PolyJet Investment Casting

DESIGN GUIDE

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A GLOBAL LEADER IN APPLIED ADDITIVE TECHNOLOGY SOLUTIONS

POLYJET INVESTMENT CASTING DESIGN GUIDE

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1. Introduction and Background

1.1. Scope

This technical design guide describes the design, processing, manufacture, and post-processing techniques and procedures for additive manufactured investment casting master patterns using Stratasys PolyJet™ technology. The principles discussed and requirements provided in this guide should be followed whenever possible. Due to the various casting industry best practices, deviations to this design guide may be implemented at the discretion of the individual user's expertise.

1.2. Application Overview

Investment casting is a manufacturing process used to produce cast metal components. PolyJet models are used to create the master models which allow for the formation of a ceramic shell, also called an investment, which molten metals can be poured into to create the desired final-part geometry.

1.3. Background and Purpose

Traditionally, investment casting, also known as lost wax casting, uses an injection molded wax component as the master model. As such, this requires the manufacture of injection mold tooling. In the case of prototype components and low-volume production, this tooling often involves excessive lead time and/or is too costly to be practical. Also, the geometry may not be finalized yet due to unforeseen issues that arise during testing. Because of this, investment casting foundries, as well as the company purchasing the castings, have sought out alternate methods to allow the creation of investment cast parts without the cost and time burden associated with permanent tooling.

In contrast, 3D printed investment casting patterns can be created in a much shorter timeframe and at lower cost than traditionally manufactured patterns. This design guide provides best practices for the design, fabrication and preparation of additive manufactured investment casting masters, as well as relevant performance characterization data.

2. Industry Relevance and Benefits

The six fundamental drivers of additive manufacturing listed below were assessed to determine how additive manufacturing improves tooling for investment casting applications.

2.1. Economic Low-Volume Production

The cost of tooling for subtractive-based manufacturing methods has been expressed as a concern from partners in various investment casting markets including aerospace and automotive. The need to increase the return on investment in a competitive production environment is highly prized. Additive manufacturing takes advantage of just-in-time manufacturing principles that allow the economic production of low-volume and one-off designs.

2.2. Reduced final part dimensional variability

When using the traditional investment casting practices, the coefficient of thermal expansion needs to be considered not only for the cast molten metal but also for the wax master pattern processing. Without strict process control, the wax master will add a level of dimensional uncertainty to the final parts. Utilizing PolyJet masters, the need to account for processing inaccuracies of the master is removed. Also, minor adjustments can easily be made to the master while reprinting to account for the molten metal shrinkage leading to a very accurate, near-net shape, final part.

2.3. Supply Chain Realignment

Stratasys makes it easy to evaluate the technology to ensure it fits in a unique manufacturing environment. Stratasys Direct Manufacturing™ can produce PolyJet investment casting master patterns to ensure the capability meets the specific application requirements. Increasing production throughput justifies printing in-house as a means to reduce part cost.

2.4. Life Cycle Sustainability

Whether it is through good corporate social responsibility, legislative compliance, or an understanding of environmental good practice, casting foundries are beginning to focus more on their environmental impact. But this is not limited just to the impact of the initial production tooling, but the impact of their products during and after their effective working life.

Additive manufacturing is used to reduce the life-cycle environmental impact of products in a number of ways:

- Additive manufacturing processes can be highly material-efficient, using only the minimal material needed to make a part, with little waste. This differs greatly from processes such as machining, which rely on billets of feed stock, often largely reduced to scrap.
- As a digital-based technology, additive manufacturing can also be used to position material only where material is needed, making parts that have the perfect balance of strength and weight. Again, this reduces the amount of raw material needed to drive the supply chain, as well as the amount of energy needed to make the part.

2.5. Cost Effective Product Customization

Increased complexity comes at little cost vs. the overall size of the tool, allowing engineers and designers to consider the end product's key characteristics, not the process that creates the tool.

2.6. Increased Product Complexity

Wax masters are held to the majority of the same design considerations that injection molded plastics are held to due to the process limitations. However, most of these limitations do not exist in the additive design space. Due to this, several design considerations that need to be addressed for traditional manufacturing can be disregarded using PolyJet technology:

- **Drafted surfaces:** Due to the manufacturing process of injection molding, surfaces touching the mold tooling require a draft angle applied away from the parting line of the tool to allow the part to be ejected. Without this draft the part could potentially stick in the tool and damage the part, tool, or both. Since PolyJet components are not constrained to the requirements of ejecting from a tool, drafting of the surfaces is not necessary.
- **Undercuts:** Similar to the notes about drafting, the same design considerations apply to undercuts. To be able to remove the part from the tool, undercuts can't be produced without special considerations to the tool design. There are options to add pick-outs and slides, or other means of producing challenging geometry, but these add cost and complexity to the tool which is generally avoided. These limitations do not apply to a PolyJet master pattern, which allows the user to build castings that likely couldn't be produced in a traditional manner.
- **Flash / Parting line:** Tool machining imperfections, tool wear, and process errors can all lead to flash on the injected masters or visible shifts at the parting line of the tool. Without post-processing, these imperfections will transfer to the cast metal component. None of these considerations will affect a PolyJet master pattern.
- **Ejector pin setup:** To remove the wax injected parts from the tools, an ejector pin system is employed. These systems must be precision machined to match the face of the pin into the cavity of the tool, and often time still result in a witness mark on the produced geometry. Similarly to that noted before, without post–processing, these imperfections will translate through to the final cast part. Once again, due to the difference in processing, PolyJet masters do not exhibit these same shortcomings.

Incumbent technologies cannot replicate all of these characteristics in a single technology. Traditional methods used to manufacture investment casting masters are well suited for large-volume production runs, but in a high-mix, low-volume market, PolyJet investment casting remains advantageous to meet unique applications and requirements.

3. Design Overview

3.1. Design Guide Objectives

The objective of this design guide is to provide best practices for the manufacture of PolyJet master models for investment casting. The intent is to aid in bridging the knowledge gap between design-for-additive-manufacturing techniques and conventional investment casting best practices.

This design guide aims primarily to provide:

- Key properties and characteristics for relevant materials
- Advantages and key considerations for PolyJet masters
- Best practices for design, construction and optimization of PolyJet masters
- Best practices for file preparation, processing and fabrication
- Best practices for post-processing PolyJet masters
- Modifications to traditional investment casting process to facilitate PolyJet masters

3.2. Key Design Considerations

CONSIDERATION	VALUE
FullCure RGD720 ash content	0.01-0.02%
VeroBlack™ ash content	0.01-0.02%
VeroClear™ ash content	0.02-0.06%
VeroBlue™, VeroGray™, VeroWhite™ ash content	0.21-0.26%
Slurry & sand composition	Non-quartz based
PolyJet model wall thickness	0.05”-0.06” (1.27 mm – 1.5 mm)
Fillets	0.03” (0.76 mm) Minimum radius
Model edges	0.01” (0.25 mm) Minimum radius (avoid knife edges)
Cast part wall thickness	0.05” (1.27 mm) Minimum thickness

4. Materals

While most of the offerings in the PolyJet material family will perform adequately for the creation of an investment casting master model, two materials are best suited for this application: FullCure RGD720 and VeroBlack. These materials offer the strength needed for handling the parts during the remaining processing steps, while also producing the lowest ash content after burning out the master. While the other offerings in the Vero family will be suitable as a master material, the residual ash content will be higher. As a result, extra care should be taken to ensure that all residual ash is removed during the core washing stage of the process due to the higher risk of part imperfections.

5. Master Pattern Creation

5.1. General Design Considerations

Several of the design practices that govern the design of a good investment casting component still exist when using PolyJet to create your master models. In general:

- Fillets should be made to a 0.03 inch (0.76 mm) minimum radius to ensure that they form correctly on the final part.
- Edges of parts should have a minimum radius 0.01 inch (0.25 mm) to ensure that material flows to properly fill these features. As such, knife edges should be avoided due to the high likelihood of failure to create these features.
- Wall thicknesses of the final part should be maintained to a minimum of 0.05 inch (1.27 mm) to ensure that material can flow to all areas of the final geometry.
- All geometries will need to be scaled up to account for shrinkage as the cast metal cools. This should be uniformly applied to the starting CAD model, based on the material that will be chosen for the final component.

On the opposite side of this, however, are several design features that don't need to be considered while using PolyJet models as masters. These items include, but are not limited to:

- **Undercuts:** Since the parts do not need to be ejected from a mold, there is no need to eliminate undercuts from your design. As long as the geometry has enough access to be shelled, and the shell can be knocked out after casting, there should be no concerns. This allows for significantly more freedom in the design process, especially if the volume is low enough that hard tooling will not be created down the road. In this case, the full benefit of additive manufacturing can be utilized to build weight- and strength-optimized parts, which will then be cast into a final metal component.
- **Draft:** For parts that will not be mass produced with a tool in the future, designing with PolyJet allows you to skip the requirements of adding draft to the final part. This can be especially helpful for parts that need post-machining, or will be assembled to other components without machining, and the drafted surface is not ideal.

5.2. PolyJet Specific Design Considerations

Beyond good general design practices, the key consideration is pattern modification to prevent shell cracking and to minimize residual ash. Ceramic shells have a very low coefficient of thermal expansion, so any expansion of the pattern during the burnout cycle will cause the shell to crack. PolyJet material does not melt like wax; it burns and leaves a slight amount of ash in the shell cavity. To address these constraints, the pattern is modified to reduce the amount of material and to minimize expansion forces. This is achieved by hollowing the STL file for the master part(s) to yield thin, yet sturdy, wall sections.

Testing has shown that the upper limit for wall thickness is 0.100 inch (2.54 mm), and the ideal wall thickness is 0.05-0.06 inch (1.27 mm – 1.5 mm). At 0.100 inch, the investment-cast shell may develop hairline cracks, but is not likely to fail. Proper judgement will need to be exercised to determine the appropriate wall thickness for the specific geometry being built. To generate the shelled model, there are three distinct approaches that can be taken depending on the user's specific geometry, and desired workflow to get to the finished part.

5.2.1. Hollowing the Part, Building in Multiple Sections

This method works best for geometry of limited complexity, and can be performed on any of the PolyJet systems with no consideration needed for support material used. The main reason for this recommendation is that the intent is to split the part into the minimum number of discreet sections to be able to print the internal structure support-free.

5.2.1.1. File Processing

5.2.1.1.1. Geometry Modifications

Using either CAD or STL manipulation software, perform a hollowing operation to create the desired wall thickness of the model (Figures 1 - 3).

After hollowing, the parts will then need to be split into individual bodies that can be built without trapped support. On simple geometries, this could be as simple as two bodies (Figure 4).

Or it could be more complex, requiring multiple bodies to be trimmed apart (Figures 5-8).

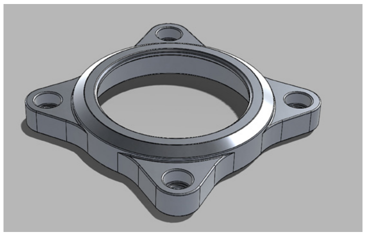

Figure 1: Bearing housing example, shown as a solid body.

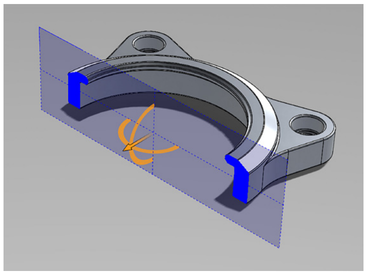

Figure 2: Sectioned solid bearing housing.

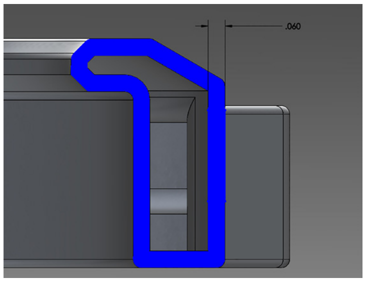

Figure 3: Bearing housing, shelled.

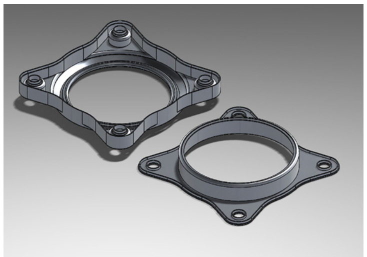

Figure 4: Part sections prepped for printing.

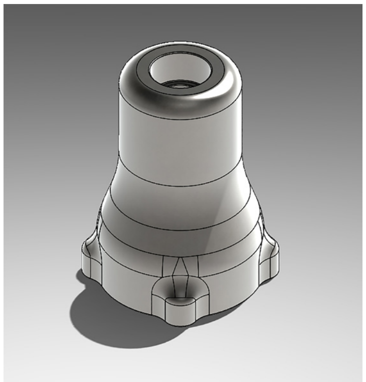

Figure 5: Multi-part component.

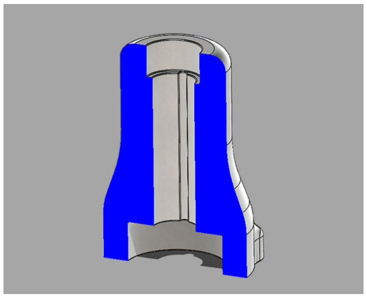

Figure 6: Multi-part component, sectioned.

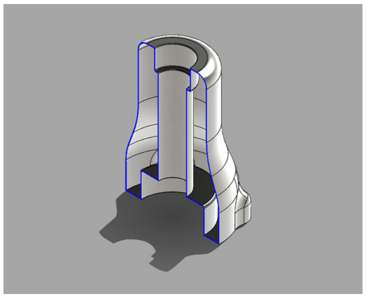

Figure 7: Multi-part component, shelled.

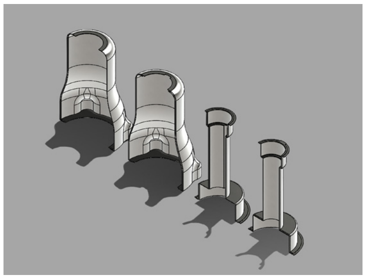

Figure 8: Multi-part component showing all sections.

During the body separation operation, it is necessary to put indexing features in the cut joints to ensure the pieces can be assembled back to the proper orientation and location without adding an excessive amount of error into the model. Depending on the number of degrees of freedom that need to be constrained, the two preferred methods are lap joints and keyed joints (Figures 9 - 10).

It is also possible, and often times preferred, to use these in combination to control both the orientation and location at the same time. Here is an example of this in practice (Figure 11).

Another key item to address when creating the joint is to add clearance into the model to allow for the items to be assembled. Without this step, the parts will not likely fit together well or at all, which will diminish the accuracy of the overall model. The recommended amount of clearance is 0.004 inch (0.1 mm) between the sliding surface interfaces only. The parting line surfaces should be left as line-to-line contact in the model (Figures 12 - 14).

After these steps have been executed, the files should be saved as individual files to be processed in the PolyJet operating software.

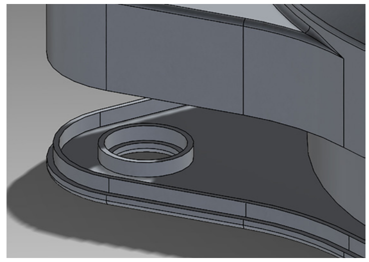

Figure 9: Lap joint example.

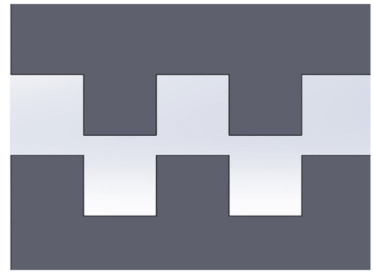

Figure 10: Example of a keyed design.

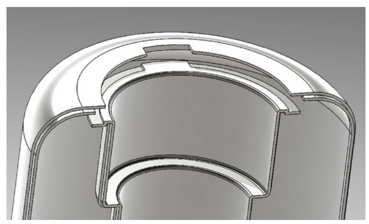

Figure 11: Example of a keyed lap joint.

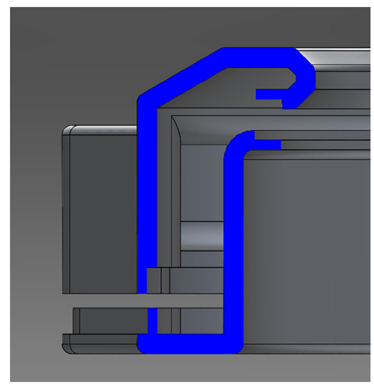

Figure 12: Example of clearance in the model, showing sections separated.

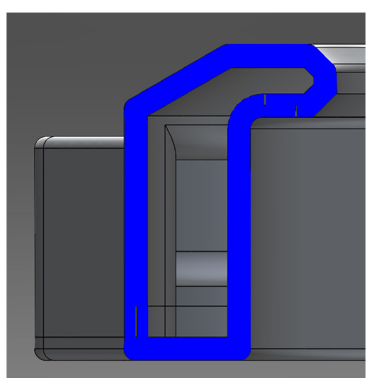

Figure 13: Example showing sections assembled.

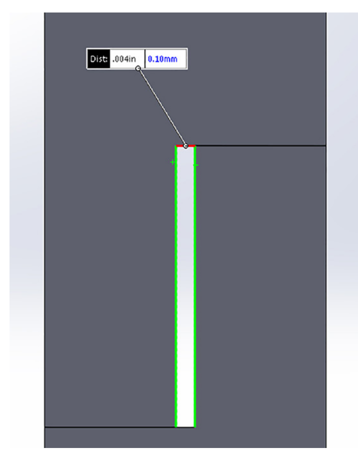

Figure 14: Clearance in a lap joint.

5.2.1.1.2. PolyJet Operating Software

Start by loading your files into your machine operating software. Using the info from the Stratasys PolyJet machine operating best practices, orient the models to provide the best surface finish for the given geometry and minimize the amount of support material used during the build. Apply the appropriate build material to all of the models, prioritized by ash content, based on customer availability. The following table provides the ash content of the PolyJet materials for reference:

MATERIAL	ASH CONTENT
FullCure RGD720	0.01-0.02%
VeroBlack	0.01-0.02%
VeroClear	0.02-0.06%
VeroBlue, VeroGray, VeroWhite	0.21-0.26%

To provide the most accurate master pattern, it is advised to build the components using matte surface finish mode for all geometries.

After the materials have been applied, and the surface finish chosen, the build mode can be set. To get the highest aesthetics on a part, it is advised to use the high quality mode where applicable. However, on geometries of limited complexity, or where high quality mode is not an option for the given machine, a high speed build mode will still produce an aesthetic surface finish for the casting model.

5.2.1.2. PolyJet Post-Processing

After the components have been built, the support needs to be removed using standard PolyJet support removal techniques. See the Stratasys operators' information to become familiar with these procedures. If using a waterjet, it is advised to reduce the pressure to the lowest value that will still effectively remove support to avoid damaging the fragile master.

Once all of the support has been removed and the parts have been allowed to dry, start the assembly process by dry-fitting the components together. If any areas do not fit easily, a very light sanding with 220 – 320 grit sandpaper can be used to address the areas.

With dry-fitting complete, the components are now ready to be assembled. Gather up the following supplies to perform the task:

- Rubber gloves
- Lint free cloths
- Isopropyl alcohol
- Cyanoacrylate or equivalent adhesive

Start with the inside geometry and work your way to the outer shell of the model. For internal seams that do not need to be sealed entirely, a few strategically placed drops of adhesive can be used to complete the bonding. However, in an external seam area, the full perimeter needs to be sealed to ensure the part will be structurally sound enough to survive the proceeding operations and also to keep the slurry mixture from getting to the inside of the model. Run a small bead of the adhesive around the full perimeter and bond the outer components together. Use a lint free cloth soaked with alcohol to remove any excess adhesive from the surface of the assembled master.

After all of the seams have been properly bonded together, and excess adhesive cleaned from the surface, a light coating of a clear, fast-drying acrylic paint is recommended to promote adhesion of the first layer of the shelling process.

The master pattern is now complete and ready to move on to the gating and tree creation step.

5.2.2. Hollowing the Part, Building with Support Structure Inside, with the Intent to Remove the Support

This method works for more complex geometries where splitting the master into sections is not an option. This can be done using any of the PolyJet materials, but has to be built with either Support 706 on the Connex3™ machines or with Support 707 on an Eden260VS™ machine.

5.2.2.1. File Processing

5.2.2.1.1. Geometry Modifications

Using either CAD or STL manipulation software, perform a hollowing operation to create the desired wall thickness of the master pattern (Figures 15 - 17).

NOTE: The hollowing operation can also be completed inside of the PolyJet operating software, but does not provide the level of control that CAD or STL manipulation software provides. It is up to the user to decide on the appropriate workflow for their given operation.

If the gating location is known, the optional next step is to thin out the area that will be at the gate location. This eases breaking through the shell to access the inside of the model to remove the trapped support material (Figures 18 - 19).

This area should be thinned to no less than 0.03 inch (0.75 mm) to ensure it builds as expected.

After hollowing the geometry and adding the optional breakout areas, proceed to the file processing.

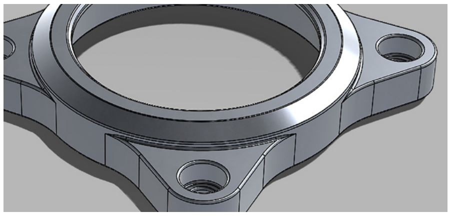

Figure 15: Bearing housing example, shown as a solid body.

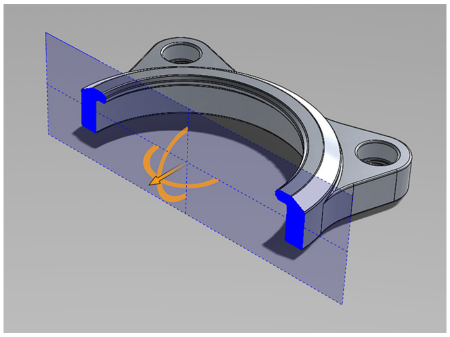

Figure 16: Sectioned solid bearing housing.

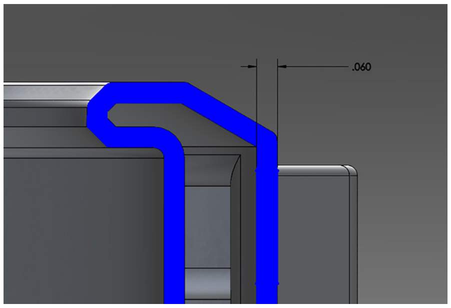

Figure 17: Bearing housing, shelled.

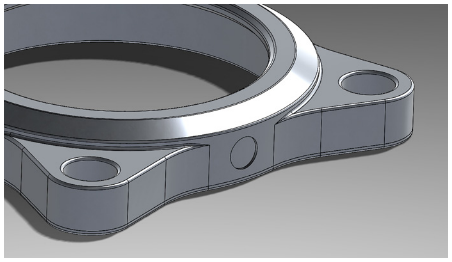

Figure 18: Spot face example.

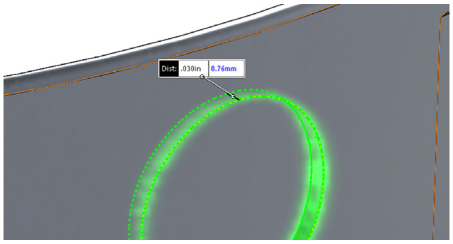

Figure 19: Spot face depth.

5.2.2.1.2. PolyJet Operating Software

Start by loading your files into your machine operating software. Using the information from the Stratasys PolyJet machine operating best practices, adjust the orientation to provide the best surface finish for the given geometry and minimize the amount of support material used during the build. Apply the appropriate PolyJet material to all of the models, prioritized by ash content, based on customer availability. The following table provides the ash content of the PolyJet materials for reference:

MATERIAL	ASH CONTENT
FullCure RGD720	0.01-0.02%
VeroBlack	0.01-0.02%
VeroClear	0.02-0.06%
VeroBlue, VeroGray, VeroWhite	0.21-0.26%

To provide the most accurate master pattern, it is advised to build the components using matte surface finish mode for all geometries.

After the materials have been applied, and the surface finish chosen, the build mode can be set. To get the highest aesthetics on a part, it is advised to use the high quality mode where applicable. However, on geometries of limited complexity, or where high quality mode is not an option for the given machine, a high speed build mode will still produce an aesthetic surface finish for the casting model.

5.2.2.2. PolyJet Post-Processing

Start the post-processing by cleaning off the outside of the part using a water jet, or other standard cleaning process. After the outside of the model is cleaned, access holes to the inside of the model need to be created. If thinned sections were created in the first step, that area can be broken out easily with hand tools. If this step was skipped, it is advisable to use a high speed rotary tool with a bit used for glass or ceramic drilling. This should allow for the creation of holes in the part without worry of cracking the model shell (Figure 20, next page).

With access holes created, the model should be submersed in a 25% concentration solution of Tetra Methyl Ammonium Hydroxide. This solution will remove the exposed support material without swelling or damaging the model material. Leave the model submerged for 3-4 hours to remove the internal supports. If the support hasn't been fully removed in this timeframe, continue to leave it submerged, rechecking every 1-2 hours until the support is 100% removed. Gentle agitation of the solution should decrease the amount of time needed to remove all the support as well, if this function is built into the equipment.

After all of the support has been removed, allow the model to dry completely. A light coating of a clear, fast-drying acrylic paint is recommended to be applied at this point to promote adhesion of the first layer of the shelling process.

The master pattern is now complete and ready to move on to the gating and tree creation step.

5.2.3. Hollowing the Part, Building with Support Structure Inside, with No Intent to Remove the Support

This method works for any geometry, but has currently only been confirmed to work on an Objet Eden 260VS machine while using the Support 707 material option.

5.2.3.1. File Processing

5.2.3.1.1. Geometry Modifications

Using either CAD or STL manipulation software, perform a hollowing operation to create the desired wall thickness of the master pattern (Figures 21 - 23).

NOTE: The hollowing operation can also be completed inside of the PolyJet operating software, but does not provide the level of control that CAD or STL manipulation software provides. It is up to the user to decide what the appropriate workflow for their given operation is.

If the gating location is known, the optional next step is to thin out the area that will be at the gate location to ease breaking through the shell. This will ease the creation of the vent hole to remove trapped support material later in the process (Figures 24 - 25).

This area should be thinned to no less than 0.03 inch (0.75 mm) to ensure it builds as expected.

After hollowing the geometry and adding the optional breakout areas, proceed to the file processing.

Figure 20: High-speed rotary tool bit.

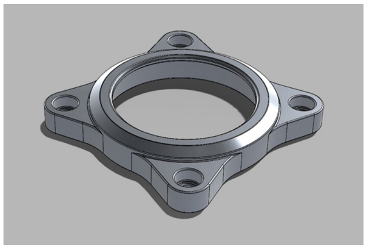

Figure 21: Bearing housing example, shown as a solid body.

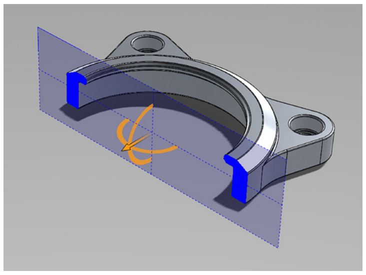

Figure 22: Sectioned solid bearing housing.

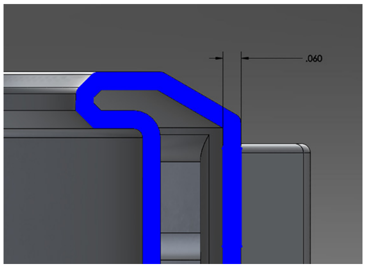

Figure 23: Bearing housing, shelled.

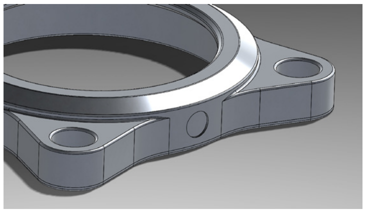

Figure 24: Spot face example.

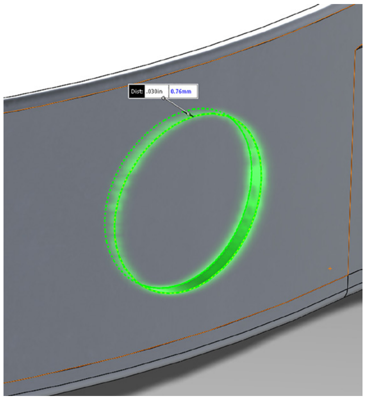

Figure 25: Spot face depth.

5.2.3.1.2. PolyJet Operating Software

Start by loading your files into your machine operating software. Using the info from the Stratasys PolyJet machine operating best practices, adjust the orientation to provide the best surface finish for the given geometry and minimize the amount of support material used during the build. Apply the appropriate PolyJet material to all of the models, prioritized by ash content, based on customer availability. The following table provides the ash content of the PolyJet materials for reference:

MATERIAL	ASH CONTENT
FullCure RGD720	0.01-0.02%
VeroBlack	0.01-0.02%
VeroClear	0.02-0.06%
VeroBlue, VeroGray, VeroWhite	0.21-0.26%

To provide the most accurate master pattern, it is advised to build the components using matte surface finish mode for all geometries.

After the materials have been applied and the surface finish chosen, the build mode can be set. To get the highest aesthetics on a part, it is advised to use the high quality mode where applicable. However, on geometries of limited complexity, or where high quality mode is not an option for the given machine, a high speed build mode will still produce an aesthetic surface finish for the casting model.

5.2.3.2. PolyJet Post processing

Start the post processing by cleaning off the outside of the master pattern using a water jet, or other standard cleaning process. Allow the model to dry completely after removing the outer layer of support.

After the outside of the master pattern is cleaned, access holes to the inside of the model need to be created. If thinned sections were created in the first step, that area can be broken out easily with hand tools. If this step was skipped, it is advisable to use a high speed rotary tool with a bit used for glass or ceramic drilling. This should allow for the creation of holes in the part without worry of cracking the model shell (Figure 26 on next page).

The final recommended step is to add a light coating of a clear, fast-drying acrylic paint at this point to promote adhesion of the first layer of the shelling process.

The master pattern is now complete and ready to move on to the gating and tree creation step.

6. Casting-Tree Creation

The casting tree and its components (e.g., wax sprue and gates) require no modification from standard processing. Also, it is recommended to use standard wax components to build this section, unless a complex shape is required, based on the specific geometry. This limits the amount of PolyJet material that needs to be built, reducing the time on the machine, and reduces the amount of ash that will be present in the shell after burnout.

One highly recommended change, however, is the addition of extra venting locations, which will promote airflow to the PolyJet master pattern, allowing gases to escape during burnout. The goal is to get oxygen to the PolyJet master pattern early in the burnout cycle to promote burning of the pattern and provide a better path to vent gases. To do so, position gates, and size accordingly, to achieve maximum burn. As a secondary benefit, addition of these gates will greatly facilitate the complete removal of any residual ash from the PolyJet material burnout by providing a better path for the wash water to reach all areas of the shell (Figure 27).

Figure 26: High-speed rotary tool bit.

7. Shell Creation

In general, there are not many modifications needed to utilize PolyJet-built components as your investment casting masters in regard to the shelling process. The two major considerations that need to be looked at are as follows:

Figure 27: Part with added venting.

7.1. Slurry / Sand Composition

Since the shell must be cooled down after firing to allow for the shell-washing step, the composition of the shell material must be considered to ensure a material is chosen that can handle the cool-down and reheat cycles. Our experience has shown that a quartz-based slurry and sand combination is not capable of handling these cycles and should be avoided. Zirconium-based solutions have proved to be capable of handling these heat-up and cool-down cycles, and have been the base for our testing. Other solutions will certainly work but it is at the discretion of the individual foundry to ensure their solution can handle the requirements.

7.2. Shell thickness

The shell build-up method does not change from the standard processes of the foundry. But, the buildup of the ceramic shell around the casting tree should be made slightly thicker than normal to account for the expansion forces that the PolyJet master will exert on the shell. Although dependent on part configuration and foundry practices, the general recommendation is to add three coats to the standard shell thickness.

8. Tree Burnout and Shell Firing

8.1. Wax Gating Removal

The process of removing the wax tree structure should be completed using an autoclave for best results. Processing in the autoclave should be set to a minimum of 101.5 PSI (700 kPa), at a temperature of 275 °F (135 °C) for the duration of processing. Time in the autoclave should be minimized. In general, the process should take no more than 5-10 minutes to complete.

Note: This step of the process will also remove any of the trapped support material if the models were created using the process detailed in 5.2.3. If you followed this process for your pattern creation, any wax reclaimed during this process is not suitable for reuse.

At this point, all that remains inside the shell should be the remaining PolyJet material used for the master model. The next step is to remove that material.

8.2. PolyJet Master Burnout and Shell Firing

The burnout and firing of the shell has two recommended procedures depending on the geometry being burned out. Each of these options are meant to be suggested starting points for the foundry. Some adjustments may be required based on individual user experience.

8.2.1. Temperature Ramp Up (Ideal Case for Burnout)

This procedure works best for more complex geometry, where the flash firing method is not advised due to shell cracking concerns. This would typically be geometry that has wall thicknesses beyond the recommended values, or geometry that cannot be hollowed due to feature size.

This burnout cycle involves temperature ramping in two- to four-hour cycles over a 20 hour period. The ideal cycle is as follows:

- 200 °F (93 °C) – 2 Hours
- 250 °F (121 °C) – 2 Hours
- 300 °F (149 °C) – 2 Hours
- 350 °F (177 °C) – 2 Hours
- 425 °F (218 °C) – 4 Hours
- 500 °F (260 °C) – 4 Hours
- 1600 °F (871 °C) – 4 Hours

Following the four-hour, 1600 °F cycle, the shell should be inspected to determine if the master pattern has been completely burned out. If not, the shell should continue to be fired at 1600 °F until the evacuation is complete. Once complete, cool down in a controlled manner until the shell is at room temperature. At this point it is ready for the remaining processing steps.

8.2.2. Flash firing (Non-Optimal)

For larger master patterns with minimal complexity and where the wall thickness is kept to the recommended thickness uniformly, this procedure should produce crack-free shells. To use this method a furnace needs to first be preheated to 1600 °F (871 °C). Once preheated, the shell should be placed in the furnace for a minimum of 4 hours. After the 4-hour cycle the shell should be inspected to determine if the master pattern has been completely burned out. If not, the shell should continue to be fired at 1600 °F until the evacuation is complete. Once complete, cool down in a controlled manner until the shell is at room temperature. At this point it is ready for the remaining processing steps.

9. Shell Washing

The interior of the fired shell MUST be washed after cooling down to remove residual ash from the pattern firing procedure and any ceramic dust left in the shell. Use a forceful stream of water to evacuate any remnants in the shell. Also, filling the shell with water and using manual agitation has proven to be successful at removing remaining contaminants. Continue to rinse until the water runs clear out of the shell.

Failure to perform this step will result in contaminants left in the shell, resulting in inclusions in the casting.

10. Remaining Foundry Processes

After washing the shell the remaining the balance of the investment casting process is unchanged from the standard procedures. These steps include:

- Pre-heating the shell
- Casting metal alloy
- Removing the shell (knock out)
- Gate removal
- Part inspection
- Heat treating
- Machining

11. Conclusion

With PolyJet master patterns, investment casting is a practical, cost-effective solution for prototypes, bridge-to-production applications, and low-volume production. In a minimal amount of time, castings can be created in the final alloy required for your particular use. Although legacy tool production methods still reign supreme in the investment casting industry, especially as volumes increase, utilizing PolyJet masters for investment casting masters solves many problems including high tooling cost, long lead times and producing complex geometric shapes. Understanding the PolyJet design-for-additive-manufacturing principles can enable these benefits and the design freedom advantages to be realized within the investment casting industry. With this design guide and the skills of a qualified foundry, companies in all industries can capitalize on the efficiency, capability, and quality of investment casting.

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