

Stereolithography Patterns for Investment Casting: Prototyping to Production

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Introduction

Most people in the investment casting industry are aware of the use of rapid prototyping technology to make patterns that can be used in place of the traditional wax patterns for investment casting. Many foundries have begun to make use of various rapid prototyping techniques to broaden the range of options that they can offer to their customers. However there is still a reluctance on the part of many foundries to commit resources in order to understand and implement this 'new' technology.

Traditionally the primary users of investment casting parts made from stereolithography patterns have been the aerospace and medical industries. However, there is also a vast market for other industries that can benefit from stereolithography processes. Parts need to be made for the automotive industry, hand and power tools, oilrigs and recreational equipment to mention just a few.

In order to have a broader acceptance for stereolithography in investment casting there are two things that must happen. The first is that users must be made aware of the benefits of this. The second is that the preconception must be overcome that stereolithography patterns will just not work as well as wax patterns to produce cast parts of acceptable quality.

Our goals are:

- To convince those foundries that have not used stereolithography, or have had a brief but negative brush with it, that it makes good business sense to learn how to work with stereolithography patterns.
- To show those foundries that currently use stereolithography patterns regularly how they can expand their use of stereolithography in ways that will bring in revenue from new sources.
- To show that stereolithography patterns need not be restricted to casting *prototype* parts but can be extended to casting *production* parts as well.

The steps to accomplishing these goals are:

- Help people in the investment casting industry to become aware of the viability of stereolithography patterns and the benefits of using this technology.
- Establish reliable techniques for building stereolithography patterns that will withstand the stresses of shell preparation without physical deformation.
- Establish reliable procedures to remove the stereolithography patterns from the ceramic shell without shell deformation or fracture.
- Develop procedures that result in minimal residue left behind after burnout.

Implementation

There are many benefits to using stereolithography patterns in place of the traditional wax patterns in the investment casting process. There is no need for creating a tool to build the pattern. Instead, the pattern is built directly on a stereolithography machine using a CAD file that has been prepared to the exact specifications of the customer. This allows the foundry to use complicated patterns with fine detail and excellent accuracy, and in turn shortens the lead-time needed to turn out a set of parts. These patterns have a very smooth surface that is comparable to that achieved with wax patterns.

When using stereolithography patterns it is easy to modify the original design of the piece if examination of the final casting shows that a change is warranted. Design changes can be evaluated in a few days rather than waiting for weeks to see the result.

It is recognized that foundries have been using wax patterns for many years and understand how to work with them. As with any well-established process it is difficult to make a change. Our objective is to integrate the procedures for working with stereolithography patterns smoothly with existing methods.

Several factors must be considered when using stereolithography patterns. The pattern should be built by someone who is experienced with building parts of this type. A pattern that is properly built is essential to the success of the project. For a 3D Systems 'Quickcast™' part there must be no solid resin in the interior framework of the piece. The operator must also understand that certain geometries require special build orientations to produce a good part. For example solid, flat surfaces thicker than 20-30 thousandths of an inch should be avoided.

The designs for gating and rigging are different than those required for wax patterns. New processes are needed for removing the pattern once the shell is created. The material must be heated to a high temperature (about 1800°F) in order to vaporize all of the pattern. With a wax pattern, heating in an autoclave at a much lower temperature allows the wax to melt and run out. This is followed by high temperature firing to remove residual wax and to cure the shell.

For a stereolithography pattern made by using the Quickcast™ process, there is less thermal expansion of the material due to the internal structure of the part. Expansion of the wax pattern is one of the main reasons for shell failure during burnout. At the same time consideration must be made for the fact that the entire stereolithography pattern decomposes during burnout. There must be some provision for assuring that there is no internal pressure increase which can cause cracking of the shell.

The use of wax patterns is well characterized after many years of usage. On the other hand, few foundries have enough experience with stereolithography patterns to feel confident in working with them. Those that do work with these patterns sometimes find that different processes are necessary to work with different pattern materials and different geometries. Once they have invested the resources to develop a working process, a foundry is often reluctant to publicize its findings to the rest of the industry.

A knowledge gap must be bridged before production quality parts can be reliably created from stereolithography patterns. The means for building this bridge is already in place. This work will be done by the areas of expertise that already exist in the foundries. These are **1) Pattern Creation, 2) Shelling Process, 3) Burnout Process and 4) Casting Process**. Each has their own concerns that must be met.

Pattern Creation

The challenges here are to become expert at using the materials and processes available in order to create patterns that are accurate, resistant to changes in dimension (swelling and warping), and easy to remove from the shell. The stereolithography process has been shown to be accurate and a new generation of materials exists that are resistant to moisture absorption and warping. One of the primary tools that has enabled stereolithography to be used to prepare investment casting patterns is the Quickcast™ build style. The geometry of this build style is such that the part collapses in on itself during burnout. This prevents the pattern from expanding to such a degree that the shell is fractured.

The Quickcast™ style is not an easy one to become proficient with. There are many variables to control and it requires considerable experience to build good parts. There can also be problems with porosity of the part walls and with improper resin drainage. The part surface must be wiped carefully with solvent after it emerges from the resin vat. Immersing the part in solvent to clean it will damage the integrity of the internal structure. Any cells inside the part that are not free of resin will solidify and cause damage of the shell during burnout.

What are the material properties that are desirable in stereolithography patterns?

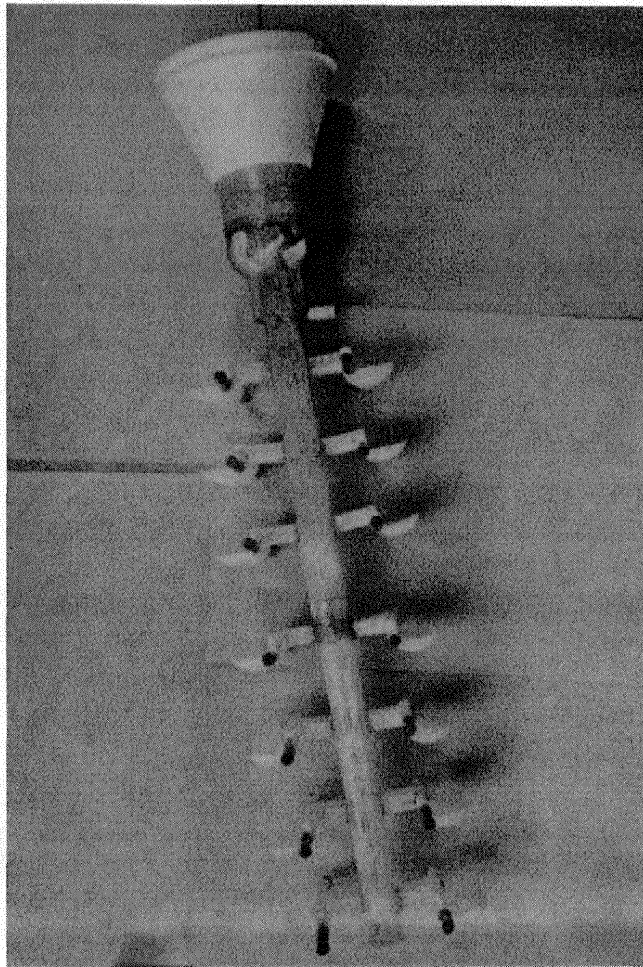
- They should have a low coefficient of thermal expansion.
- There should be little swelling of the part due to water absorption.
- The part must maintain its structural integrity during the casting process.
- There should be little or no ash residue left behind in the shell after pattern burnout.
- The presence of heavy metal contaminants must be eliminated.
- The pattern must have a smooth surface.
- The dimensions must be accurate over a period of a few days to several weeks.

There is a product on the market, Somos® 7100, that is one of the best resins for building parts with the Quickcast™ style. This material has been demonstrated to produce parts of exceptional quality (C.S. McDowell and S. Jayanthi, "Evaluation of Foundry Pattern Removal Performance of Several Epoxy-Based Photopolymers", Proceedings of the North American Stereolithography User Group Conference, February, 1997).

The physical properties of this material meet most of the current needs for stereolithography patterns. A better appreciation of the process will help to grow the market for stereolithography patterns. As stereolithography continues to make inroads into the investment casting market and as the demands upon the material increase, we

will endeavor to provide new materials and work with the foundries to develop new processes to accommodate these demands.

One of the goals of this study is to show that stereolithography patterns can be substituted for wax patterns when this would allow the project to be completed in a faster or more cost-effective manner. In addition, this process may allow the foundry to cast a part that would be difficult to produce using a wax pattern.



It is possible to build the casting tree with stereolithography instead of using the traditional wax tree (C.S. McDowell, M.C. Boomer, "Design of Stereolithography Trees for Use in the Investment Casting of Stereolithography Patterns"). This technique has the advantage of reducing the fracture of ceramic shells due to thermal expansion of the wax tree. Gates and runners can also be designed and built using stereolithography.

Pictured here is such a tree. The reader will note that the gates have also been built together with the tree using stereolithography. The pour cup is at the top and the sprue is the long tube leading from the cup to the various gates.

Some people question the ability of stereolithography patterns to take the place of wax patterns. They blame the material or the process when they try unsuccessfully to cast a stereolithography pattern using the

same process that has been used successfully for wax patterns.

It must be realized that the process must change since the material properties are very different. There is ample evidence to show that when a properly built pattern is used any part that can be cast from a wax pattern can be made using a stereolithography pattern. However the gating and rigging must also be done correctly and the proper shelling and burnout technique must be used

Shelling Process

The main problem introduced by the process of evacuation of the pattern is fracturing of the shell due to thermal expansion of the polymer or because of increased internal

pressure during burnout. According to previous experiments (K. Loose, Proceedings of Rapid Prototyping and Manufacturing, 1996, Dearborn, MI) the tensile stresses caused by thermal expansion are much greater than those caused by gas pressure. In addition, the Quickcast™ style is designed to limit the amount of expansion by the pattern during burnout. However it has been shown (C.S. McDowell and S. Jayanthi, see above) that the thermal expansion coefficient of the photopolymer material is an important factor in the shell preparation process.

Stereolithography can also be used as a secondary process to create wax patterns. Here the mold pattern (which is different from the investment casting pattern) is created by stereolithography. An investment casting pattern is made by injecting the wax material into the mold cavity and following the normal procedure for injection molding. This produces a pattern with all the advantages of one made directly by stereolithography. This brings a whole new set of requirements to the process that must be understood in order to make accurate and reliable tools.

Casting Process

Once the shell is prepared, there is very little difference in this part of the process from that used for shells made from wax patterns. If there are small channels within the part, the gating and rigging design will have to allow for these in order to insure complete filling of the pattern and a good casting.

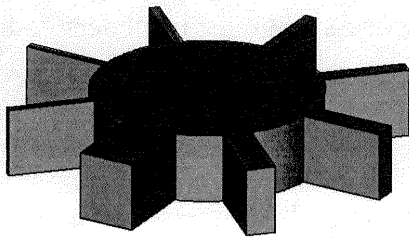
The main obstacle to moving from prototype parts to production casting is that end users must be assured of the reliability of the parts under stress conditions. The concern has been that the burnout process may not remove all traces of the pattern so that some residue remains inside the shell to interact with the metal during casting. This is particularly a concern when the resin contains small amounts of heavy metals. These metals will not evaporate during the burnout process and this can lead to the formation of zones that are susceptible to stress fracture. This cannot be tolerated in production parts.

Standards must be developed which will evaluate the reliability of the pattern removal process. If it can be shown that stereolithography patterns can be removed as reliably as wax patterns this will go a long way toward gaining acceptance in the investment casting industry. One solution would be to adapt current test methods that are used to evaluate parts cast from wax patterns.

It is particularly important to the aerospace industry that the cast parts are free from any failure zones if they are to be used as functional parts. The stresses on a turbine blade during use are much higher and failure is much more critical than for a bracket or a stethoscope head. Currently some production parts are made for aerospace using stereolithography patterns but this is for low stress applications. In the critical area of blade and vein work, all castings are still done with wax patterns.

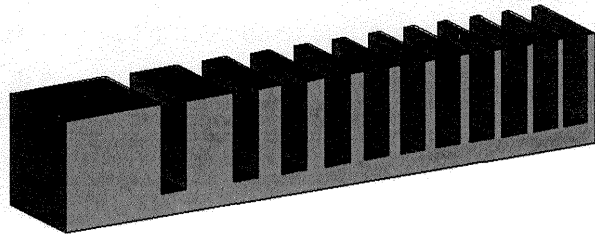
Evaluation of Test Parts

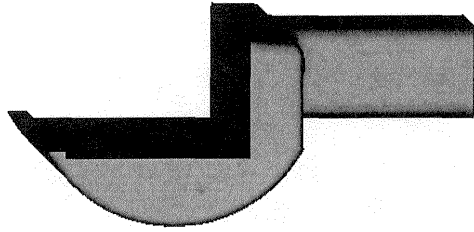
An essential component of comparing resin materials, build styles and casting processes is the design and evaluation of test parts. What is the thinnest cross-sectional area that will still allow the resin to drain from the part effectively? How thin can the part be and still maintain its structural integrity? What is the effect of different stresses on the part? How does the part hold up to points of high stress such as thin sharp edges? How do parts with a large z-height respond to the shelling process?



Several test parts have been designed to evaluate these properties. One is a disc with radiating arms of varying thickness. The objective of this piece is to see how thin a section can be before there is insufficient drainage of resin from the section. In addition, if the arm is too susceptible to bending there may be deformation from the desired geometry during the casting process.

Another piece looks like a rectangular comb with teeth of varying thickness. The objectives are similar to those for the piece described above but using angular rather than circular geometry.





This part has been designed to test the susceptibility of the shell to failure when there is a point of high stress on the piece. The thin, sharp front edge of the piece is an area where shell fracture during burnout is much more likely to occur than for right angles or rounded surfaces. With this geometry it is efficient to compare the effect of the casting, autoclaving and burnout process on the type of resin or to compare different processing methods with the same material.

A careful evaluation of the casting process and the resulting parts made with these test geometries is necessary to understand the performance of the stereolithography material and the build style used to prepare the pattern.

Future Work

There are three contributors to successful stereolithography-based investment casting. These are the materials, the processes and the end users. It is necessary that all these be working together if we are going to see a real expansion in the market. We at the Somos® group have the expertise in materials. It is up to us to evaluate how the material properties of stereolithography patterns impact the investment casting process.

We have seen a clear correlation between the Coefficient of Thermal Expansion of the pattern material and successful pattern removal. Further work needs to be done to expand on these findings. There needs to be a better understanding of the effects of heat deflection temperature and modulus of elasticity on the investment casting process. Through carefully planned experiments, we plan to examine more closely the relationship between physical properties, investment casting processes and the characteristics of the final cast part.

Going forward there will be further evaluations done with existing test part geometries. New part designs will also be used to evaluate materials and processes. Collaborations with various foundries will be undertaken with the goal of promoting the spread of stereolithography into the investment casting market. There will also be projects done with the cooperation of the American Foundrymen's Society and the Investment Casting Institute. We intend to publish our findings along with procedures on pattern preparation

and casting processes in order to make it easy for anyone to take advantage of the benefits of stereolithography for their investment casting business.

Acknowledgements

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