabricated wax material or a combination of both. You would either design the entire model with gates to be built and assembled as a QuickCast pattern, or you could leave the gates out of the model and plan to attach molded or hand fabricated wax gates.

There are significant advantages of using QuickCast for the majority if not all of the gates in your assembly.

- Consistency from pattern to pattern
- Assembly time savings
- Elimination of the autoclave step to remove wax from the mold before burning out the plastic.

QuickCast sprues and runners typically make sense only for very small components where the entire assembly can be built in one piece. If QuickCast sprues and runners are used, and they are made in multiple pieces, it is important that a path for airflow is created between the components during assembly. For example, if a QuickCast pattern is to be glued to a QuickCast sprue, holes should be drilled in each of the mating surfaces and aligned so that when they are glued together, there is a path for airflow from one component to the other. That flow path is critical in the burnout phase of processing.

As normal, gating is to be considered not only for feeding the metal into the cast part, but as structural components during the shelling process. Over-gating will have advantages for QuickCast patterns - it allows for better oxygen flow throughout the assembly during the burnout process; and adds strength to the assembly to withstand forces during the dipping process.

Because the QuickCast pattern is mostly hollow and filled with air, its density is significantly less than that of slurry. Dipping a QuickCast pattern may be somewhat similar to pushing a beach ball under the surface of a pool. The resulting buoyancy forces stress the attachment points, and if the pattern is not attached securely, the pattern can break away from the sprue. Over-gating increases the ability of the assembly to withstand buoyancy forces. In extreme cases, it may be necessary to add additional strengthening features as well.

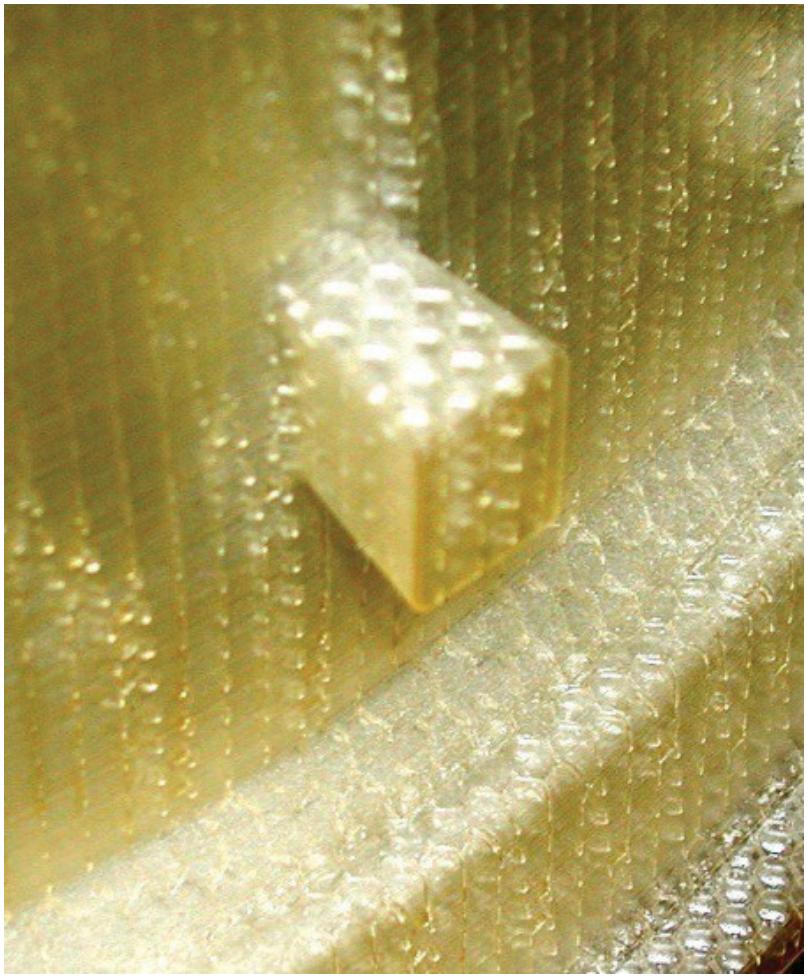
5.2 SLA Best Practices Quickcast Investment Casting Guide Attaching Wax Gates

Wax gates can be attached directly to the pattern. In many cases, however, the pattern is designed with gate "stubs" as shown in the picture. Wax gates can be bonded directly to the pattern surface, attached to gate "stubs or pads (see picture)" or even melted into pockets designed to hold the wax gate more securely to the pattern. You may also consider using metal sprue hardware to fasten the down sprues to the QuickCast pattern, designing in attachment pockets for nuts and bolts, which connect to the dip mounting plate hardware and be removed after burnout.

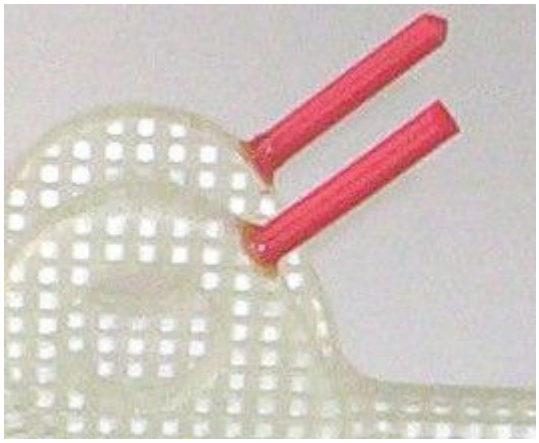
Using designed attachment features will help ensure alignment of the gates, and enhance the strength of the bond between these different material - wax and plastic.

When attaching gates it is advisable to drill small holes (1/8 inch or 3 mm) in the pattern before covering the area with a wax gate. When the wax is melted away, these holes will act as a pressure relief to keep air from expanding in the pattern during autoclave or burnout. These holes will also aid in air flow during the burnout of the pattern.

The pattern can be attached just as wax patterns with gate wax, or "sticky wax". However, the surface to be gated may need some preparation to aid in a strong bond for the wax gate. This area can be cleaned by wiping the surface with Isopropyl Alcohol, and roughing it up with course sandpaper.



5.3 SLA Best Practices Quickcast Investment Casting Guide Vents



We recommend that at least one vent be attached to each QuickCast pattern in the assembly. Although it is possible to successfully cast QuickCast patterns that are not vented, vents reduce the risk of failure in two important ways.

1. Vents allow steam to enter the pattern during the autoclave cycle. The steam softens the internal support structure of the Quickcast pattern, turning to the consistency of gummy bears. As a result, the pattern can collapse inwardly as it was intended to avoid cracking the shell. Much more detail is given in the autoclave section in part 4.
2. Vents significantly increase airflow to the pattern during the burnout process, increasing the amount of oxygen available for combustion.

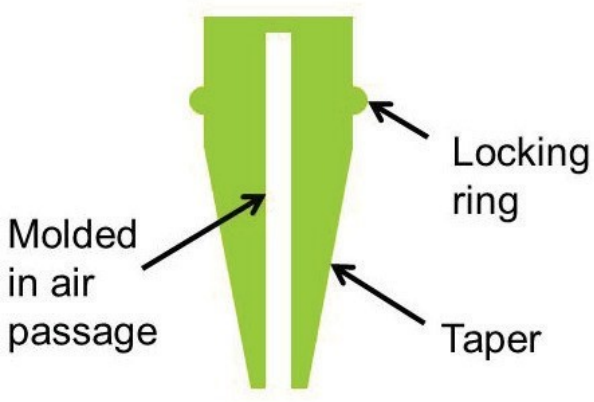
Vents can be created by adding wax plugs to the pattern, which will be opened after the shelling operation. Pieces of ¼" spaghetti wax, about 2" long is often used for these vents.

Vents can be designed into the CAD model so they are built in place on the QuickCast pattern. Building QuickCast vents will eliminate some of the manual labor needed during processing, but it does require careful consideration of where the vent will be after the pattern is assembled. After assembly, the vent should be on the outside of the assembly where it can be easily reached and opened, rather than on the interior of the assembly.

One of the easiest ways to vent patterns is to use the vent kits available from your on 3D Systems on Demand sales representative. The vent kits have unique features which simplify and speed not only the assembly process, but several other steps in the casting process. The following charts illustrate the vent and their use.

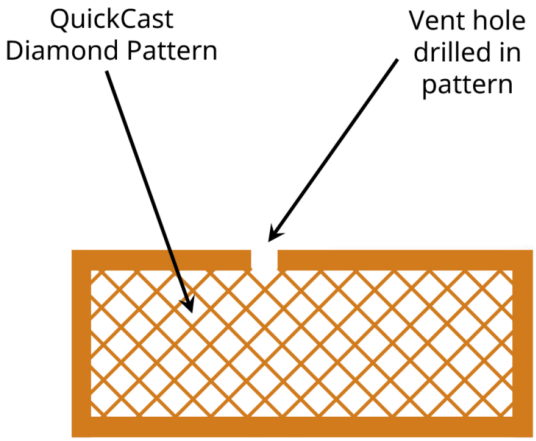


The vent kit consists of two parts; a molded wax vent and a ceramic plug that will plug the vent hole.

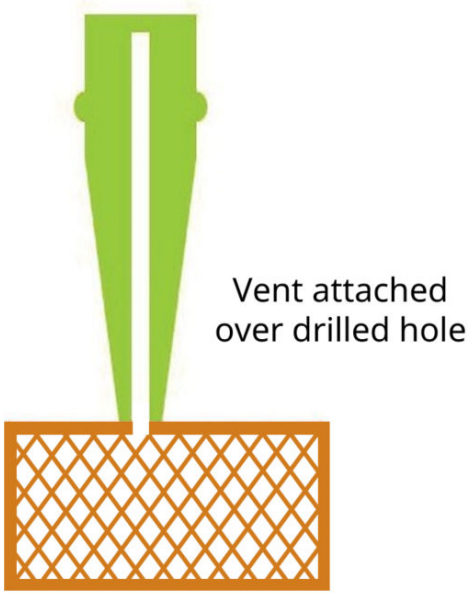


The vent has some unique features:

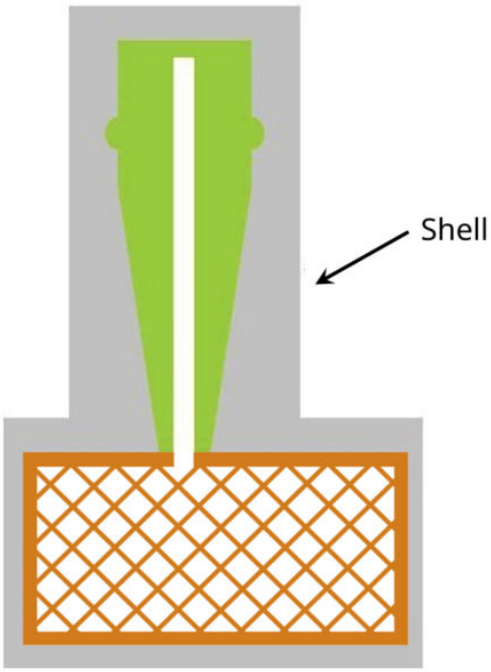
1. The vent is tapered at the same angle as the plug so that the plug will seal tightly.
2. A blind hole is molded into the vent that will serve as an air passage later in the process.
3. A locking ring is molded onto the vent that will serve to lock in the patch.



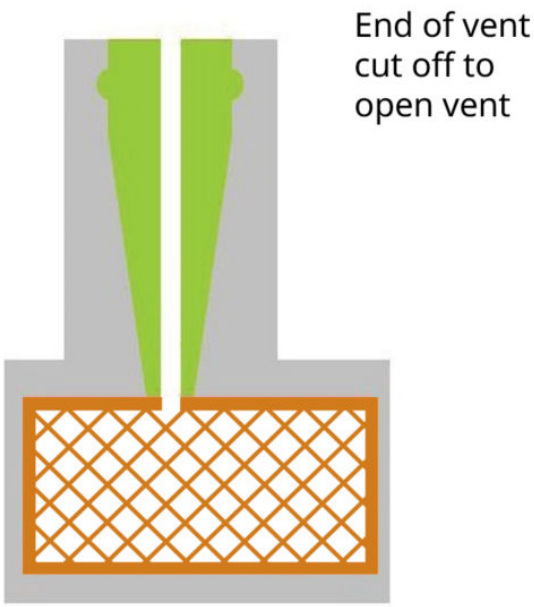
The first step is to drill a 3/16"-1/4" hole into the pattern. This can be done with a drill, with a hand grinder with an appropriately sized bit, or even with a hot iron.



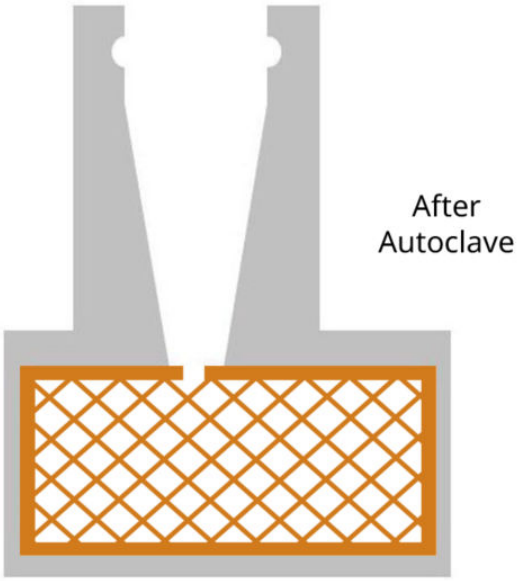
The vent is then attached over top of the hole, locating the vent so that the blind hole is directly over the drilled hole. The vent can be attached with sticky wax.



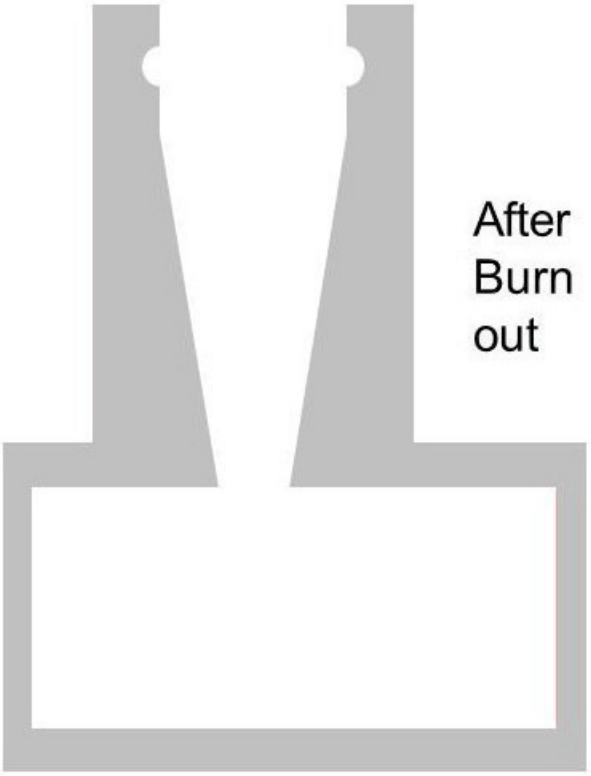
The pattern is then shelled normally with some care taken to avoid knocking off the vent.



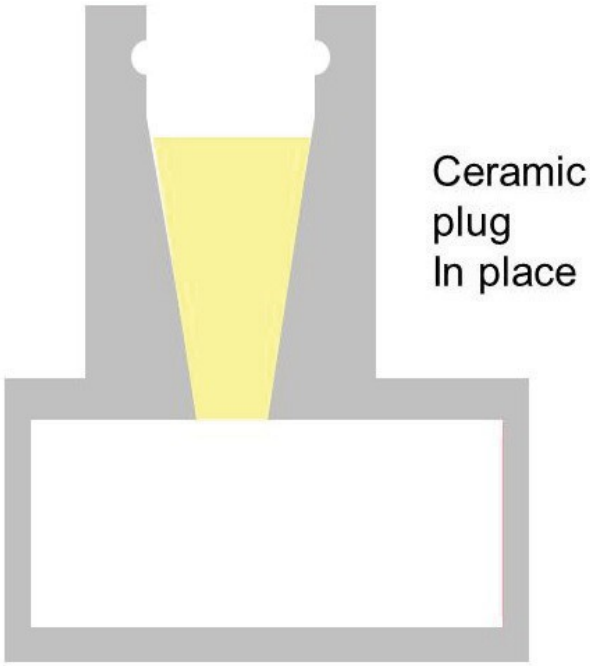
After the shell is built, the end of the vent is cut off to ex- pose the air passage. The cutoff is most easily done with hand held electric cutter, but can also be ground off. The pattern is now ready for autoclaving. The air passage will allow steam to enter the pattern quickly and soften the internal structure, enabling the pattern to collapse internally as intended.



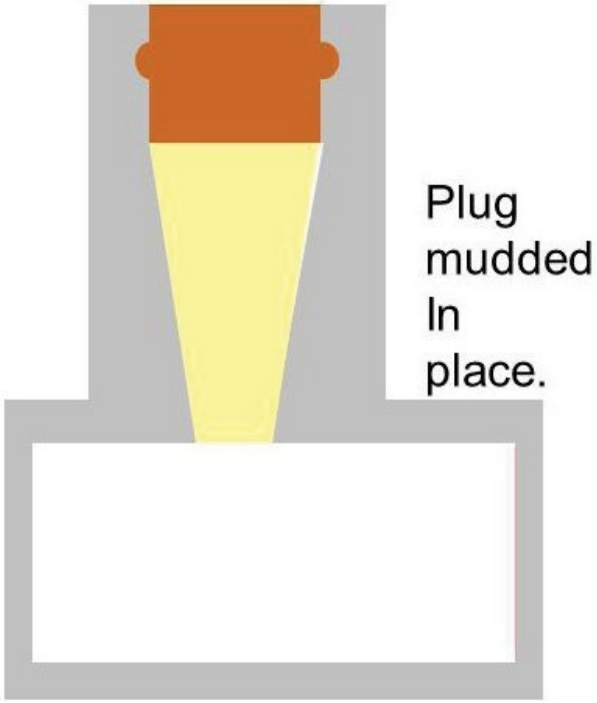
After autoclaving, the vent will have melted out, leaving a larger air passage. This passage will serve as a chimney during burnout and will allow air to flow through the mold, bringing in fresh oxygen for combustion.



After burnout, the pattern will be reduced to a small amount of ash. The vent now will make rinsing the shell easier to remove any ash remaining in the shell.



After rinsing, the plug can be inserted into the vent pas- sage. Because the angle of the plug is the same as was on the vent, it will seal tightly.


Plug
mudded
In
place.

6 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE SHELL BUILDING

Over the years, however, a number of misconceptions about shelling QuickCast patterns have emerged. For the most part the same shelling method can be used for QuickCast patterns as is used for normal wax pattern assemblies. In general, existing shell building practices can be used successfully to shell QuickCast patterns. Most foundries use the same shelling method for QuickCast patterns as they do for their normal wax pattern assemblies. However, added shell thickness is a good idea to strengthen the shell for the added forces typical when burning out QuickCast patterns. Also, for very large Quickcast patterns, where buoyancy may be a problem in dipping in the slurry tank, it may be preferable to flow-coat the slurry over the pattern assembly.

6.1 SLA Best Practices Quickcast Investment Casting Guide Pre-Shelling Checks

It is worthwhile to perform a final check on a few items before beginning the shell building process:

1. **Water-tight Patterns** - It is imperative that the pattern assembly be completely sealed to avoid slurry leaking into the pattern during dipping. Slurry that seeps into the pattern will likely result in an inclusion in the casting. The pattern was most likely checked on receipt, but it is worth another leak check after pattern assembly before proceeding with shelling to make sure it is still sealed. if it does not pass the leak check, it is necessary to find the hole or crack and seal. The resulting hump can be smoothed in finishing. Please refer to the Checking the Holes for Leaks section found in the QuickCast Post Processing Guide for further details.
2. **Vents** - It is critical that the pattern include at least one vent to allow steam to enter the pattern during autoclave and to allow airflow during the burnout phase. If vents were not added in the assembly process, add them now.

6.2 SLA Best Practices Quickcast Investment Casting Guide Assembly Preparation

Wax assemblies are typically dipped in an etching solution to remove oil, mold release and any other materials on the surface of the pattern that might inhibit adhesion of the shell. A common misconception is that etching solutions can damage or even dissolve QuickCast patterns, and many foundries avoid etching assemblies with QC patterns. As a result, they sometimes have issues with shell adhesion on wax components of the assembly, especially molded wax sprues.

3D Systems has tested patterns from a number of investment casting resins in both solvent based and citrus based etching solutions.

Based on these results, we see no reason that assemblies containing QuickCast patterns should not be etched in the same manner as wax assemblies.

6.3 SLA Best Practices Quickcast Investment Casting Guide Pattern Dipping

It is important to keep in mind that unlike wax patterns, QuickCast patterns are mostly hollow and are lighter than the slurry solution in which they will be dipped. The buoyant force experienced during dipping places additional stresses on the assembly and can damage it. Flow-coating the slurry over the pattern rather than dipping very large patterns is one way some foundries have found reduces the difficulties of buoyant assemblies. Use care in dipping the assembly. As mentioned in the Pattern Assembly section in this guide, additional gates or runners to the pattern will strengthen the assembly and make it better able to resist buoyancy forces.

6.4 SLA Best Practices Quickcast Investment Casting Guide Shell Types

While each foundry customizes their shell system to best perform for them, nearly all shell systems in use fall into one of two basic types:

Fused Silica or **Alumino silicate** systems. Either shell system may be used successfully for QuickCast Patterns.

Fused Silica systems are designed to weaken after firing in the burnout oven. At temperatures above 1650° F the fused silica is crystallized into cristobalite. This crystallization weakens the shell and aids in the shell removal after metal is poured and cooled. The cristobalite conversion presents special challenges in the processing of QuickCast patterns and is discussed in detail in Part 4.

Alumino silicate shell systems are stronger and do not undergo a transformation at higher temperatures allowing them to be cooled to room temperature and reheated when the foundry is ready to pour metal.

Regardless of the shell type, or the base liquid of the slurry, QuickCast patterns can be and are regularly successfully shelled and casted. To our knowledge, no combination of shell system and slurry type has a higher probability of failure than any other.

6.5 SLA Best Practices Quickcast Investment Casting Guide Shell Adhesion

Some foundries have observed poor shell adhesion to QuickCast patterns. A few even developed methods to improve shell adhesion such as coating the pattern with a spray adhesive. We suspect, however, that shell adhesion problems were the result of other deviations from standard shell procedures since there are many foundries that have not had problems with shell adhesion.

3D Systems has tested patterns using a number of slurries and various finishes including:

- No finish
- Lightly sanded
- Clear coated
- Sandblasted (smooth or rough)

Good slurry adhesion was obtained in all cases.

6.6 SLA Best Practices Quickcast Investment Casting Guide Shell Coats

Shell Building Summary

- Inspect the assembly prior to dipping for cracks, leaks and solid sections
- There is no need to avoid the use of etching or pre-wet solutions
- Take care in dipping to avoid damage to the assembly from buoyancy forces.

Currently, foundries often used more coats on shells for QuickCast patterns than they did for wax patterns to provide greater strength to resist expansion of the shell during autoclave and burnout phases. Recent testing has shown, however, that cracking of the shell in the autoclave can be avoided relatively easily without the use of additional shell coats and is discussed in detail in the Pattern Removal section in this guide. Consequently, it is generally not necessary to use more coats for a QuickCast pattern than would be normally used for a wax pattern.

There are exceptions to this rule; if the geometry is particularly challenging, or contains thin walls that are solid rather than hollow, foundries may still elect to add additional coats. Given the cost of QuickCast patterns, adding extra coats is a relatively inexpensive way to increase the probability of a successful casting. Additional methods to add strength include; using wire mesh, adding chopped ceramic fibers or chopped stainless steel wool between coats.

Foundries often use a pre-wet solution to assist in shell building for certain shell situations. The assembly is dipped in the pre-wet solution to assist slurry to flow into tight areas and around complex features. A number of foundries avoid using pre-wet solutions with QuickCast patterns because they believe that contact with the pre-wet solution may damage the pattern. While we have not done extensive testing, suppliers of pre-wet solutions have assured us that pre-wet solutions are much less aggressive than etching solutions and if etching solutions have no effect, pre-wet solutions certainly will not.



Adding extra backing layers to the shell mold will help overcome the higher stresses placed on the mold by specific QuickCast style pattern geometries.

7 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE PATTERN REMOVAL

7.1 SLA Best Practices Quickcast Investment Casting Guide Background

This part of the process corresponds to the de-wax step in conventional investment casting; which whether done with an autoclave or a flash-fire furnace, eliminates all wax components, including sprue, runners and patterns from the shell. De-wax would be a misnomer since we are specifically discussing QuickCast patterns, not wax patterns. However, the goal of the pattern removal portion of the process is the same; eliminating the sprues, runners and patterns from within the shell.

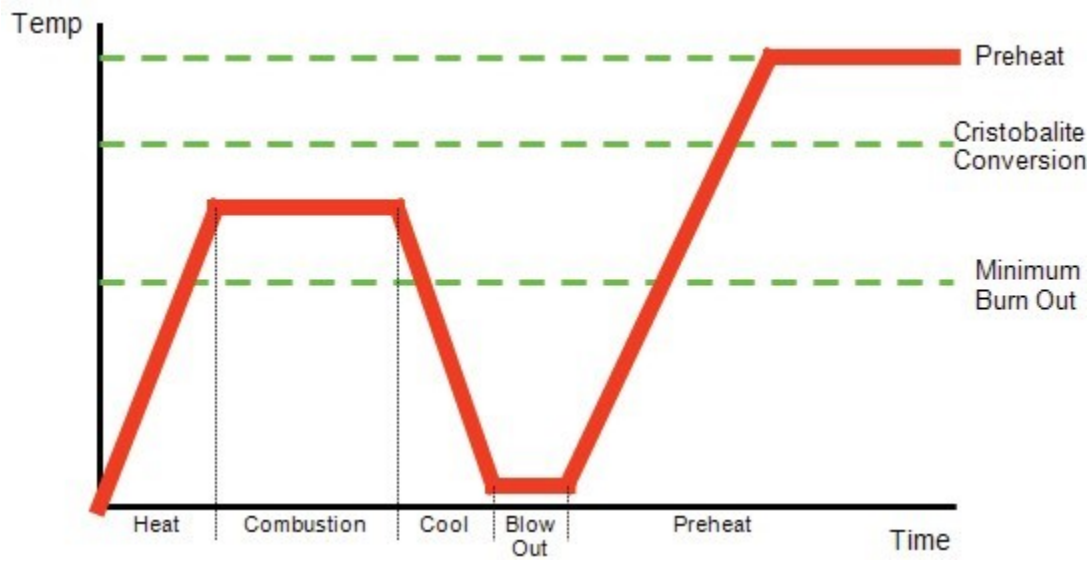
Background

The stereolithography resins used to build QuickCast patterns are photo-cured materials, which, unlike thermoplastic materials, will not melt. Consequently, they cannot be simply melted out of the shell like wax patterns. They must instead be burned out of the shell which creates several problems in shell processing. Initial attempts to process QuickCast patterns using the same process used for wax yielded unsatisfactory results.

1. Shells are likely to crack in the autoclave, often beyond repair.
2. Patterns often did not burn completely, leaving a black tar or charcoal residue in the shell which was very difficult to remove
3. If the pattern did burn completely, there was still a significant amount of ash left in the shell that needed to be removed from the shell prior to pouring in order to yield an acceptable casting. Consequently, it was usually necessary to cool down the shell after burnout and remove the ash from the shell prior to re-heating and pouring metal.
4. If a fused silica shell system was used and the shell was burned out at conventional preheat temperatures, the cristobalite conversion had already taken place and the shell was now significantly weaker when it was cooled down to clean out the ash. The resulting weaker shell potentially presented a dangerous situation when it was reheated and metal was poured.

Most foundries gravitated to the following general process:

1. Vents are added to patterns to provide for additional airflow during combustion. Vents are opened after shell building was complete.
2. Shells can be autoclaved to avoid the risk of cracking. Instead, the wax components of the assembly, sprue, runners and gates, are melted out manually using a hand torch. (Foundries with flashfire furnaces are able to melt out the wax and burnout the pattern at the same time.)
3. For foundries with a fused silica shell system, burnout was accomplished using a process illustrated in the following figure. (Alumino-silicate shells can burn out at higher temperatures since there is no cristobalite conversion)
   a. The shell was fired for approximately 2 hours at a temperature below the cristobalite conversion temperature, usually about 1500F.
   b. The shell was cooled to room temperature and ash was cleaned out, usually with compressed air or by rinsing the shell with tap water.
4. Vents are patched and the shell was reheated to conventional pre-heat temperatures and poured.



7.2 SLA Best Practices Quickcast Investment Casting Guide Process Tips

While this process yields good castings, several issues remain for the foundry:

1. Manual labor is required to add vents to the pattern, open the vents after the shell is built, melt out the sprue and runners, patch the vents, and clean the ash out of the shell. Melting the sprue by hand alone typically takes half an hour or more of labor. All the associated manual labor adds significantly to the cost of processing a QuickCast pattern.

1. For foundries with only one furnace, lowering the temperature to below the cristobalite conversion temperature to burn out the pattern means that normal production has to stop for that period, further increasing processing cost.

1. At several steps in the process, there are significant deviations from the normal process the foundry uses. Every such deviation is an opportunity for a mistake to be made, potentially resulting in a failed casting. Given that the cost of QuickCast patterns is high, and there is significant additional cost to process a QuickCast pattern, the cost of failure can be much higher than for a molded wax pattern. In addition, it may take a few days to obtain a replacement pattern and the resulting delay in delivering a casting to the customer may be longer than for the traditional wax method.

3D Systems has worked with several foundries and shell suppliers as well as developing new resins and build styles to improve the procedures for evacuating the shell. This will increase casting yields and reduce the cost of casting. Additionally, a number of key process improvements have been identified that greatly simplify the processing of QuickCast patterns.

Efforts were concentrated in the three areas that in the past have been most problematic for foundries:

1. Use of the autoclave to remove wax components of the assembly.
2. Burnout of the QuickCast pattern.
3. Ash removal.

7.3 SLA Best Practices Quickcast Investment Casting Guide Autoclaving the Assembly



Generalize

For conventional investment casting, autoclaving is the most common way of de-waxing, or eliminating the wax patterns from the shell. The QuickCast pattern, unlike wax, will **not** melt in the autoclave. However, there is typically a good amount of wax in the shell in the sprue, runners, gates and vents that must be removed prior to pouring. It is very desirable to be able to autoclave the shell to remove this wax prior to going into the furnace to burn out the QuickCast pattern.

Many foundries have had difficulty attempting to autoclave QuickCast patterns. Shells tend to crack during the autoclave cycle, often beyond repair. As a result, many foundries skip the autoclave step altogether and melt the sprue out with a hand torch as shown in the photo. Any wax remaining in the shell is later burned out in the furnace. While this work-around avoids cracks in the shell, it typically requires 30 minutes or more of labor per shell to melt the sprue. Any residual wax generates a great deal of smoke in the furnace.

In addition, this manual step is a disruption to the normal process flow of the foundry and therefore increases the chances that a processing error will be made. It would be preferable to directly autoclave the shells, avoiding labor, smoke, and any disruption to the regular foundry process.

Some foundries have reported that the shell in the sprue area gets red hot before all the wax is melted out. In some cases, that area of the shell gets hot enough to go through cristobalite conversion and as a result, the strength of that area of the shell is seriously compromised when reheated prior to pouring. If the shell gives way during pouring, a very dangerous situation will then result.

3D Systems ran tests in conjunction with two customer foundries to determine the cause of shell failure during the autoclave cycle and potential solutions. It was never previously clear whether it was thermal expansion of the pattern material or expansion of the air inside the pattern that caused the cracking. We designed the following test to identify the cause:

In the first test, eight QuickCast patterns were built. Four trees were then created with two patterns per tree. A hole was drilled into the pattern on the surface of the gate that would be attached to the sprue and the pattern was attached to the sprue using sticky wax.

Shells were then built using a fused silica shell system. The four shells were then prepared as follows: Shell 1 had no additional processing. In Shell 2, the sprue was melted out with a torch, exposing the hole drilled on the gate surface. Shells 3 and 4 simply had holes drilled through the shell into the pattern, simulating a vent. The wax sprue was left in place.

All four shells were placed in the autoclave at once. The autoclave was pressurized to 106 psi with 350ºF steam in 2.87 seconds. Shells were held under pressure for 20 minutes. All four shells were inspected after the autoclave cycle. Shell 1 had cracked. The remaining three shells had no damage.

From this test, it is clear that venting the interior of the pattern before autoclaving reduces the likelihood of shell cracking. The shell that cracked was the only one of the four assemblies that had a sealed pattern at the beginning of the cycle. All the patterns that were vented survived the autoclave cycle intact.



While venting had a significant effect, the cause of cracking was not obvious. It had always been assumed that thermal expansion of the pattern material was responsible. In fact, the design of the QuickCast build style was an attempt to allow the pattern to collapse inward as it expanded rather than exert excess pressure on the shell. However, if the root of the problem was differential thermal expansion of the pattern material, all the shells would have cracked.

One theory was that internal pressure resulting from heating of the air inside the pattern caused the cracking. That would explain why the vented patterns did not crack. However, it was calculated that the pressure rise inside the pattern from a temperature rise of 275F would be approximately 8 psi. Considering that this internal pressure is resisted by an external steam pressure of more than 100 psi, it doesn't seem likely that the pressure would crack the shell.

A second theory was that the greater external pressure resulted in a compressive failure of the shell. With vented patterns, the internal pressure would be the same as the external pressure, eliminating any net forces on the shell. Sealed patterns would have a lower internal pressure and the resulting net external force on the shell could potentially result in shell failure. However, the cracks we observed were very clean breaks as would be expected in a shell tension failure. We did not see any crumbling of the edges of the crack, or multiple crack lines as would be expected in a shell compression failure.

The second test in another foundry confirmed that external pressure was not the culprit. In that test, four 9-wall patterns were shelled. Each pattern was vented in three places, yet all four patterns cracked in the autoclave. In each case, it was clear that the crack initiated at the 0.040" thick wall - the thickest wall that was built solid. This failure points to thermal expansion of the pattern material.

In the first test, we broke apart the shell that cracked to inspect the pattern. We were somewhat surprised to find that the pattern was very rubbery and could easily be compressed. With this information, we theorized that upon exposure to the superheated steam, the resin softens quickly, and even though it expands with heat, it can deform and collapse inward, instead of exerting pressure on the shell. Venting allows the steam to reach the interior of the pattern, accelerating the softening of the honeycomb structure and skin of the pattern. Conversely, if the pattern is sealed, heat must be transferred through the skin of the pattern before reaching the internal hexagonal honeycomb structure, significantly slowing the softening process.

The mechanism of softening, however, is not entirely clear. Is it heat alone that softens the material? Or is it primarily absorption of humidity with the rate of absorption is accelerated by the heat? It may be a combination. Further testing will be done to learn more.

Any wall that is not drained properly, and is therefore solid plastic will potentially exhibit thermal expansion and forces beyond the strength of the shell, resulting in shell cracking.



As a result of these tests and our current understanding of the process, we recommend the following procedure for avoiding shell failure during the autoclave process.

1. **Include at least one vent on every pattern on the tree!.** A simple piece of spaghetti wax will suffice. A hole can be drilled under the vent so that as soon as the wax vent is melted out, there will be a path for pressure release from the pattern. However, it may be prudent not to drill the hole. If the vent is dislodged during a dip, the hole would allow slurry to enter the pattern, ruining the casting. If the hole were not yet drilled, the pattern could still be salvaged. More than one vent will provide a path for steam to flow through the pattern, accelerating the softening. An alternative to using a wax vent is to include the vent in the pattern model and it will be built as part of the QuickCast pattern. This approach will minimize downstream labor.

2. **After the shell is built, cut off the portion of the shell at the end of the vent to expose the vent.** The end of the vent can simply be ground or cut off.
3. **Melt out the wax in the vent.** This can be done with a lance heated in a flame as shown in the photo. If a QuickCast vent is used, there is no need to melt out the vent. It may be worthwhile, however, to poke through some of the honeycomb structure to increase the area available to flow of steam into the pattern.
4. **Puncture the skin of the pattern.** To be really safe, you can use a thin drill bit, but the hot lance used to melt the wax will work fine. If a QuickCast vent is used, this step will not be necessary.
5. **If there are solid areas on the pattern, melt out the sprue by hand.** There is little that can be done to ensure that the substantial solid areas of the pattern will soften quickly enough to avoid cracking the shell from thermal expansion. Extra coats on the shell will strengthen the shell, but it is hard to predict how much it can resist the thermal expansion.

With the above steps, most shells can be successfully autoclaved.

7.4 SLA Best Practices Quickcast Investment Casting Guide Burnout Process

To summarize the burnout process:

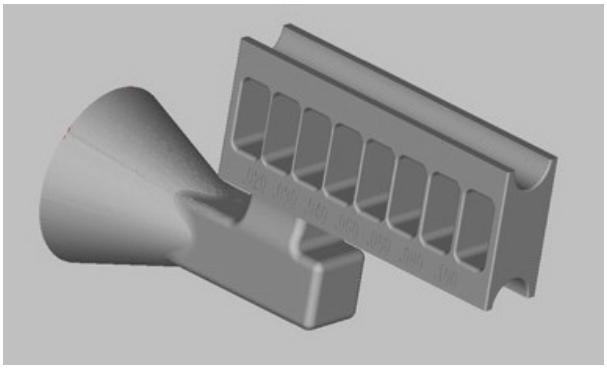
1. **Ensure that vents are opened and there is a path for airflow through the shell to bring fresh air to support pattern combustion.** If you opened the vents to get them through the autoclave, that should be sufficient.
2. **Ensure that there is adequate oxygen in the furnace atmosphere.** There are several ways to do this as explained in the text.
3. **Burnout in a furnace with a temperature of a minimum 1500ºF or higher.** Higher temperatures may speed combustion and could result in a more complete combustion.
4. **Burnout for a minimum of two hours for small patterns, three hours or longer for larger patterns.** These times are conservative. Residual ash testing shows that it takes a minimum of 90 minutes burn time to achieve low ash levels.

After autoclaving, all the wax will have been eliminated from the mold. However, the QuickCast patterns are still intact within the shell. The stereolithography resin used to build the pattern will **not** melt and must instead be burned out of the shell. The burnout process must not only result in the complete combustion of the pattern, it must also not compromise the integrity of the shell. Unfortunately, the process of heating the pattern in the mold to achieve combustion also causes some dimensional expansion which can exert forces on the shell causing cracking or even full failure if not done correctly - primarily by following the procedures outlined in the earlier sections of this guide. Typically, if the shell was not compromised during the autoclave step, then then the burnout will not cause failure either. The plastic material will have become softened during the autoclaving from the heated steam. Therefore if the burnout process is done while the mold is still very warm, without a complete cool down period, the plastic will collapse inward as heated further, instead of outward against the shell walls.

In order to achieve complete combustion, and leave only a minimal amount of ash requires the right conditions. Once done, the shell is every bit the equal of one built using molded wax patterns.

Burnout under the wrong conditions, however, can result in incomplete combustion, leaving a tarry substance in the shell that can be very difficult to remove. Several variables affect the burnout process. They include:

1. Furnace Temperature
2. Time in the furnace
3. Oxygen Content of the furnace
4. Shell composition



Foundries who have been successful with QuickCast patterns have generally had to experiment with the above variables until they found a process that worked for them. In addition, they generally have held that process close to the vest, being reluctant to give competitors any information about it. Over the years, we have picked up bits and pieces of information about what has worked and what has not worked, but never have been able to provide a complete recipe to foundries.

3D Systems has worked with a number of foundries to more completely understand how each of the above variables affects the burnout process and to be able to provide specific process recommendations to the foundry. In one test, 36 patterns were burned

out in an attempt to determine optimum temperatures and times for burnout. The QuickCast pattern used in the test was the 9-wall part, a test part that has been used since the mid 1990's in developing the ability to successfully cast QuickCast patterns. The 9-wall patterns contained 9 thin walls ranging from 0.020 inch to 0.100 inch. At least two of the thinnest walls would be extremely difficult to build hollow so there would be two or more solid thin walls in the pattern. Consequently, to eliminate the possibility that the wax gates and sprue could affect the results, the pattern was built with a gate and sprue attached as shown in the photo. The patterns were not vented.

36 such patterns were shelled using a fused silica shell system.



Two different furnace temperatures (1500F and 1800F) and 6 different times(30, 60, 90, 120, 150 and 180 minutes) were chosen for 18 distinct temperature/ time combinations. Two patterns were burned at each combination. The furnaces used did have plant compressed air added during firing to add oxygen. The air was not directed into the shells.

18 shells were placed in each furnace. The pattern material burst into flame almost immediately and burned quickly, as shown in the photo. The flame went out within a few minutes, so the material apparently burned out rather quickly.



At each half hour increment, the furnace was opened and two shells were removed. Over the period of three hours, all 36 shells were removed from the furnace. After the shells had cooled, one of each pair was cut open and inspected for signs of incomplete combustion.

We expected to find incomplete combustion at the lower furnace temperature and shorter burn times. However, we found no sign of incomplete combustion in any of the shells. The photo shows part of the shell which was burned at 1500F for 30 minutes. Even the 0.020 inch wall section (where the pattern was solid) burned out cleanly. We could then conclude that, for the set of conditions used in the test, and assuming that there is adequate oxygen available to support resin combustion, patterns will burn out adequately at any temperature above 1500F and for any time longer than 30 minutes.

Foundries have reported successfully burning out patterns at temperatures as low as 1100F.

Oxygen Content: Sufficient oxygen is necessary for proper combustion of the QuickCast pattern. If there is not enough oxygen, ash content increases significantly and will look like small pieces of charcoal rather than the white feathery ash normally associated with QuickCast patterns. In extreme cases, a tarry residue will be left in the shell.

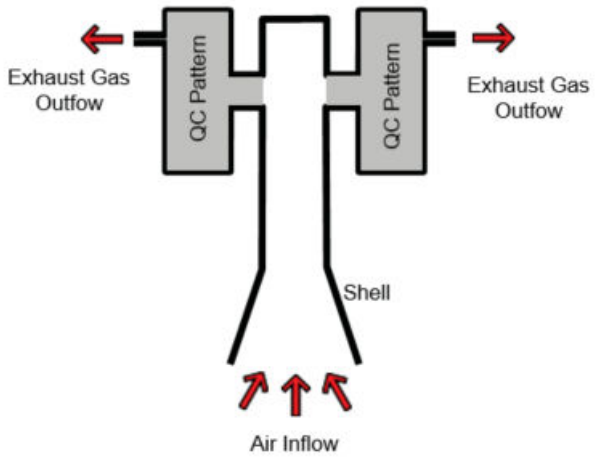
Oxygen is not necessary for preheat. Consequently, most preheat furnaces do not have the capability to increase the oxygen level in the furnace and much of the oxygen that was originally in the furnace is depleted in the process of heating the furnace. Without somehow adding oxygen to the furnace atmosphere, it is difficult to achieve complete combustion in a conventional pre-heat furnace.

Oxygen is not effective unless it is present in the far reaches of the shell cavity where pattern combustion needs to take place. The shell used for conventional investment casting makes it very difficult for oxygen to reach the pattern and for combustion gases to escape. While the pouring cup is fairly open, the passage to the QuickCast pattern narrows considerably at the gate. Since the cavity is a closed vessel, there is minimal airflow into the cavity, increasing the difficulty of getting oxygen directly to the combustion site and of getting combustion gases out.

Fortunately, there are relatively simple solutions to this problem. The vents that were added to help get the shell through the autoclave safely will also be of tremendous value getting oxygen to the pattern and allowing combustion gases to escape.

Some foundries simply make a long nozzle for an air gun (stainless tubing works well) and use it to blow air directly into a vent, forcing plant air into the shell. Oxygen is supplied by the plant air and consequently it is not necessary to adjust the oxygen level of the furnace atmosphere. There are some potential downsides to this method, however. First, the plant air could cool the inside surface of the shell and introduce thermal stresses that could cause some local cracking. This effect will be at least partially offset by the heat generated by combustion. Second, air must be blown into each cavity, which can be time consuming for an assembly with multiple patterns. It might also be difficult to get to all the patterns if they are spaced around the assembly.

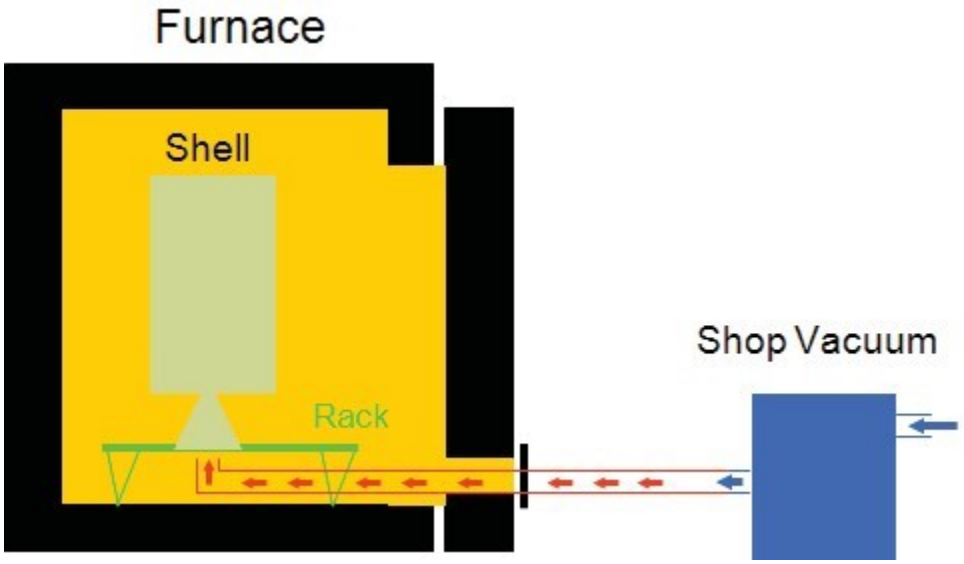
A better process may be to allow the vents to act as "natural chimneys" for the gases of combustion to escape as illustrated in the figure. As combustion gases escape through the vents, air will be drawn naturally through the pouring cup. This configuration will provide good burning provided that:



1. **Air can get in through the pouring cup.** It will not work if the pouring cup is set on a flat floor of the furnace, effectively closing off the flow of air. Most foundries will set the assembly on a grate above the floor of the furnace. Alternatively, the assembly can be placed on top of two bricks placed an inch or two apart. The space will allow air to flow between the bricks and up into the pouring cup.

1. **The furnace atmosphere has sufficient oxygen.** If the furnace has no provision for adding oxygen to the atmosphere, there will probably not be sufficient oxygen in the furnace. Some foundries run a line with plant compressed air into the furnace and turn it on when they are burning out QuickCast patterns.

One foundry came up with a novel solution. They drilled a hole through the door of their furnace and covered it with a simple swinging plate. They use the same steel rack for all QuickCast shells and the shell is always located on the same spot on the rack. They have locating pegs in the furnace so that when the rack is inserted, the pouring cup will be positioned in exactly the same spot each time. They also have a locating bracket on the floor of the furnace directly below the pouring cup. To deliver the air, they simply attach a long pipe with a 90 degree elbow on the end to the exhaust of a simple shop vacuum cleaner. During the burnout process, they insert the pipe through the hole they cut in the door and push it in until it reaches the bracket. It is then located directly below the pouring cup with the elbow pointing right into the pouring cup. When they turn on the shop vacuum, the furnace is provided with a steady source of low pressure, oxygen rich plant air to support combustion. The setup is illustrated in the figure below.



Shell Type: Alumino-silicate shell systems are stronger and do not have a transformation at higher temperatures allowing them to be cooled to room temperature and reheated when ready to pour metal.

Fused silica shells, however, are a little more complicated to work with. Fused silica undergoes a conversion to Cristobalite at temperatures above about 1650F. In general, foundries prefer to avoid the cristobalite conversion because shell strength decreases dramatically when the shell is cooled to remove burnout residue. The shell may not have sufficient strength upon reheating to safely allow pouring. To avoid the conversion to Cristobalite, many foundries burn out the shell at a lower temperature, generally around 1500ºF, although we have heard of some burning out as low as 1100ºF.

Many foundries, however, only have a single preheat furnace which complicates processing QuickCast patterns. If the temperature is lowered to burn out a QuickCast pattern, the furnace can't be used to preheat regular production shells. Consequently, production stops to burnout QuickCast patterns. Of course, it is possible to schedule QuickCast burnout around regular pouring schedules, but it increases scheduling complexity and may increase the time required to process QuickCast patterns

We know of at least two foundries that burn out fused silica shells at 1800ºF routinely and have not had significant concerns with shell strength. However, we suspect that the strength of the shell after cristobalite conversion may vary significantly with the particular formulation of the shell system. Burnout at temperatures above the conversion temperature may work well with some shell systems and not at all with others. In addition, the fluid pressure on the shell will vary with the size (primarily height) of the casting. The weakened shell may be able to withstand the pressure of small castings, but not larger ones.

7.5 SLA Best Practices Quickcast Investment Casting Guide Ash Removal

To summarize the ash removal steps:

1. **Cool the shell after the burnout process**
2. **Clean the remaining ash out of the shell using either compress air or by rinsing with water**

Once the combustion is complete, there will be a small amount of ash in the shell.



Ash removal is a significant disruption to the process, typically requiring the shell to be cooled before ash removal. If the ash removal step could be skipped, then the vents could simply be patched (although carefully since the shell is hot) and the casting poured. Not only would it save time and effort, it would eliminate the concern of cristobalite conversion and weak shells.

If the casting is poured without removing the ash, it typically will float to the top of the melt and result in some pitting on the surface of the casting, as shown in the photo. For some applications, the resulting minor surface imperfections are acceptable. Even if the resulting surface is not acceptable, it may be possible to repair the surface with minor welding.

For the majority of applications, however, it will be necessary to remove the ash to minimize imperfections in the casting. There are differing opinions on how best to remove the ash.

One foundry uses a method that it is best to remove the ash by blowing out the shell with compressed air while it is still hot. They mentioned that the ash is fine and feathery while hot, but as the shell cools, it is more likely to stick to the walls of the shell and be much harder to remove. To be sure they have removed as much ash as possible, however, they still allow the shell to cool and rinse it afterwards.

Most of the foundries either blow the shell out with compressed air, or rinse the shell with water. With either method, the shell is first cooled to a temperature at which it can be easily handled, usually near room temperature.

If compressed air is to be used, it is best to remove the ash before the vents are capped. That way, air blown into the sprue passage will blow ash out the vents and vice versa. The vents allow for flow through the cavity. If the vents are capped first, it will be much more difficult to remove the ash.

If water is to be used, it is best to cap the vents first so that water doesn't leak out of the shell in several places. Once the vents are capped, the water can be poured into the shell, swished around to pick up any ash that is there, and simply poured out. Foundries often pour the water out through a sieve fitted with a filter cloth to see how much ash was in the shell.



To be thorough, one might use both methods;

- Blow out the shell with compressed air
- Cap the vents
- Rinse with water

Some foundries use boiling water to rinse the shell or even citrus solutions.

8 SLA BEST PRACTICES QUICKCAST INVESTMENT CASTING GUIDE TROUBLESHOOTING

PROBLEM AREA	SYMPTOM	POTENTIAL PROBLEM	SOLUTION
Pattern Issues	Softness in Patterns	Moisture Absorption	Dry pattern in a very low humidity environment
Return to pattern supplier for replacement			
Holes in Cracks in Pattern	Damage to Pattern	Return to pattern supplier for repair or replacement	
Patch with wax			
Incomplete finishing	Return to pattern supplier for repair or replacement		
Leak Test Failure	Surface holes or Cracks	Find leaks and repair or return to pattern supplier for repair or replacement	
Has not proven to affect the performance of the pattern	Overexposure to UV light	Most likely will not affect performance of the pattern	
	Solid areas in pattern	Return pattern to pattern supplier for repair or replacement	
Shelling Problems	Poor Shell Adhesion on QC Patterns	Contaminants on pattern	Wipe with etch solution or dip assembly in etch
Poor Shell Adhesion on Runners, Gates or Sprues	Contaminants on runners and sprues	Wipe with etch solution or dip assembly in etch	
Autoclaving Problems	Shell Cracks in Autoclave Cycle	Vents not open to pattern interior	Make sure all vents are open at the ends and where they attach to the pattern - pattern skin is punctured, prior to placing he shell in the autoclave
Inadequate venting	Increase number and size of vents. There should be at least one vent per pattern		
Burnout Problems	Incomplete combustion (material other than ash in the shell after burnout)	Inadequate venting	Increase number and size of vents. There should be at least one vent per pattern
Inadequate oven temperature	Increase furnace temperature to 1500F or higher		
Inadequate burnout time	Increase time in furnace to 2 hour for small patterns, 3 hours or longer for large patterns		
Inadequate oxygen to support combustion	Ensure that patterns are vented		
Ensure that there is adequate oxygen in the furnace			
Ensure that air can get into the shell easily			
Casting Problems	Inclusions in the casting	Leakage of slurry into pattern	Ensure patterns are properly sealed
Hex pattern on castings	Leakage of slurry into pattern	Ensure patterns are properly sealed	
Surface Pitting	Incomplete combustion of pattern	Increase airflow through pattern	
Increase oxygen in furnace			
Increase burnout temperature			
Increase burnout time			
Ash remaining in shells after combustion	Rinse shell prior to burnout		

PROBLEM AREA	SYMPTOM	POTENTIAL PROBLEM	SOLUTION
Blow out shell hot if unable to cool for rinse			



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