Application Guide

Somos®
Investment Casting Guide

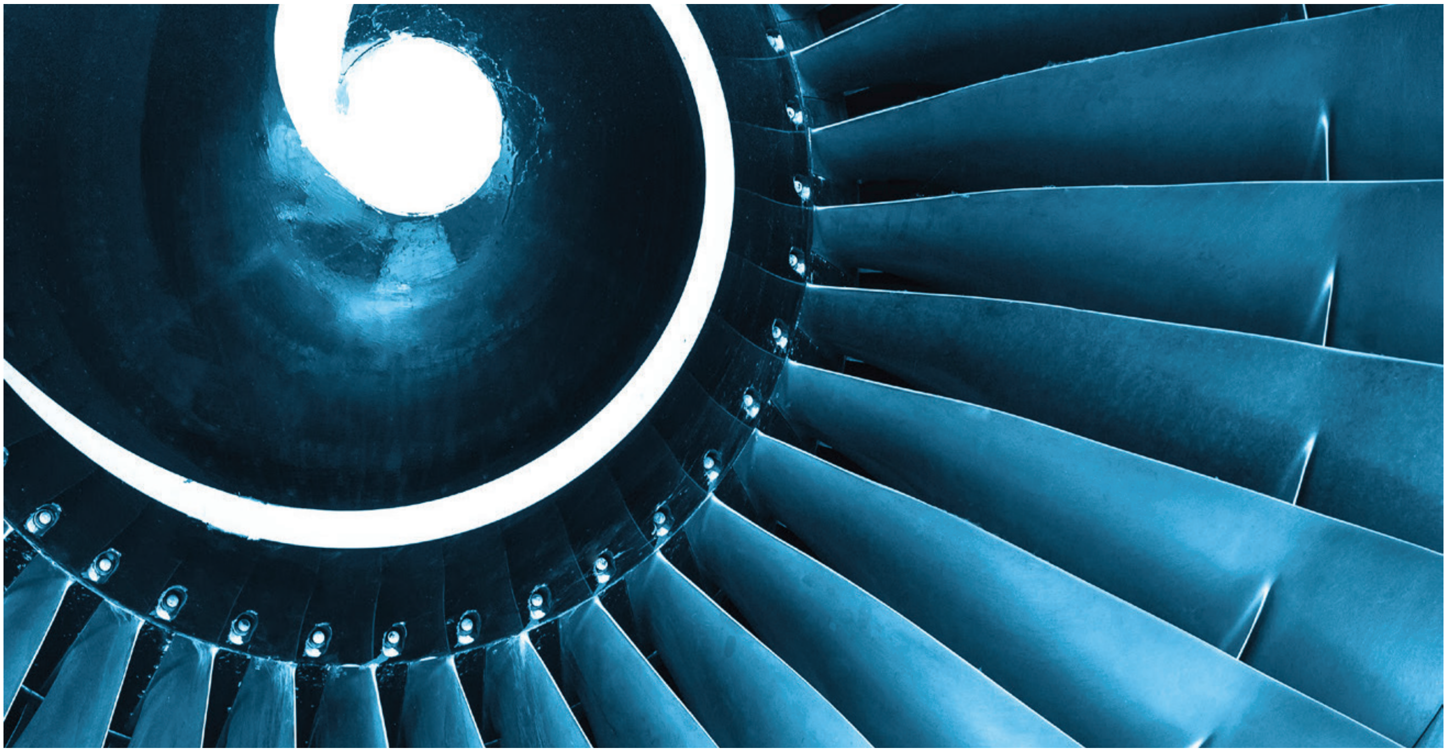
stratasys

Introduction

Investment casting, also known as Lost Wax Casting, is one of the oldest metal casting processes and is still very much in use today. Investment casting produces near net-shape metal castings and is known for providing a high quality surface finish compared to other casting techniques. Investment casting is an ideal process to cast metal parts when the final design of the part is still undergoing changes or when relatively low numbers of castings are needed.

The investment casting process utilizes sacrificial patterns and ceramic shell molds that allow for highly complex casting designs to be achieved. Traditionally these patterns are created by injection molding wax, and as such require the use of metal tooling. The substantial cost and time required to generate wax pattern tooling limits the range of applications for which investment casting is economically competitive.

With the development of new materials especially designed by Somos® for the investment casting process, foundries can realize significant savings in time and costs by directly printing stereolithography (SL) patterns and eliminate the need for metal tooling altogether.



Overview

An introduction into using SL Patterns to save you time and money on your next project.

Application Details

Creating 3D printed patterns for investment casting allows for significant time and cost savings over traditional tooling methods making it a cost effective solution for prototype castings and low volume manufacturing. In addition, patterns created by SL are highly accurate and allow for complex geometries to be created without increasing cost.

When to Use SL Patterns

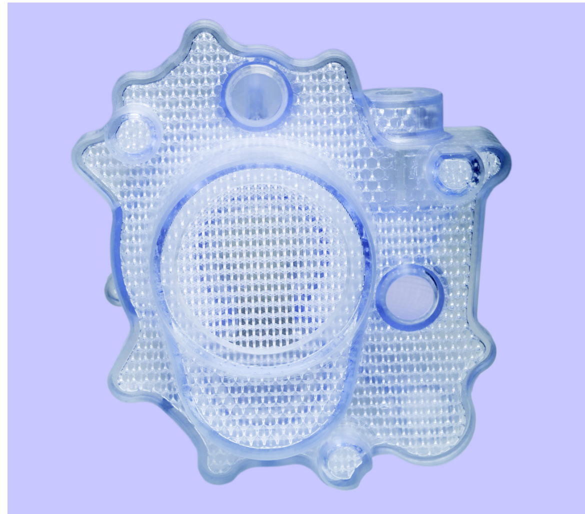
- For prototype castings
- During process development
- First run production castings
- Low volume production

Benefits of Using SL Patterns

- Eliminate upfront tooling costs
- Shorten process development time
- Eliminate tooling rework
- Flexibility in design revision and optimization
- Faster turnaround
- Increased margins

Pattern Design

The key to ensuring the success of casting projects begins with the pattern. The following are some things to take into account when designing your pattern.



TetraShell™ Structure
TetraShell™ is an SL build prep software that allows a user to hollow out and create a tetra-lattice structure within an .stl file.

Considerations

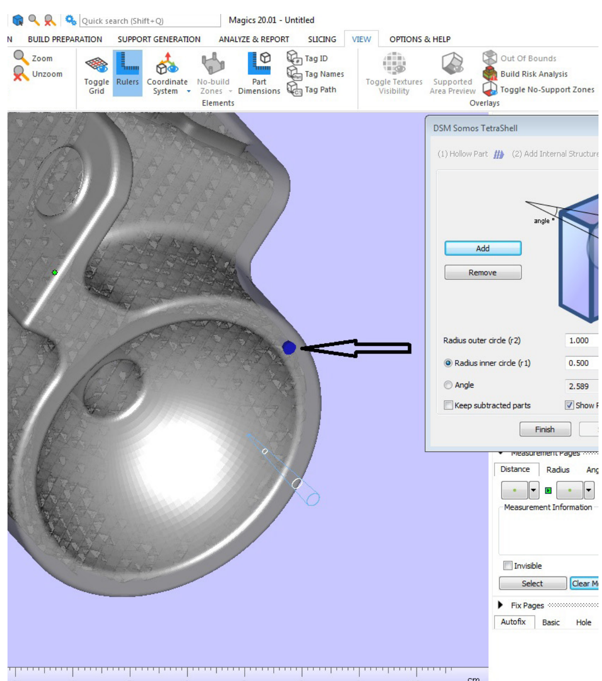
Using SL patterns allows for savings in both cost and time. In order to have the best chance of success, the pattern design itself must be considered not just for the final metal casting, but also in how the pattern will perform during the process. The following topics will outline items to think about when designing the pattern.

Hollowing Process

Typically, once the design is complete, the file must be hollowed to remove the bulk of the pattern while still leaving a lattice like structure internally allowing for enough strength so that the pattern does not break during the process. The idea is to remove as much solid mass from the pattern as possible, so that the amount of material that must be burned out and residual ash is minimized. There are a number of programs that can be used to hollow the CAD or .stl data file. Somos® recommends using TetraShell™, a module available in Materialise's Magics Software that allows for manipulation of .stl files used in SL equipment. The TetraShell™ software allows the user to accurately control the thickness of the pattern wall, as well as control the internal lattice structure to create the lightest, strongest pattern possible. It is important to note that the minimum wall thickness of the pattern is determined by the SL machine being used, as some are more accurate than others. On average, the minimum wall thickness should be 0.4mm or greater.

Drain Holes

Consider the best areas to insert drain holes. TetraShell™ allows for custom-sized drain and vent holes to be placed anywhere along the .stl file surface. The holes should be placed in areas that can easily be filled or plugged later after the SL pattern is fabricated. The holes should also be sized and placed to allow efficient draining of the SL pattern. Patterns are often centrifuged to remove as much liquid resin as possible – placing the drain holes in corners or other areas may require extra work to drain the pattern.



Drain Holes
Adding drain holes in .stl file.

Shrink Factors

Patterns must be scaled to compensate for metal shrinkage during solidification. CAD models can be scaled on the SL machine to any factor and the machine has the ability to scale the three coordinate axes independently. The foundry should specify the shrink factor(s) required for the project. However, if different features of the pattern require different shrink factors, this must be completed in the part design using CAD.

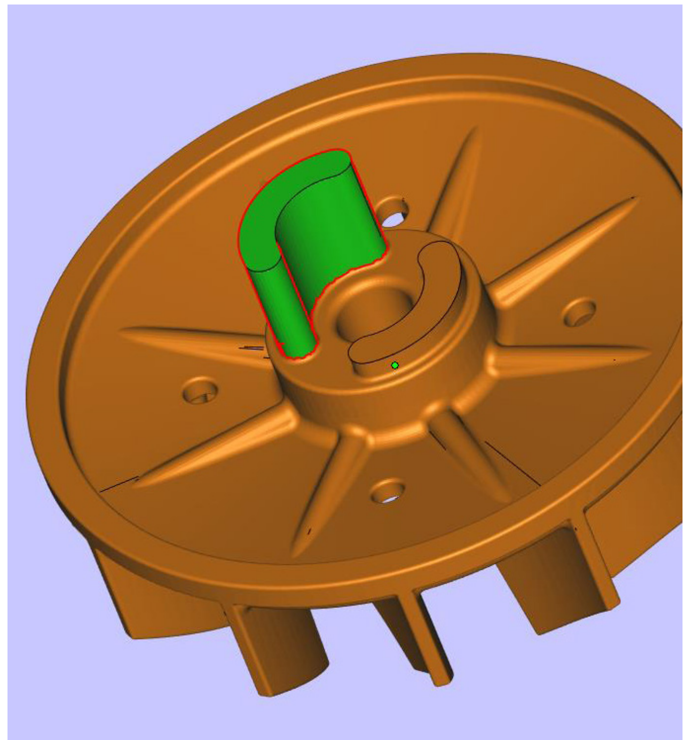
Tolerances

It is very important for the foundry to communicate the tolerances required for the part. The tolerance of the pattern must be less than that of the final casting. Foundries commonly set the pattern tolerance at half that of the final casting.

Tolerance

Machine Stock

Machine stock can be added in the CAD design or in the .stl manipulation software, although adding in the CAD design is recommended if the stock is to be added to contoured surfaces. If the machine stock will be required on a flat surface, the .stl file manipulation software can used.



Machine Stock
Adding machine stock to an .stl file

Gate Stubs

Although gates will need to be attached to the pattern, it is recommended that gate stubs be built directly in the SL pattern. This moves the gate attachment point further away from the part and reduces the risk of damaging the part surface during pattern assembly.

Draft

As the use of SL patterns eliminates the need for tooling to create injection molded wax patterns, draft angles can also be eliminated. However, if the project is for prototyping with the final manufacturing process ultimately to be moved to traditional wax patterns, draft may be left on to better represent the final manufacturing process.

Obtaining the Pattern
External Sourcing

If procurement of a SL pattern is to be outsourced, steps must be taken to evaluate the ability of the service to provide quality patterns that will yield the desired degree of quality, accuracy, cost and timing. The topics below will help in qualifying a service provider to create SL patterns.

Top Ten Questions to Ask Potential Provider

1. Will my pattern be built at your facility or will you outsource?

Service providers may outsource jobs for multiple reasons. If the provider outsources the job, there will be less visibility and requirements must be communicated by the provider to whomever they are outsourcing to mitigate potential problems in quality.

2. Can you provide references of foundries you provide patterns to on a regular basis ?

If the provider does not regularly work with a foundry, they may have little experience in creating patterns and you may want to consider going with another service provider to guarantee a high quality level.

3. What SL material(s) do you have available for making patterns and which do you recommend using and why?

There are many SL resins available on the market. Not all are suited for use as investment casting patterns. If the provider cannot recommend a material with good reasons, they may not have very much experience in producing patterns.

4. What process do you use to drain the patterns?

As SL patterns are mainly hollow, liquid resin will be trapped within the pattern. This liquid will need to be drained and this is done by strategically placing drain holes and vents into the pattern (as discussed in the Drain Holes section on previous page). The more completely the pattern is drained, the less residual ash will be left after burnout. Less ash leads to better quality castings. Liquid resin left in the pattern during burnout may also lead to shell cracking due to expansion. Draining the pattern using gravity only is not sufficient in most cases, as the resin hangs up on the walls of the pattern leaving too much behind. A high quality service provider will have a centrifuge to spin the pattern and force the maximum amount of resin from the pattern.

5. How do you check to make sure the patterns are water-tight?

As the patterns are hollow, any holes in the outer wall of the pattern can allow slurry to enter the pattern which will lead to casting defects. Providers who consistently produce quality patterns use pressure and vacuum to test for leaks and provide documentation of testing/inspection.

6. How do you determine accuracy of the patterns?

Accuracy in the pattern is crucial in achieving quality casting results. The best providers will have CMM capability to inspect the pattern and ensure best quality.

7. How do you handle multi-piece patterns?

In some cases, the pattern size may be larger than the platform size of the SL machine. This should not discourage the use of SL patterns, as they are commonly bonded as multi-piece patterns. It is important that any seams or joints are not only firmly attached and oriented to not introduce dimensional errors, but also completely sealed so as not to allow slurry to enter the joint and cause casting defects. Commonly, the same resin that was used to make the pattern, two-part epoxies or cyanoacrylates are used to bond pattern sections. Adjacent holes should be drilled on mating surfaces such that air can pass between the two joined patterns.

8. How are the patterns packaged and shipped?

SL patterns are thin walled and therefore somewhat fragile. Care must be taken when packaging to ensure the pattern will arrive undamaged. The provider should be able to describe how they package the patterns and what their policy is on delivery of damaged patterns.

9. What data formats can you accept?

Pattern providers will require an .stl file to build the pattern on the SL machine. Many providers can convert CAD data like STEP into an .stl, but it is good practice to ask in advance what the provider will accept.

10. How involved are you with the investment casting industry?

If a pattern provider's business is focused on investment casting, they are typically active with organizations such as the American Foundry Society, the Investment Casting Institute or the European Investment Casters' Federation.

Receiving/Inspecting the Pattern

It is especially important to inspect patterns that are received from an outside service provider. Care should be taken to make sure the pattern will perform as expected before processing.

Visual/General

A careful visual inspection of the pattern surface should be done to look for cracks or shipping damage. There should be no liquid resin within the pattern. The pattern should be rigid, with smooth surfaces. Any softness should be investigated, as this could mean the pattern has absorbed moisture, which may lead to deformation during dipping. It is important to check for any distortion in the pattern surface as it will also be directly transferred to the casting.

Dimensional

A good provider will send an inspection or quality document with the pattern noting the results of dimensional testing. Upon receipt, the pattern should be measured and critical dimensions recorded and compared to requirements. Typically, it is good practice to require that the pattern does not contribute more than 50% of the tolerance of the finished casting.

Leak Inspection

The pattern must be completely sealed and water tight to prevent slurry from flowing into the pattern that will cause casting defects like inclusions. The provider will provide a document noting that the pattern was inspected and passed a check for leaks.

The foundry should also vacuum test the pattern to ensure the pattern was not damaged during shipping. If the pattern does not have a tube or port to attach a vacuum, a tapered tube can be bonded to the pattern and a hole punched in the skin.

Measuring with a Pressure Gauge
Ensures no small holes are in the shell which can cause slurry to get inside the pattern.

Testing for leaks is easily accomplished using a hose attached to a port on the pattern and an automotive leak tester or other pump and carefully drawing a vacuum on the pattern to 10 in/Hg (250 mm/Hg). Too much vacuum can damage the pattern. If the pattern holds and does not leak it has been properly sealed.

A vacuum leak indicates a hole.

In order to find the hole, use a low pressure regulator blowing 1–10 psi air pressure into the port on the pattern. Too much pressure can damage the pattern. Escaping air can be felt or heard. In addition, while the air testing is being conducted, a dishwashing soap solution or mineral spirits can be brushed onto the part where bubbles indicate escaping air.

Pattern Sourcing Summary

Qualifying a pattern provider ensures that they have the knowledge, experience and capability to provide a pattern that will meet your requirements.

The provider must be supplied with adequate information about shrink, tolerances, gate location and machine stock to the provider to ensure that the pattern will result in an acceptable casting.

It is essential to inspect the pattern to ensure that it is leak tight and meets the dimensional requirements of the casting.

Pattern Storage

Patterns that will not be immediately used should be stored in a cool, dry environment, away from UV light, from windows or fluorescent lights. It is recommended that pattern be sealed in a plastic bag containing dessicant to ensure the part does not absorb moisture from the air over time, which would affect dimensional accuracy. If the part is stored for a long period of time, more than 30 days, it is recommended that the leak and dimensional checks be repeated.

Pattern Sourcing Summary

- Qualifying a pattern provider to ensures that they have the knowledge, experience and capability to provide a pattern that will meet your requirements.
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- It is essential to inspect the pattern you receive to ensure that it is leak tight and meets the dimensional requirements of Measuring with a Pressure Gauge Ensures no small holes are in the shell which can cause slurry to get inside the pattern.

Printing the Pattern & Finishing

Patterns can be produced using various technologies. Only UV curable photopolymer systems such as stereolithography and DLP are addressed in this guide.

Part Orientation, Drainage and Orientation

- Patterns need to be either designed with vents and drains or have them manually punched after building is complete to allow uncured liquid resin to drain back into the machine.
- Patterns should be oriented on the machine platform to allow for optimum quality, good drainage of the pattern and required speed. In some cases, patterns may need to be tilted to a 45° or placed on edge in the Z-axis angle to reduce stair-stepping and produce a smoother surface.

Support Removal

- Once the part has completed building, it needs to stay on the platform to allow drainage of uncured resin from the pattern.
- After all resin has drained, the pattern can be carefully removed from the platform and any supports gently scraped off with a spatula. The pattern is not fully cured and must be handled gently to prevent breakage or distortion.

Draining (Centrifuging)

- After the supports have been removed, the parts should be centrifuged to remove as much uncured resin from the pattern as possible.
- Commonly used in the industry are commercial grade "honeyspinners" (as shown below). The pattern can be placed into a cardboard box and wrapped in paper towels to absorb resin. The box can then be attached into the honey spinner using bungee cords or straps.

Cleaning

- Once the uncured resin has been removed via the centrifuge, a soft paper towel soaked in isopropyl alcohol can be used to wipe the outer surface of the pattern and remove any uncured residue.
- The pattern should never be submerged in cleaning solvents. Any solvent that enters the pattern will have to be removed. Solvent left in the pattern can cause failures such as shell cracking during the burnout phase - it can also cause softening of the pattern.

Post Cure

- Once the pattern has been drained, centrifuged and wiped clean it should be placed into a UV Post Cure Apparatus (PCA) to fully finish curing the polymer resin.
- PCA intensities vary from machine to machine, so it is recommended to test the system by starting with a sample pattern at 15 minutes per side and increase time until the desired surface hardness is achieved (hard, non-tacky).
- If the patterns appear too brittle or very yellow this can be due to overcuring in the PCA, and time should be reduced.

Hole Filling

- Any drain holes and vents will need to be sealed to prevent shell slurry from entering the pattern during the investment casting process.
- The holes can be filled using the same SL resin as the patterns that are produced from and then cured using a UV light pen.
- There are also other materials such as UV-curable adhesives, cyanoacrylate adhesives and two part epoxies that can be used to fill holes.

Leak Inspection

Refer to page 7 for more details.

Bonding Large Assemblies

- If the size of the pattern is too large to fit on the 3D printing machine platform, it may be necessary to build it in smaller sections and then bond them together to create the finished pattern.
- The same adhesives recommended to fill the drain holes can be used. Two-part epoxy and cyanoacrylates typically work better than UV curable adhesives as some of the bonding areas may be internal and not reachable with light.

Honey spinner used for removing resin from the pattern

Pattern Assembly

As with wax patterns, SL patterns must be incorporated into a system including the pouring cup, sprue, runners and gates which will allow flow of molten metal inside the cavity created by the pattern after burnout.

Sprue and Runners

- Standard foundry gate wax is the most common material used on SL patterns for the gate and runner system.
- SL can also be used for sprues, and is easily attached to the pattern. This can eliminate the need for de-waxing.
- It is recommended SL sprues only be used on very small components because SL sprues will add more costs, can be difficult to attach to hooks for the dipping process and also add buoyancy which can cause issues with dipping.
- If using SL sprues, holes must be drilled to the mating surfaces to allow airflow throughout the entire assembly which is necessary for good combustion during burnout.

Gating

Proper gating is necessary to feed molten metal to the casting. With SL patterns it is often difficult to optimize gating, and typically overgating is needed to ensure the optimal flow of metal.

- Overgating should be used to ensure metal flow is optimum, allows for better oxygen flow during burnout and strengthens the pattern to help it compensate for buoyancy forces during dipping, as the patterns are hollow and full of air.
- Wax gates can be attached directly to the pattern. Gate stubs can also be designed into a pattern.
- Moving the point of attachment away from the surface of the pattern reduces chances of damaging the surface during assembly.
- It is recommended when attaching gates to drill 1/8" (3 mm) holes in the pattern before covering with wax. This allows for pressure relief during autoclave and burnout and also aids in airflow during burnout.

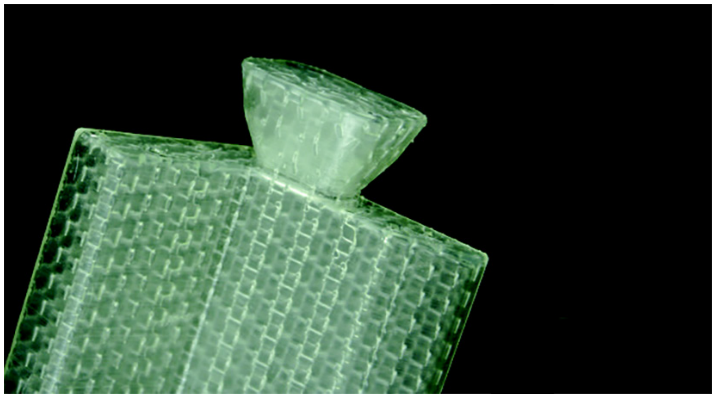
Vents

It is highly recommended to have at least one vent attached to the pattern assembly. Vents reduce the risk of failure during burnout.

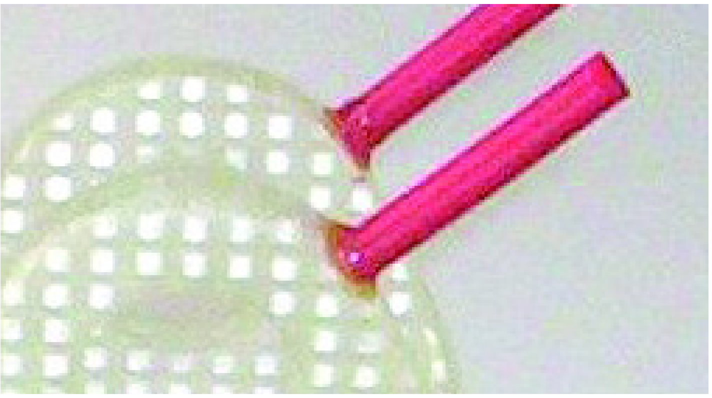
- Vents allow steam to enter the pattern during the autoclave process, which will soften the pattern making it deform more easily and reduce the chance of shell cracking.
- They significantly increase airflow to the pattern during burnout, increasing oxygen needed for combustion.
- Vents can be created by adding spaghetti wax plugs to the pattern which will be opened after shelling.
- Vents can also be designed into the SL pattern, eliminating some of the labor needed during processing. Careful consideration of vent placement must be taken as they should be on the outside of the assembly where they can be reached and opened, as well as not interfere with the assembly itself.
- Large patterns, patterns with thin walls or complex geometry should utilize more vents.

Surface Treatment

Surface treatment, such as etching solutions, can be used with SL patterns and are recommended to remove dirt and oils that could prevent good shell adhesion.



Gate Stub
Many of the foundries that reliably cast SL patterns have stubs built at the gate locations.



Vent
Building SL vents will eliminate some of the manual labor needed during processing.

Shell Creation

In general, existing shell building practices can be used successfully to shell SL patterns. Most foundries use the same shelling method for SL patterns as they do for their normal wax pattern assemblies.

Preparation

As stated earlier, patterns should be cleaned using an etching solution to remove debris, oil or dirt from the surface.

Dipping

- SL patterns are hollow and therefore buoyant which can cause some difficulty during the dipping process. Additional force is needed to submerge the patterns which will cause more stress on the patterns potentially leading to a failure.
- Additional gating or runners on the pattern will strengthen the assembly and make it better to resist any increased forces due to buoyancy.

Shell Materials

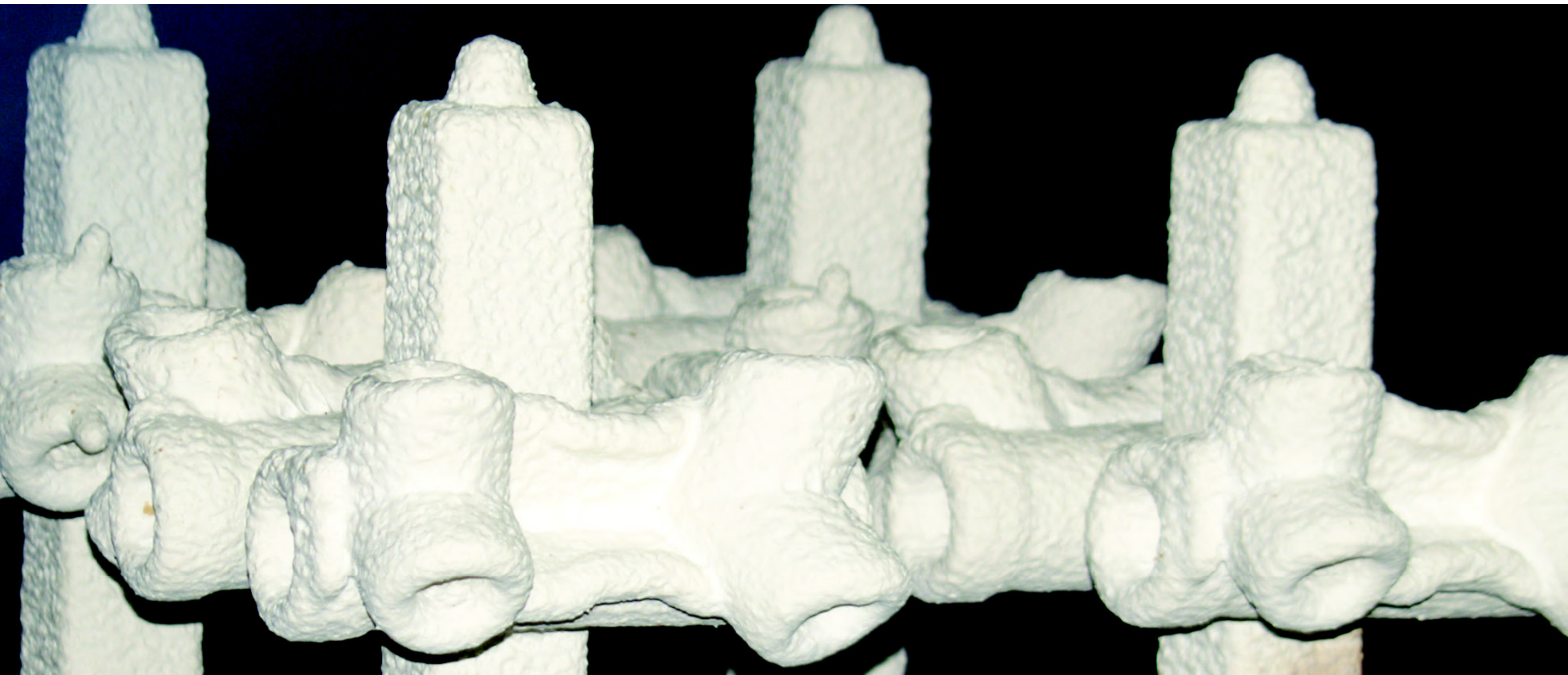
- Common shell materials such as fused silica or alumino silicate can be used with SL patterns.
- Fused silica will need extra steps to be successful due to cristobalite formation during burnout which causes these shells to be weaker. See page 11 for more information.
- Water-based or alcohol-based slurries are equally usable with SL patterns.

Shell Adhesion

- Shell adhesion is not typically an issue with SL patterns as long as standard procedures are followed.
- Finishing of the pattern surface such as sanding or lacquer does not affect shell adhesion.

Number of Coats

- Standard practices for the number of shell coats can also be used for SL patterns.
- Some foundries have adopted the practice of adding additional coats for SL than used for the wax process, but it has been found that this can actually cause shell cracking as the thicker shell will be more rigid and less likely to flex due to thermal expansion during autoclave or burnout.
- It is recommended that the same amount of coats used for wax patterns be used for SL patterns.
- Additional coats may be considered where there are challenging geometries involved or where thin, solid walls will be used.
- Other methods of strengthening the shell can include wire mesh, chopped ceramic fibers or chopped stainless steel wool between coats.
- Pre-dip solutions may also be used to increase flow of the slurry and allow for better coating of hard to reach areas and complex geometries.



Burnout Process

Unlike wax patterns, SL patterns must be removed through a burnout process or procedure. Complete removal of the pattern from the shell is important for the overall success of the finished casting.

De-Wax

De-waxing is traditionally used to melt and eliminate all wax components from the mold. Using SL molds is different, in that the SL material is not wax and is a highly cross-linked polymer. Therefore, it must be burned out to remove from the mold.

- Shells are typically not autoclaved to prevent cracking due to pressure. If autoclaving is deemed necessary to help soften the pattern, at least one vent should be attached to each pattern on the tree to allow a path for pressure release. Spaghetti wax can be used to create the vent.
- After shell building is complete, simply cut off the portion of the shell at the end of the vent to expose and melt out the wax with a torch and proceed with the autoclaving process. Alternatively, vents can be created and built in the SL pattern model, which eliminates downstream labor.
- Wax gates and runners can be melted with a hand torch or if the foundry has a flashfire furnace, they can be melted during the burnout step.

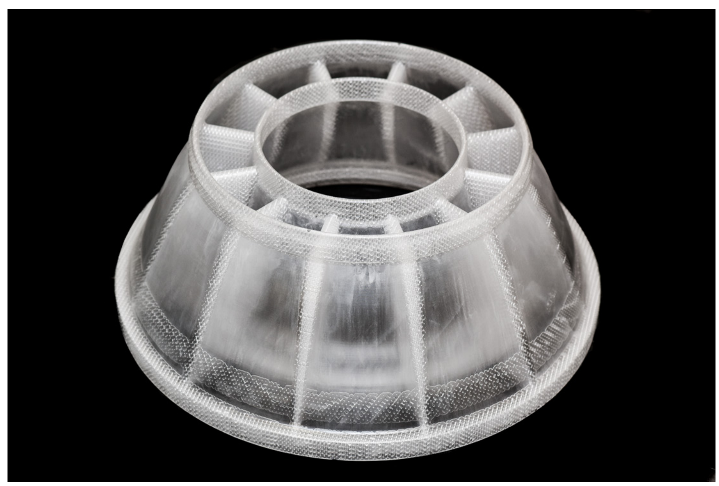
Temperatures and Combustion

In order to achieve the cleanest burnout possible, furnace temperature and available oxygen must be sufficient.

- As mentioned in earlier steps, vents should be added and opened after shell building to allow additional airflow during combustion.
- Fused silca shell systems will need extra precaution to avoid the formation of cristolbalite by keeping below 1,500°F (815°C). If the shell undergoes formation of cristobalite, it may be weakened and can potentially cause dangerous failures during pre-heat and pouring. The following process model can be used to avoid cristolbalite formation:
  1. Firing the shell for 2 hours at 1,500°F (815°C).
  2. Cooling the shell to room temperature and remove ash using compressed air or by rinsing with water.
  3. Patching all vents and reheating shell to conventional pre-heat temperatures and pour metal.
- Aluminosilicate shell systems do not form cristolbalite and therefore can be burned out at higher temperatures.
- Airflow has been stressed throughout this guide. Sufficient oxygen is required for complete combustion.
- Most pre-heat ovens do not have the ability to increase oxygen levels. Therefore, the following steps can be used:
  1. The pouring cup can allow air to flow into the mold, up an out through the vents (See Appendix A).
  2. The pouring cup should be elevated off the furnace floor using a grate to allow air to enter the pouring cup.
  3. If the furnace has no provision for adding air, plant air can be piped into the furnace during burnout.

Ash Removal

- Burnout of the SL patterns will result in some small degree of ash. Ash is typically left from SL resins that contain antimony or other heavy metals that cannot combust. Newer SL resins are virtually antimony-free, and thus have almost no ash.



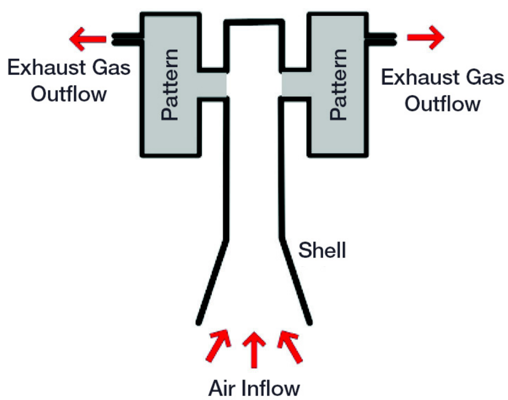
As no antimony is used, patterns created with Somos® WaterShed AF leave much lower amounts of ash residue after burnout, reducing clean-up and speeding up mold production.

- Any ash left in the mold after burnout can adhere to the mold and cause surface defects in the casting, therefore it is very important to clean out the mold with either compressed air, water or both.
- The best way to limit ash residue is by choosing a SL material such as Somos® Element or Somos® WaterShed AF, which leave only 0.005% ash, compared to standard SL materials that are around 0.1% ash.
- Reducing or eliminating ash can save both time and money for the foundry.

Appendix A

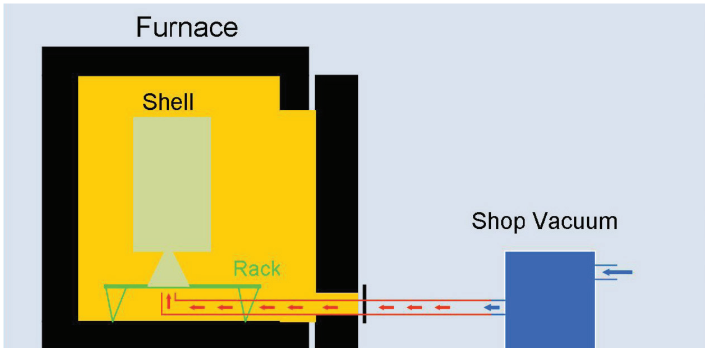
Creating “Natural Chimneys”

As combustion gases escape through the vents, air will be drawn naturally through the pouring cup.



Simple System to Add Oxygen

When the shop vacuum is turned on, the furnace is provided with a steady source of low pressure, oxygen rich plant air to support combustion.



Pattern Weight

Pattern weight and resultant ash can be affected by resin viscosity. Lower viscosity resins will drain faster and thus have less material trapped within the pattern, which also equates to lower total residual ash.

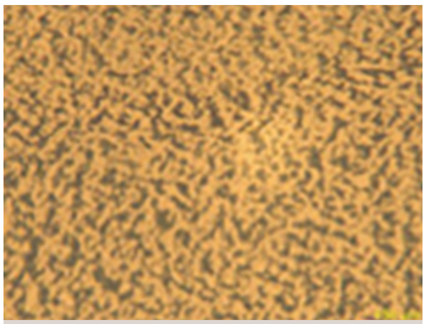
Antimony

Antimony (Sb) is a metalloid element. It cannot be burned out during the process, and contributes greatly to residual ash. Antimony also plays an adverse role in Titanium and Super Nickel alloy metallurgy causing potential defect sites in the casting.

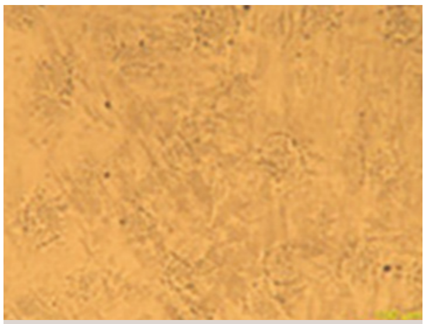
	Somos® Element & Somos® WaterShed AF	Standard material (containing Antimony)
Antimony Content (Detection level 1 ppm)	No detectable Sb	4 ppm
Ash Content After Burnout	0.005%	0.1%

SL Patterns

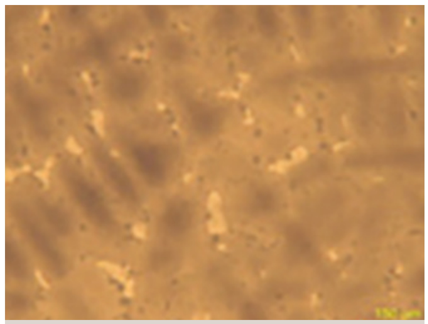
SL Patterns made using Somos products do not affect sub-surface microstructures and behave similarly to wax patterns.



Titanium



Nickel Based (IN100)



Martensitic Steel

Appendix B: Troubleshooting Guide

Problem Area	Symptom	Potential Problem	Solution
Pattern Issues	Softness in patterns	Moisture absorption	Dry pattern in a very low humidity environment.
			Return to vendor for replacement.
	Holes or cracks in pattern	Damage to pattern	Return to vendor for repair or replacement.
			Patch with wax.
		Incomplete finishing	Return to vendor for repair or replacement.
	Leak test failure	Surface holes or cracks	Find leaks and repair or return to vendor for repair or replacement.
	Discoloration	Overexposure to UV light	Most likely will not affect performance of the pattern.
Shelling Problems	Poor shell adhesion on SL 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	
Autoclaving Problems	Shell cracks in autoclave cycle	Inadequate venting	Increase number and size of vents. There should be at least one vent per pattern.
		Vents not open to pattern interior	Make sure that wax in pattern is removed prior to autoclaving and that the skin of the pattern is punctured prior to placing the shell in the autoclave.
		Solid areas in pattern	Do not autoclave. Melt sprues and runners out by hand or use flashfire furnace.
Burnout Problems	Incomplete combustion (material other than ash in the shell after burnout)	Inadequate oven temperature	Increase furnace temperature to 1,500°F (815°C) or higher.
		Inadequate burnout time	Increase time in furnace to 2 hours for small patterns, 3 hours or longer for large patterns.
		Inadequte 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	Leakage of slurry into pattern	Ensure patterns are properly sealed.
	Hex pattern on castings		
	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 pouring metal.
			Blow out shell hot if unable to cool for rinse.

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