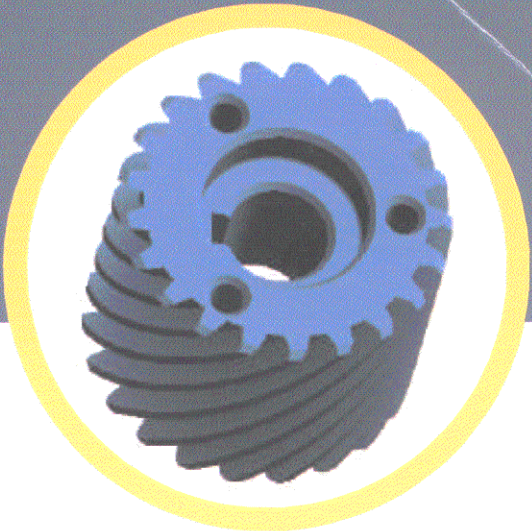
Produce metal parts without tooling!

APPLICATION GUIDE

Investment Casting QuickCast™ Patterns

Produced using 3D Systems stereolithography products



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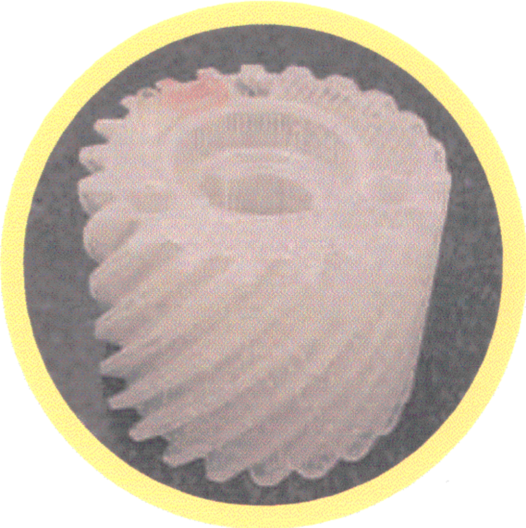
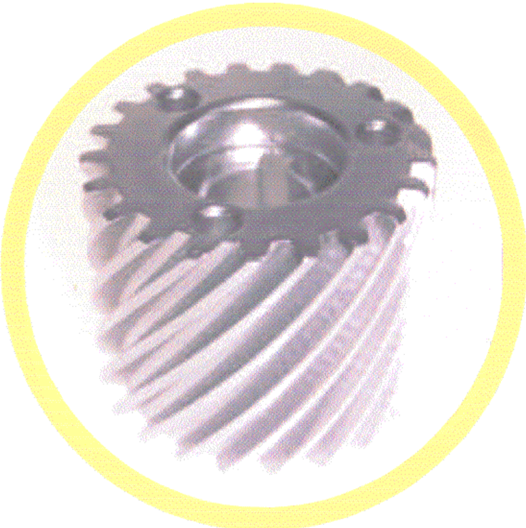


TO PATTERN



TO CASTING

SYSTEMS

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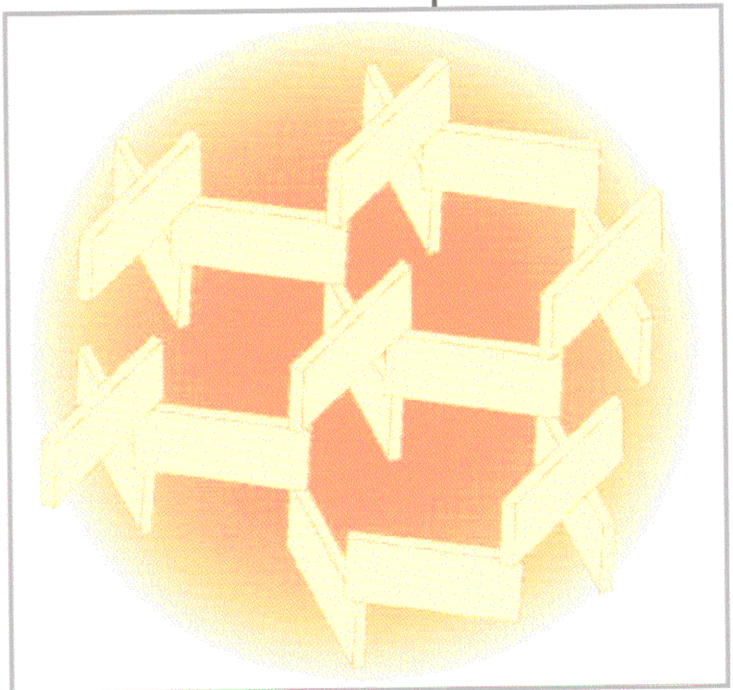
Introduction to the QuickCast build style

With 3D Systems SLA systems and the QuickCast build style, you can rapidly produce functional metal prototypes before production of hard tooling at a fraction of the cost and time of traditional methods. The QuickCast build style is a proven product facilitator that reduces long lead times on metal castings by as much as 80 percent or more.

QuickCast patterns replace traditional wax patterns for investment casting with patterns produced directly from your 3-D CAD data using 3D Systems SLA system technology. The QuickCast method allows you to rapidly build highly accurate, robust patterns in 3D Systems' stereolithography systems (SLA systems), bypassing the expensive and time-consuming step of machining hard tooling. The net result is QuickCast patterns in as little as 2 to 4 days and quality metal castings in 1 to 4 weeks (depending on part geometry), compared to 18 to 20 weeks by conventional methods.

The QuickCast build style has proven its versatility in literally tens of thousands of different complex configurations and geometries in an extensive range of metals, including aluminum, stainless steel, tool steel, magnesium, titanium, copper-, nickel and cobalt based alloys.

The QuickCast build style was developed through an intensive cooperative effort with leading manufacturers and foundries throughout the world and its widespread acceptance is now firmly established. Thousands of metal parts have already been processed in QuickCast using no tooling whatsoever by hundreds of manufacturers and dozens of forward thinking casting foundries.



The QuickCast build styles utilizes a honeycomb-like internal structure that provides necessary structural integrity during pattern preparation, yet readily collapses during flash fire or autoclaving operations, and burns out during flash fire operations.

The QuickCast build style is a mathematical algorithm that will automatically hollow a solid SLA geometry with a "honeycomb" structure inside, removing up to 90% of the mass. This structure minimizes the mass to burnout during the casting process (see illustration at right).

Except for creating your 3-dimensional solid design in CAD, there is nothing special required in CAD. When you're ready to create your design as a QuickCast pattern, you will simply choose the QuickCast build style from the menu in 3D Systems' build file preparation software.

Guidelines to produce a QuickCast pattern

Selecting a Foundry

Selecting a foundry should be your first step to ensure success.

The selection criteria may be based on material to be cast, part size, cost, geographic location, vendor preference and/or experience with casting QuickCast patterns. Your 3D Systems' application engineer or sales representatives can provide assistance in recommending an experienced foundry. There are many foundries with QuickCast build style experience.

Before the design is final, contact a foundry to discuss your casting requirements. Establishing effective communication is key to casting success. Providing a drawing or preferably a model of your future casting will aid the foundry engineer and assure successful casting of your project. Be prepared to explain what you wish to achieve in terms of accuracy, finish, NDT (Non-Destructive-Testing) requirements, detail and delivery. The designer, pattern builder and foundry working concurrently will aid design, manufacture, schedule and cost.

Design Considerations

Most of the same design considerations for conventional investment wax patterns apply to QuickCast patterns also. These considerations include sharp corners, wall thickness, holes, undercuts, draft, dimensional accuracy, etc.

Although sharp corners are achievable in the investment casting process, generous radii are preferred whenever possible. Shell investment casting involves pouring molten metal into a fired ceramic shell, this can create stress concentrations at sharp corners. Solidification is accelerated at external corners and retarded at internal comers, causing residual stress buildup leading to the formation of cracks in the shell. Ample fillets and radii facilitate the flow of the molten metal into the shell. This will result in better quality and more dimensionally stable parts. Input from the foundry engineer will identify problem locations and provide suggestions for change. Corners and fillets should have minimum radii of 0.040 in. (1.0 mm). If your CAD system is unable to perform this function adequately, it may be accomplished manually with the foundry adding wax fillets.

The minimum thickness of casting walls is determined by the fluidity of the metal to be cast. Another factor is the length of the section involved. If the wall is long, a heavier wall may be required. The ratio of thickness to height and location of the adjacent heavy sections are a factor. The minimum wall thickness of cast parts is generally 0.040 - 0.060 in. (1.0 - 1.5 mm) but foundry recommendations should be adopted. QuickCast build style walls thinner than 0.04 in. (1.0 mm) are very difficult to drain. For best results in designing and spacing thin cooling fins or heat sinks communicate with your foundry. Resin expansion, metal flow and foundry gating are factors in wall thickness design.

Small holes are susceptible to shell failure during firing. By omitting holes for screws and fasteners, as an example, you increase the part yield and these can easily be machined later. If holes cannot be eliminated, the length to diameter ratio should be not greater than L/D=1 for blind holes and L/D=2 for through holes. If the holes are smaller than .125 in. (3.0 mm) the foundry may require alternate techniques to shelling, such as coring the holes.

Undercuts are more producible on QuickCast patterns than conventional wax patterns and draft is not required, because the need for tooling is eliminated.

There are two major factors that influence dimensional accuracy of QuickCast investment castings.

The first factor is the shrink rate which you would need to obtain from the foundry. This is the shrinkage rate of the metal as it changes from a molten to a solid state. Although shrinkage is predictable, there is some variation in the amount of shrinkage on individual features, which results in the loss of dimensional accuracy. You may find that additions of machine stock may be necessary to insure the machining aspect of the part and working with the foundry will help you define these areas as well.

The second factor is the quick cast pattern itself. Remember that whatever your pattern is dimensionally, the casting process will reproduce minus the foundry shrink rate.

A thorough dimensional check of key characteristics on the patterns up front has the potential of saving you some big dollars and time by helping to avoid problems with the fit, form and function of the castings at a later stage. (ref. page 2.9)

Typical linear tolerances published in investment casting handbooks and adopted by foundries are shown to the right. These tolerances are repeatable under production conditions. Tighter (premium) tolerances can be cast, but require added operations at additional cost. You must communicate any special requirements to the foundry.

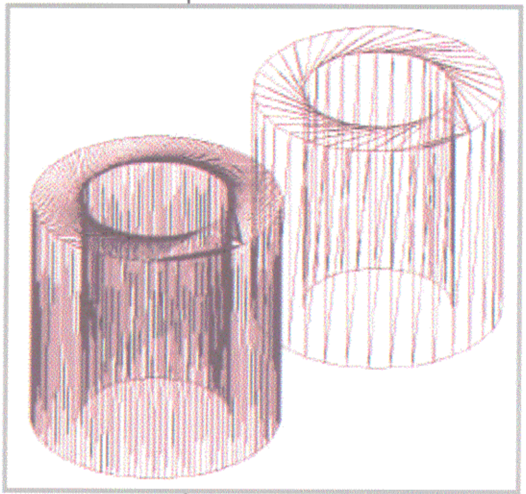
Dimension	**Tolerance**
up to 1 in. (25.4 mm)	+/- .010 in. (0.25 mm)
up to 2 in. (50.8 mm)	+/- .013 in. (0.33 mm)
up to 3 in. (76.2 mm)	+/- .016 in. (0.41 mm)
up to 4 in. (102 mm)	+/- .019 in. (0.48 mm)
up to 5 in. (127 mm)	+/- .022 in. (0.56 mm)
up to 6 in. (152 mm)	+/- .025 in. (0.64 mm)
up to 7 in. (178 mm)	+/- .028 in. (0.71 mm)
up to 8 in. (203 mm)	+/- .031 in. (0.79 mm)
up to 9 in. (229 mm)	+/- .034 in. (0.86 mm)
up to 10 in. (254 mm)	+/- .037 in. (0.94 mm)
Greater Than 10 in. (254 mm)	allow +/- .005 (.13 mm) inch per inch

Typical linear tolerances published in investment casting handbooks

Example:

20 in. (508 mm) would calculate, 20 in X .005 in, to allow a tolerance of +/- .100 in. (2.54 mm)

Creating the .STL File



A wireframe view of a tesselated .stl file

STL files are typically created in your CAD system, but can be created in other software packages too. As a general rule, your product design can be exported or "saved as" from your CAD package to the STL file format. STL files are made up of tessellated triangles placed on the solid model surface. Therefore, on curved geometries, smaller triangles will achieve better surface resolution. Large triangles will result in a polygonized or facetted surface. What you see as triangular facets on your .stl viewing software will be replicated on your pattern.

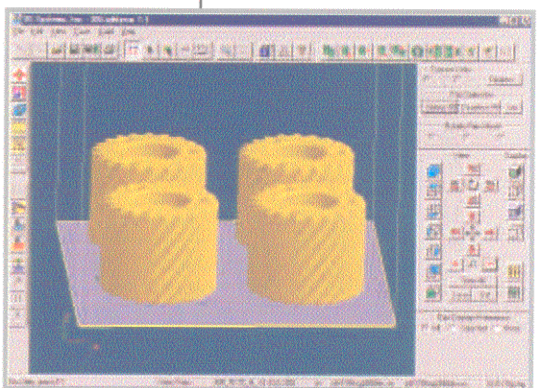
Methods vary with different CAD systems but the criteria should be a balance between acceptable surface resolution and the size of the data file. Large radii and long, gently curved surfaces show individual triangles the most. Examine these areas for acceptability before preparing to build parts.

Incorporating the Metal Shrink Rate

You must obtain the metal shrink rate from your selected foundry and incorporate it into the pattern. For example if you are producing an aluminum casting, with a 10 in. dimension and the foundry recommends a .5% shrink rate, .005 in. per inch, you must increase your database 100.5% to produce a pattern that is 10.050 in. (255.3 mm) to allow for the .050 in. (1.3 mm) shrinkage of the material.

Based on the geometry the foundry may ask for a different rate in each axis. Do not assume that the shrink rate from one foundry is the same as another foundry. Many variables, primarily gating methods, can have dramatic effects on metal shrinkage.

The easiest place to add the foundryís shrink rate is in the CAD model directly or 3D Lightyear software.

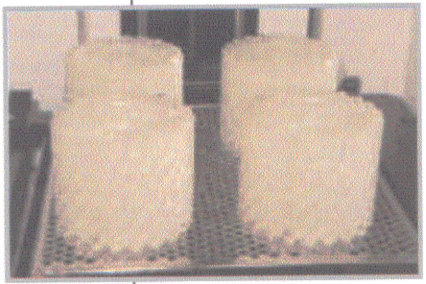


CAD design saved or exported as .STL file is oriented on 3D Lightyear buildfile preparation software included with each SLA system

Build Orientation

Orientation or positioning the part to build in the SLA is independent of the CAD location or orientation. Positioning in the SLA should be dependent on the feature and/or function of the part. Flat planar surfaces are best when positioned horizontal as upfacing or downfacing surfaces. Cylindrical features such as holes or bosses should be built in a vertical orientation to better define the shape. Tapered parts such as airfoils that transition with thick sections to a trailing edge should be positioned with the thin edge oriented vertically to aid in the draining of resin.

However, don't be afraid to be creative, most epoxy resins are strong enough to build on an angle. This may significantly reduce the amount of supports. A 45 degree angle is the most desirable because it has an equal pitch (the run is equal to the rise). Building on a 45 degree angle can also optimize a part that has cylindrical features in several planar orientations. Avoid shallow angles if possible, as the angle decreases the steps become wide, as each layer builds.

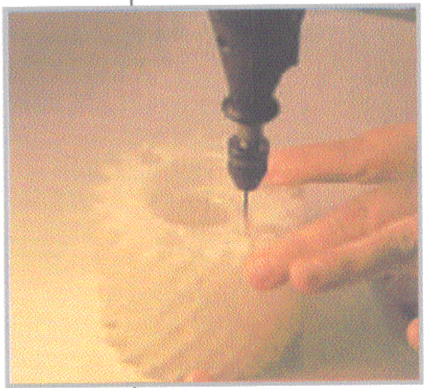


SLA system platform with four QuickCast patterns draining prior to removal from the system.

Draining the Resin

Draining the resin from the pattern is crucial to successfully yielding a cast part. The best castings are consistently made from patterns with the highest void ratios. QuickCast parts should be drained as soon as possible after they have been built. Delays increase the chance of trapping resin in the pattern. Solid walls or sections thicker than 0.060 in. (1.5 mm) will expand faster than the ceramic shell, exerting forces that can crack the shell. The critical solid thickness depends upon the strength of the shell system used. Removing the uncured liquid resin from sections greater than .060 in. (1.5 mm) is therefore vital.

Drain and vent holes can be put into the part prior to building with 3D Systems' software or manually drilled into the part after building (see photograph at bottom right). The size of drains will vary between 0.100 - 1.000 in. (2.5 - 25 mm) depending on the part size. Vent holes can be small, between 0.050 - 0.100 in. (1.3 - 2.5 mm) is adequate. Multiple vent and drain holes can be used. The shortest drainage time is achieved by having the longest dimension vertical. This increases gravitational pressure

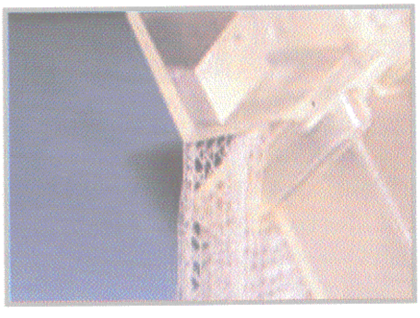


One draining option is to drill the finished QuickCast pattern after building on the SLA system.

Support Removal

Exercise care when removing supports that you do not tear downfacing surface skins and create "pinholes". Pinholes will allow the face coat investment slurry to penetrate the pattern, leading to an inclusion. Fine Point supports, introduced with 3D Systems' Lightyear 1.1, are significantly easier to remove and far less likely to tear the QuickCast skin.

> *"Supports that used to take 45 minutes and various tools to remove now just take one minute, without any damage to the part. It's effortless!... one of the best improvements I've seen in nine years of using your systems."*
>
> **Judy Gill, Raytheon/TI SLA Lab**

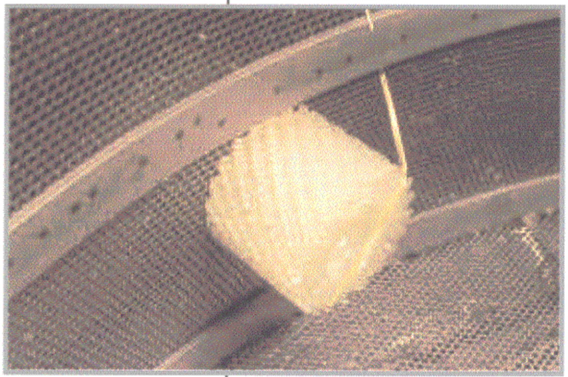


New FinePoint supports provided with 3D Lightyear build file preparation software offer extraordinarily easy support removal.

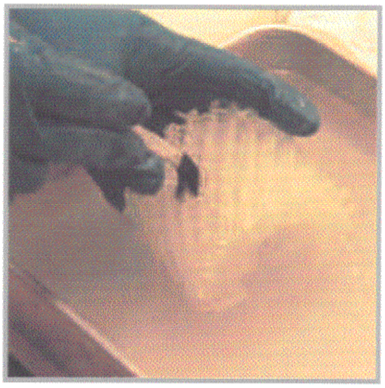
Cleaning the QuickCast Pattern

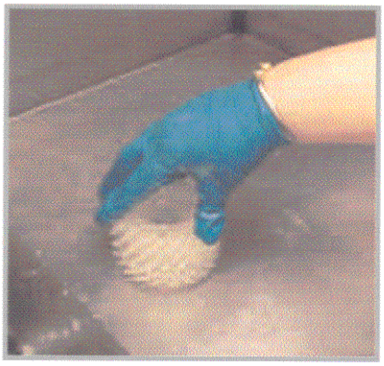
Some of the following methods may be implemented to rid the interior of uncured liquid resin:

- Low-speed centrifuge device (Honey Extractor).
- Blow dry with nitrogen pressure at 3 - 5 psi (21 - 35 kPa).
- Vacuum to suck out resin. Use suction from a vacuum cleaner as a measure of what you need.
- Wick the resin out with absorbent paper towels placed under drain holes.
- Chemically washing the part with Isopropyl Alcohol and an immediate rinse with D-Limonene (this is a citrus cleaner, used in some foundries as a de-waxing chemical). You must exercise care on resins that are not humidity resistant.
- Clean the exterior of the part by wiping with a dry paper towel or with Isopropyl Alcohol. Be aware that Isopropyl Alcohol is hydrophilic (will absorb moisture/water from the atmosphere) and this can be detrimental to resins that are not humidity resistant.
- Use alcohol only in a well-ventilated area away from flames or potential spark creating conditions. Electric motors for ventilating must be spark resistant.



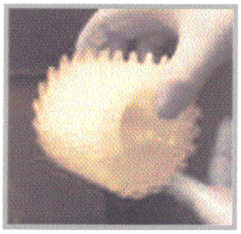
A centrifuge is a commonly used device to easily drain uncured material from the pattern interior.



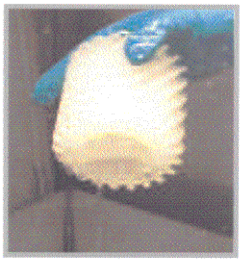


Lightly brush off the exterior of the pattern in a container of Isopropyl Alcohol.

Next, immerse the pattern in a container of Isopropyl Alcohol (see photo below left) to allow the liquid to flow into the pattern interior through the drain hole(s) (see photo at right). Allow to drain back out through the hole (see photo below right). This process should be repeated using D-Limonene citrus cleaner.



Once the pattern has partially filled with liquid, shake moderately, ensuring the liquid has completely flushed out the pattern interior, then allow to drain completely back out the drain hole(s).



Curing the QuickCast Pattern

It is recommended that you use a PCA (Post Cure Apparatus) to cure epoxy patterns. A PCA is a anxilliary product available from 3D Systems that allows you to easily "cure" patterns using its special UV light source and part rotation system. Post Curing Apparatuses are available from 3D Systems.

After cleaning, post-cure the patterns as quickly as possible to prevent moisture from producing a "tacky" surface or soft part. Post-curing time is dependent on the geometry of the part although the hollow nature of a pattern will reduce the curing time compared with an equally solid part. The curing time may vary from ½ hour to 2 hours depending on the geometry of the pattern.

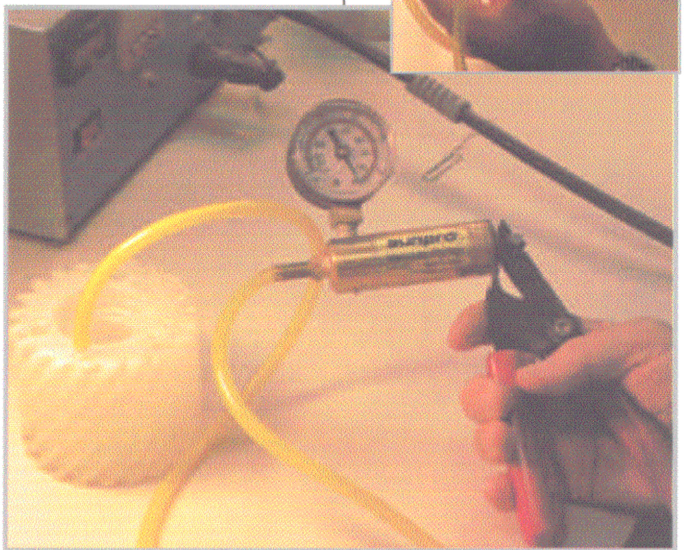
A Post Curing Apparatus (or PCA) is a device that ensures that your SLA parts and patterns are 100% cured prior to handling without gloves. The PCA shown is the size required for the smaller of the SLA systems, such as the highly popular SLA 250 and Viper si2 SLA systems.

Checking for Holes or Leaks

Holes or leaks can be created from support removal, handling, or pattern geometry. Successful casting yields depend on sealed patterns. Because the pattern is dipped in slurry to produce a shell, any small hole can allow slurry to run into the interior of the pattern creating a non-metallic inclusion in the casting.

Several methods may be incorporated to check for holes:

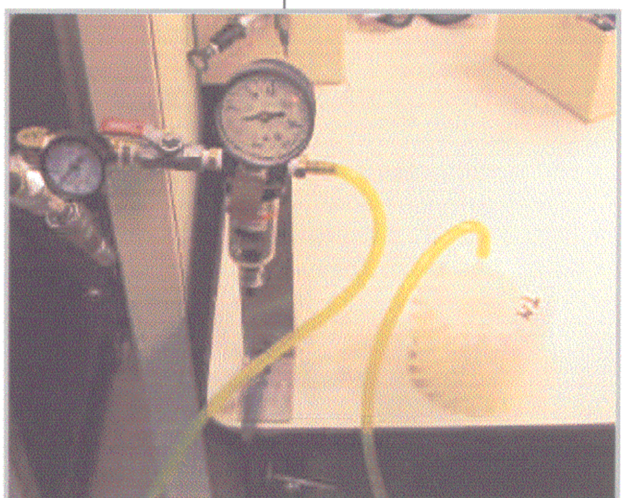
- A visual inspection for holes will find the obvious holes, but is limited by human error.
- An automotive vacuum leak tester (see photo at right) will guarantee a sealed model. Using CAD, create a tapered tube that can be merged on to the part or build the tube independently on the SLA machine and attach it to the part after building. Use the center of the tube as a drill guide to pierce the skin of the pattern and attach the vacuum hose to the tube. Begin pumping air from the pattern, stop when the gauge reaches 10-15 in/Hg (250-380 mm/Hg). If the gauge holds pressure the part is sealed, if it leaks down the pattern has a hole(s). The tube may be left on for the foundry to verify vacuum after shipment of the pattern to the foundry, they will plug it with wax before casting. It is imperative that the tube be placed on an area that will make it easy for the foundry to remove after casting.



A simple, inexpensive automotive vacuum leak tester will guarantee that a pattern is fully sealed.

- Using a pressure regulator (see photo at right), attach a low-pressure airline with 1 - 10 psi (7 - 70 kPa) to the tapered tube (described above) and pump air in. The smaller the part the less pressure required. Feel the surface or listen with a stethoscope to find the leak(s). Seal the hole(s) and repeat the vacuum check.
- As a last resort, submerging the part in fluid (Isopropyl Alcohol or D-Limonene) with the air line attached will cause air bubbles to show the leak. Take care that the air line has enough pressure to ensure that fluid does not enter the interior of the pattern.

  Caution: Care must be taken in performing this operation. Excessive pressure can separate the Skin from the Internal Hatch Structure.



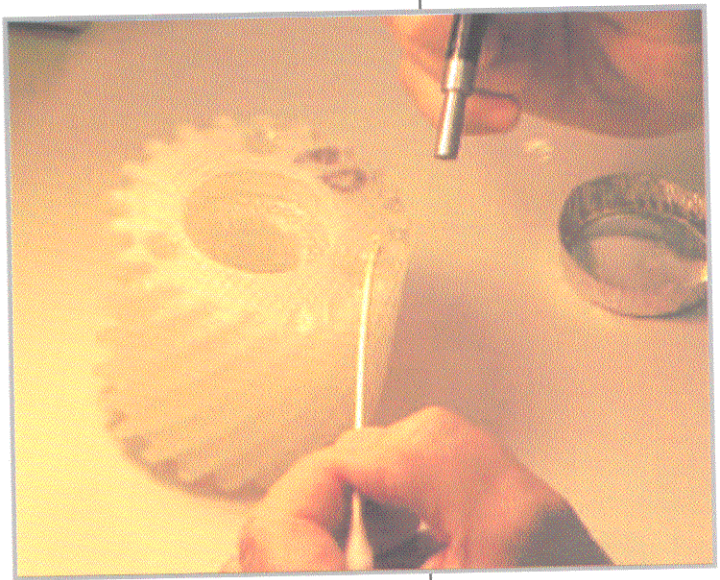
A simple pressure regulator will help you quickly and easily identify leaks in a QuickCast pattern.

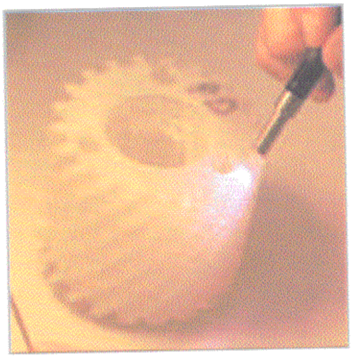
Sealing Holes or Leaks

Vents, drains and pinholes can be filled with the same resin used to create the part. The use of a spot-curing ultraviolet light is recommended for fast, localized curing. Several kinds of equipment are available from Dymax, EFOS, or Green Spot.

Here are several methods for sealing holes, depending on the size of the hole:

- For small holes, less than .200 inch (5.0 mm), a drop of resin may be placed on the hole and spot-cured. Then sand smooth (320 - 400 Grit).
- For larger holes, .200 - .500 inches (5.0 - 13 mm), place some resin on the sticky side of some transparent tape. Tape the resin over the hole and cure. Then sand smooth (320 - 400 Grit).
- For very large holes, .375 - 1.000 inches (9.5 -25.4 mm), model a "disc" in CAD .010 in. (0.25 mm) undersize the diameter and about .015 in. (0.4 mm) thick. Build this on the SLA system and place the disc in the hole sealing the edges with resin. Then sand smooth (320 - 400 Grit).

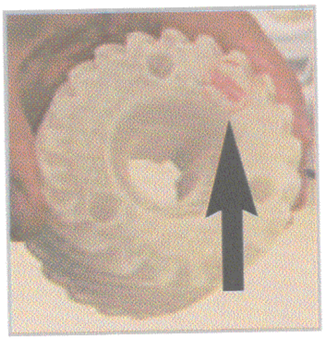




Touching up small holes with liquid resin, then using a simple UV light pen to spot cure the resin is a fast and simple method to seal holes.

Stamping Sealed Patterns

After all holes are sealed, stamp the part with a rubber stamp, "Vacuum Checked" or "Pressure Checked". This will give the foundry assurance that the part is a quality pattern and has been fully sealed and tested.



Stamping your completed pattern is an excellent method of communicating clearly with your foundry, and avoiding mistakes or unnecessary cost.

Joining Multiple QuickCast Patterns

Basically there are two methods. You may need to discuss which method your selected foundry prefers. Their decision will be based primarily on geometry.

Depending on the geometry the foundry may want to "wax weld" the pieces together.

Otherwise, use the same resin as the bonding agent. Avoid using other glues or epoxies as they may contribute unexpected results in the foundry burnout process (ash, residue, etc.). To bond, place resin on one or both surfaces and squeeze together. Wipe off excess resin and "tack weld" several areas with a light gun to avoid shifting/sliding. Then fully cure in the PCA.

When joining patterns, an opening must be made in corresponding locations on each pattern to allow air pressure to equalize between the patterns during foundry burnout. Failure to do this can cause the shell to explode in the furnace.

Very large parts can be easily and quickly joined using very simple glueing techniques, such as using SL resin to join, then curing with a UV light source.

Surface Quality and Preparation

QuickCast patterns built at .006 in. (0.15 mm) or .004 in. (0.10 mm) layers typically meet the casting industry's requirement of a 125 RMS or C-30 surface finish. Surfaces requiring better finishes should have extra machine stock added for machining.

Any surface irregularities will be reproduced on the casting. Surface may be lightly sanded (320 - 400 Grit). Avoid coating the surface with oil or paint, these may cause problems/contamination to the foundry shelling and burnout processes.

Accuracy of the QuickCast Pattern

The accuracy of the QuickCast pattern determines the accuracy of the cast part.

A preferred policy is to implement a Tolerance Envelope for Patterns that is 50% of the required End Item Tolerance Envelope.

Example:

Blueprint Dimension = 1.000 in. (25.4 mm)

Tolerance = +/- .030 in. (0.8 mm)

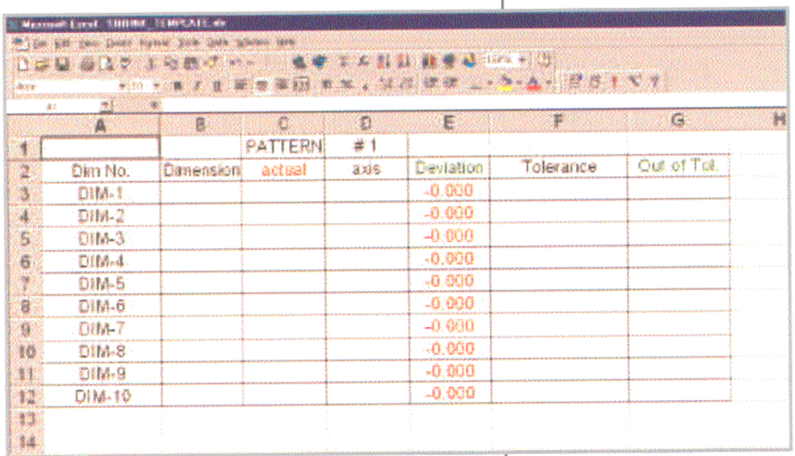
Pattern Dimension (with cast metal shrink) = 1.005 in. (25.5 mm)

Tolerance = +/- .015 in. (0.4 mm)

This is insurance that if the foundry's process variables to produce the casting are in control, you are practically guaranteed to yield a casting that is within the Blueprint Dimensional Tolerance Envelope.

Record a minimum of 2 measurements in each axis (X, Y and Z) with the actual print dimension and the applied shrink dimension. This will verify that you have included the foundry shrink factors in your pattern. One of the 2 measurements should be the overall dimension, as any error will accumulate and be the most obvious in the longest dimension. In addition, record all critical dimensions and supply this information to your selected foundry.

The use of a spreadsheet allows you to analyze pattern and part dimensional data along with importing images showing the Inspection points where the pattern and part are measured.



	A	B	C	D	E	F	G
1			PATTERN	# 1			
2	Dim No.	Dimension	actual	axis	Deviation	Tolerance	Out of Tol.
3	DIM-1				-0.000		
4	DIM-2				-0.000		
5	DIM-3				-0.000		
6	DIM-4				-0.000		
7	DIM-5				-0.000		
8	DIM-6				-0.000		
9	DIM-7				-0.000		
10	DIM-8				-0.000		
11	DIM-9				-0.000		
12	DIM-10				-0.000		
13							
14							

The use of a spreadsheet allows you to analyze pattern and part dimensional data along with importing images showing the Inspection points where the pattern and part are measured.

Keeping accuracy records can also help you determine the consistency of your process over time.

Accuracy of the patterns before they are produced into castings have many variables such as equipment, materials, environment and handling.

Equipment: The X and Y axis features are limited to the size of the beam diameter, typically .010 - .014 in. (0.25 - 0.36 mm) diameter for QuickCast patterns, but down to .003 in. (0.08 mm) on some machines. The Z-axis features are limited by layer thickness, typically .004 - .006 in. (0.10 - 0.15 mm) for QuickCast patterns, but down to .001 in. (0.025 mm) in other build styles. Your machine condition and calibration also contribute to the pattern accuracy. Your 3D Systems' Field Service Engineer is qualified to help you evaluate the condition of your machine.

Materials: Acrylate resins manufactured during the early introduction of Stereolithography are not as dimensionally stable as the newer Epoxy resins. Photocurable resins are now being developed for individual mechanical properties. As these properties differ, accuracy may also be affected. Resins that are designed to be durable and/or flexible may not achieve the same accuracy as a harder resin. Working with your 3D Applications Engineer will assist you to determine the most accurate resin available based on your particular machine and applications.

Environment: Keep the patterns in a cool dry place, away from heat and humidity. It is a good idea to keep them in a plastic bag with desiccant to prevent any water absorption.

Handling: Improper handling and stacking during post-processing (support removal and PCA curing) can affect squareness, flatness and induce twist in what are sometimes very thin, delicate configurations.

Storage and Transportation

When you store patterns for a long time, ensure they are in a dry, non-humid environment. Prolonged exposure to moisture will damage the parts. Use of desiccant (to extract moisture) in a closed plastic bag will help.

When storing or shipping QuickCast patterns, be sure to place the pattern in a sealed bag with an included bag of dessicant.

Shipping parts in a sealed plastic bag with desiccant will suffice for most situations. Ensure that parts are "free" and not in contact with other objects. Be aware that the air pockets in plastic bubble wrap will expand during high altitude transportation and pressure may be exerted on your patterns leading to deformation. The use of holding fixtures, constructed of Styrofoam, is highly recommended for large, thin parts. Patterns should have at least one opening to the atmosphere to equalize the pressure changes. Be sure to mark this opening for the foundry's convenience. It is suggested that you leave the pressure tube (as described in the section entitled "Checking for Holes or Leaks") open, this will serve as an atmospheric vent and let the foundry re-check vacuum to insure that there was no damage to the pattern during shipment.

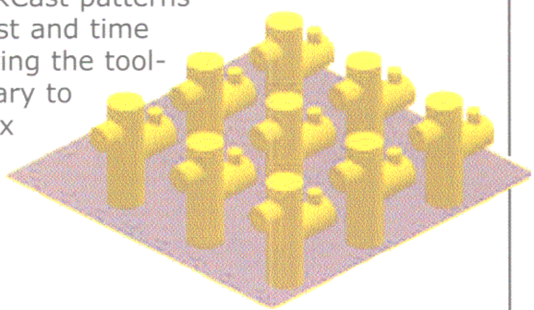
Under extreme conditions of heat the part may be shipped to the foundry in a Styrofoam box with dry ice. The dry ice will serve two purposes; 1) keep the part cool, 2) eliminate moisture or condensation. The dry ice should be separated and secured from the part. Do not place the dry ice on top of the part, as this will cause the part to freeze.

Large shipping carton with Styrofoam inserts. Note the separate cavity on either side where dry ice may be stored to keep the pattern cool in the hottest, most extreme climates.

Overview of Investment Casting with QuickCast Patterns

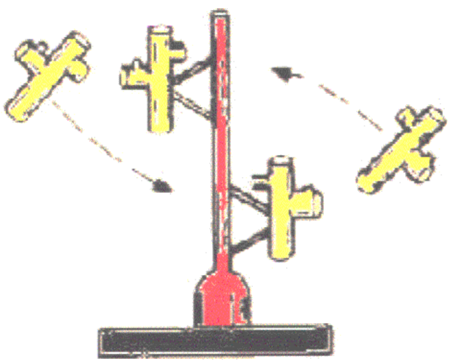
STEP 1

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



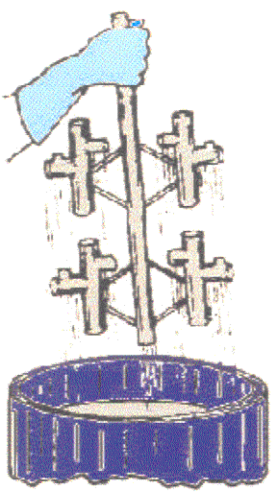
STEP 2

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



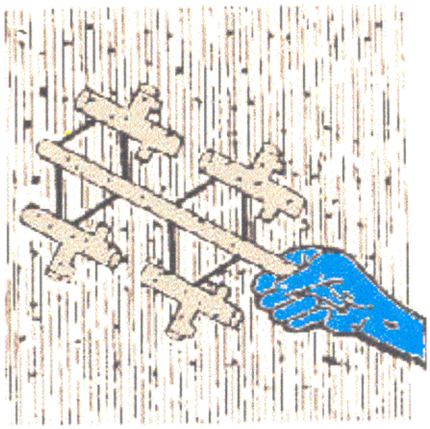
STEP 3

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 progressively coarser refractory grains to obtain the desired shell or mold thickness.

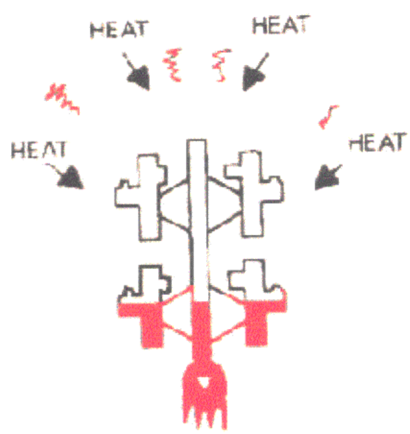


STEP 5

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.

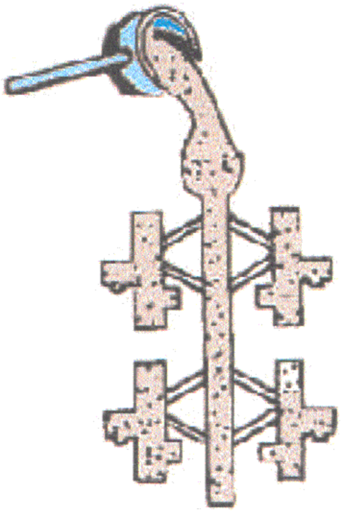
STEP 6

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.



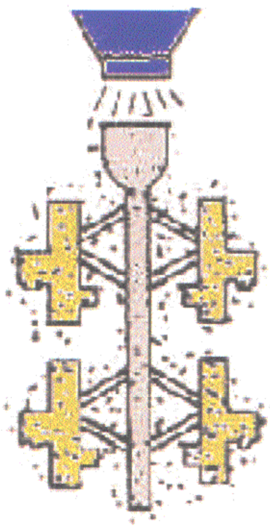
STEP 7

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



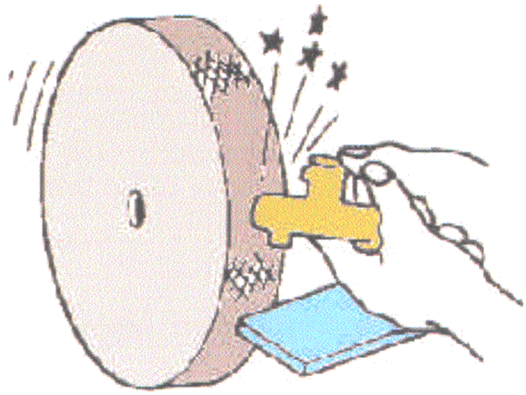
STEP 8

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.



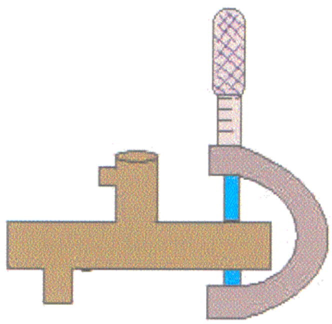
STEP 9

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



STEP 10

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



Guidelines to Investment Casting QuickCast Patterns

Receiving the QuickCast Pattern

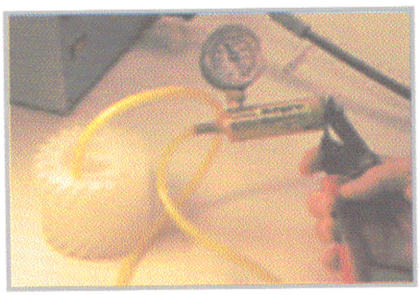
Keep the patterns in a cool dry place, away from heat and humidity. It is a good idea to keep them in a plastic bag with desiccant to prevent any water absorption. The foundry's wax room is suitable because it is generally cooler and dryer than other areas in the foundry.

Include dessicant with your QuickCast pattern in a sealed bag.

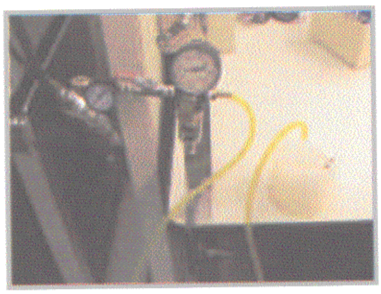
Check for Holes or Leaks

You will need to verify that the QuickCast pattern has no holes or leaks to prevent slurry from running into the interior of the pattern creating a non-metallic inclusion in the casting.

TIP: The same methods described in the earlier section entitled "Checking for Holes and Leaks" may be applied at the foundry also. Holes may also be sealed with casting wax.



Checking for holes and leaks with a vacuum leak tester or a simple pressure regulator is an excellent preventative measure.



Consider Specific Features

As with any wax casting pattern, generous radii will contribute to the success of the casting process and QuickCast patterns are no exception. The foundry may need to add wax in a fillet to follow their conventional casting design requirements.

The cleaner (better drained) the pattern the easier the part is to burn out. Solid (undrained) sections over .060 in. (1.5 mm) may tend to slightly expand and crack the shell at the burnout temperature. A technique that will prevent cracking the shell is to brush a thin coat of paraffin wax on the surface of a solid section. The wax melts quickly leaving room for any material expansion. When using this method, be careful to maintain the dimensional requirements or plan to machine/grind any excess metal to the required dimension.

Gating the QuickCast Pattern

The foundry should "over gate" (be generous with gating). Adding and removing extra safety gates takes less time and costs less than making the casting over.

Also, drill some small holes, .125 in. (3 mm), in the pattern where the wax gate will be on top. Since the wax gate will melt quickly the holes allow a "vent" to eliminate any internal pressures in the QuickCast pattern during the burnout cycle.

The area to be gated may be cleaned by wiping the surface with Isopropyl Alcohol for better attachment of the wax gate. Some resins develop a surface condition to which sticky wax will not attach. Light sanding with 180 grit sandpaper will allow a stronger bond of your gating to the pattern.

Venting the QuickCast Pattern

Venting the pattern can be accomplished several ways.

As previously mentioned venting can be accomplished by drilling some small holes, .125 in. (3.0 mm), in the pattern where the wax gate will be on top. Since the wax gate will melt quickly the holes allow a vent to eliminate any internal pressures in the QuickCast pattern.

Gating runners to the pouring cup can also serve as additional vents.

Shelling the QuickCast Pattern

There are several types of shelling systems. All will work with QuickCast patterns, some better than others. Shelling systems will vary between foundries, each has developed their own proprietary process.

Raw Silica systems are the most fragile. This is due to green strength vs. fired strength issues. Raw Silica systems are limited to only one thermal cycle. In other words, the shell is heated up to burn out the pattern and if it comes to room temperature to clean out the ash, then heating the shell again to pour in metal will cause it to deteriorate (crumble). However, Raw Silica can be used successfully with Ferrous metals due to the extreme higher temperatures of the molten metal. The pattern will be burned out of the shell and the elevated temperature of the Ferrous metal will have a greater likelihood of vaporizing any ash when poured. This makes it a single thermal cycle, never allowing the shell to reach room temperature.

Fused Silica systems are stronger, but are also limited to one thermal cycle similar to a Raw Silica shell system (described above).

Zircon and Alumina systems are excellent. Both can be cooled after the heating process. Thus any ash remaining from QuickCast pattern can be sufficiently cleaned by flushing, vacuum, vibration, etc. Since Zircon and Alumina systems will withstand multiple thermal cycles, this is the preferred shell for non-ferrous materials.

Most binders are some variation of colloidal silica. The EPA has driven out most of the alcohol-based systems. Even though the systems are now water based this has no effect on the QuickCast pattern. The first dip has a very low water content and is intended to dry very quickly. The amount of water the QuickCast pattern is exposed to before the shell takes over as an insulator is minimal. Subsequent dips are loaded with moisture, but aren't in direct contact with the QuickCast pattern.

Most facecoat slurry systems contain surfactants to promote wetting the slurry on wax. Some slurry systems may not adhere to all resins as well as wax. Facecoat adhesion to QuickCast patterns may be promoted by spraying the patterns with aerosol glue. The adhesive is applied and allowed to dry prior to dipping. Spray adhesives are available at most art or hardware stores.

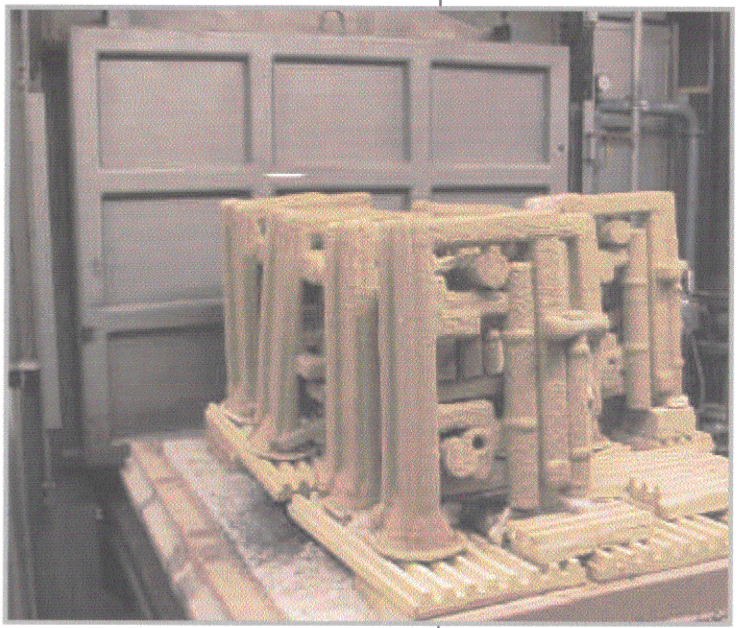
Some QuickCast patterns may produce higher stresses on the shell. This can be overcome by several methods:

- Adding extra backing coats (layers to the shell mold).
- Using wire mesh between coats.
- Adding chopped ceramic fibers, chopped stainless steel wire, or chopped stainless steel wool.

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

Burning Out the QuickCast Pattern

While an autoclave may be used to remove the wax gates and runners, this is not enough heat to remove the QuickCast pattern. The QuickCast pattern needs the higher temperatures associated with a flashfire furnace to combust. Newer flashfire furnaces also do a better job of reclaiming the wax than autoclaves.



Flashfiring provides adequate heat to completely remove the QuickCast pattern. Newer flashfire furnaces do a better job of reclaiming the wax than autoclaves.

The following steps will provide a guide for burning the QuickCast pattern from the shell:

- Preheat furnace to 1400°F (760°C).
- Load shell mold and ramp temperature up to 1800°F (982°C) in about 30 minutes
- Maintain 1800-2000°F (982–1093°C) for 1.5 – 2.0 hours.
- If the furnace has less than 7% oxygen, the QuickCast pattern may leave some residue. At 8-12% oxygen expect little to no ash.
- An alternative to pumping in extra oxygen is to sustain the shell at 1800-2000°F (982–1093°C) for several hours (3.0+ hours).

During this process, pumping 8-12% oxygen into the furnace will prevent any oxides from forming in the shell. Oxides may appear as a crystal that will be visibly seen on the inside of the shell when breaking it off the casting, though the oxide will not adhere to the metal casting it will make the surface pitted.

When pouring non-ferrous alloys the shell should be cooled (if possible) and inspected for ash or residue that will create quality problems with the casting. Because of the extreme temperature required in pouring ferrous metals, the shell does not need to be cooled down, any ash will have a greater likelihood of being vaporized.

Inspection of the Casting

When performing radiographic and/or penetrant inspections, be aware that the QuickCast patterns are built in layers. As such, these build lines are often reproduced in the casting surface and should not be misinterpreted as defects.

Supply List

Vacuum Leak Tester

Silverline Hand Vacuum Pump 04010

Mityvac	800-MITYVAC	www.mityvac.com

Sunpro Hand Vacuum Pump CP7830

Actron	800-228-7667	www.actron.com

Ultraviolet Spot Curing Equipment

EFOS Inc.	800-668-8752	www.efos.com/products
Dymax Corp.	860-482-1010	www.dymax.com/products/curing_equipment
Green Spot	800-783-1548	www.uvsorce.com

Centrifugal Spinner

Damant & Sons	217-847-3324	www.dadant.com/extra.htm

D-Limonene

Florida Chemical	813-294-8483	www.floridachemical.com

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Solidiform, Inc.

Solidiform was established in 1981 as a production aluminum sand and investment casting facility, serving military and commercial aerospace markets. After participating in 3D Systems' QuickCast beta program in 1992, the growing market demand for RP&M castings became evident. Solidform has produced in excess of 20,000 investment castings in 3,000 different configurations from QuickCast capable patterns. Over 30,000 precision sand castings of 1,000 configurations have been produced from prototype patterns and production matchplates produced from ACES stereolithography master patterns.

Ft. Worth, TX

817.831.2626

www.solidiform.com

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About 3D Systems

3D Systems provides solid imaging products and services that substantially reduce the time and cost required to design, test and manufacture products. The company's systems utilize patented technologies that create physical objects from digital input.

3D Systems currently offers the ThermoJet® office printer and SLA® industrial systems, which include proprietary software and materials. The company also licenses the 3D Keltool® process, a complementary application that produces injection molding and die casting inserts from SLA system master patterns. In February 2001, 3D Systems announced it acquired OptoForm, a French company that developed stereolithography systems using paste materials.

Based in Valencia, California, U.S.A., 3D Systems was founded in 1986 and is recognized as the world technology and market leader in solid imaging. For additional information, visit the company's website at www.3dsystems.com or phone (888) 337-9786.

About The Author - Mark Abshire

Mark Abshire joined 3D Systems in 1996 and is currently an Applications Consultant for the company's solid imaging products. Prior to joining 3D Systems he was employed at Texas Instruments for 20 years in various manufacturing and engineering positions within the Defense and Weapons Systems Division. Mark's background includes machinist/tool maker, producibility engineering, rapid prototyping specialist, manufacturing manager and rapid prototyping manager. He was instrumental in the early adoption and success of rapid prototyping at Texas Instruments to produce design and concept models for engineering as well as casting patterns for manufacturing.

Mark is a member of the ICI (Investment Casting Institute), the AFS (American Foundrymans Society) and the RPA/SME (Rapid Prototyping Association of the Society of Manufacturing Engineers).

P/N 70438

3D SYSTEMS

3D Systems

26081 Avenue Hall

Valencia, CA 91355 USA

telephone 661.295.5600 ext. 2882

fax 661.294.8406

toll-free 888.337.9786

e-mail moreinfo@3dsystems.com

www.3dsystems.com

Nasdaq: TDSC

France

telephone +33 1 69 35 17 17

Germany

telephone +49 6151 357 303

Hong Kong

telephone +852 2923 5077

Italy

telephone +39 039 68 904 00

Spain

telephone +34 93 754 04 00

UK

telephone +44 1442 282600