TECHNICAL APPLICATION GUIDE:

POLYJET FOR SILICONE MOLDS

Stratasys®
3D Printers and Production Systems

Silicone molding, which is also known as room temperature vulcanizing (RTV), is an affordable solution for prototyping, functional testing, product demonstrations and short-run production applications. Silicone molding can be used to produce small quantities and offers lead times of three to seven days which are both well under the cost of machining or injection molding.

Silicone molds are made by pouring liquid silicone rubber over a pattern. The resulting firm, but flexible, mold can reproduce extremely complex geometry and intricate detail with tight tolerances.

The traditional approach is to machine patterns for silicone molds. This method is expensive, requires lead times of one to two weeks and limits the complexity of the geometry of the molded parts. These factors diminish the value of silicone molding and present an obstacle to the redesigning process.

By replacing machined patterns with those created with a PolyJet™ 3D Printer, mold-making time is significantly reduced, and moreover, intricate or complex features can be easily incorporated into the pattern without additional time or cost.

CONTENTS

Short-run production of amplifier housing for a harmonica created with silicone molding.

A PolyJet pattern (center) was used to create this silicone mold.

Application compatibility:

(0 – N/A, 1 – Low, 5 – High)

PolyJet: Design (5)

FDM®: Idea (2), Design (3), Production (3)

Companion and reference materials:

- Technical application guide
  - Document
- Application brief
  - Document
- Video
  - Commercial
  - Success story
  - How It's Used

1. OVERVIEW

1.1. Application:

PolyJet 3D printed patterns are used to create silicone molds for the casting of urethane parts used as prototypes and for small-series production.

1.2. PolyJet is a best fit:

- Parts are challenging to machine.
  - Complex
  - Intricate
  - Feature-rich
- Parts are small to medium size.
  - Larger than 6 mm (0.25 in) in X, Y and Z.
  - Smaller than 300 mm (12 in) in X, Y and Z.
    - Larger parts are possible with larger Objet™ 3D Printers.
- Quantities are small.
  - 5 - 250 cast parts
- Design revisions/modifications are likely.
- Family molds are needed.
- Multi-cavity molds require multiple patterns.

1.3. Successful adopter traits (first iteration and long-term):

- Good mold-building and casting skills.
- Possess or have access to the skills and tools required.

1.4. PolyJet adoption obstacles:

OBSTACLE	SOLUTION*
• Silicone curing is inhibited.	• Remove all residual support material.
• Making large patterns is time consuming.	• Use “High Speed” mode. • Consider time advantage of reduced post processing.
• Pattern breaks or becomes deformed during mold making.	• Use Digital Materials™ for higher strength and heat resistance.

** Additional solutions may exist.*

1.5. Benefits:

- Lead time reduction
  - Average lead time savings: 70% - 90%
- Cost reduction
  - Average cost savings: 30% - 85%
- Quality
  - Smooth, nearly mold-ready surface finishes
  - Fine textures and details
  - Complex, intricate designs
- Efficiency gains
  - Automated pattern-making
  - Little or no pattern preparation

2. TRADITIONAL PROCESS OVERVIEW

There are many styles and approaches to silicone molding. The following information outlines one of the most common methods, cut molds.

2.1. The steps in the traditional silicone molding process are:

2.1.1. Make pattern (Figure 1).

- Construct pattern.
- Finish to desired surface quality.
- Mark parting lines.

2.1.2. Make mold.

- Make casting boxes.
- Add gates and vents (Figure 2).
- Pour mold.
  - Mix two-part silicone rubber.
  - Pour into mold box, covering pattern.
  - Allow to cure for 3 - 24 hours.
- Extract pattern.
  - Separate silicone mold.
  - Extract pattern.

2.1.3. Cast urethane parts.

- Mix two-part urethane materials.
- Cast part using:
  - Gravity pour
  - Injection (Figure 3)
  - Vacuum or pressure assist
  - Vacuum-casting system
- Allow to cure for 1/2 - 2 hours.
- Extract cast parts and finish as desired (Figures 4 and 5).

2.2. PolyJet adjustments

2.2.1. Replace machined patterns with PolyJet patterns.

- Prepare pattern in the same manner as a machined pattern.

2.2.2. Mold-making and casting:

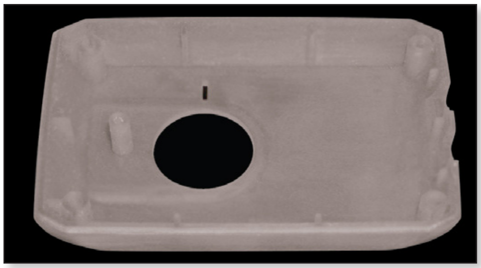

Figure 1: PolyJet pattern for silicone mold-making.

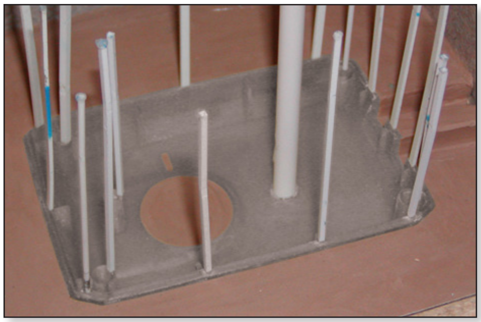

Figure 2: PolyJet pattern with gates and vents.

Figure 3: Casting urethane material (injection shown).

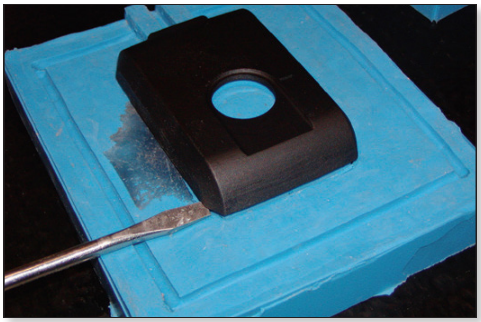

Figure 4: Extract cast part.

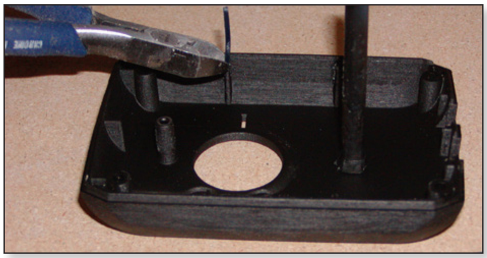

Figure 5: Trim gate and vents then finish as desired.

3. PATTERN DESIGN

Start with the CAD model for the part that will be cast. In most cases, no modifications are necessary (Figures 6 and 7).

3.1. Suggestions

The following items offer some optional and as-needed suggestions. Note that these actions apply to patterns made from any process; they are not PolyJet specific.

3.1.1. Omit draft angles (optional).

Silicone molds are flexible so draft angles are not needed. However, if they are already in the design (e.g., an injection molded part) there is no reason to remove them (Figure 8).

3.1.2. Remove features (as needed).

Eliminate problematic features from the CAD model. When finishing the cast urethane part, mill, drill or tap to add the features. Note that small undercuts are allowed since the flexible silicone material will deflect when extracting cast parts (Figure 9). Examples can include:

- “Trapped” features

  These are features which would trap the pattern in the mold. Example: A hole with a centerline perpendicular to the direction of mold separation (Figure 10). This is a trapped feature unless a side pull is added.

- Narrow holes or channels

  These features will grip the rubber which may cause it to tear when the pattern is extracted.

3.1.3. Add gates and vents (optional).

Most often, the shrinkage of the rubber is offset by the shrinkage of the cast urethane, so compensation is unnecessary. However, if the application demands very high accuracy, or if casting a urethane with high shrinkage, like a low durometer material, calculate the net shrinkage between the two. Scale the CAD model by this value to compensate.

Optionally, shrinkage compensation may be added in Objet Studio™ software (see Section 4.2.).

3.2. Export STL file.

When the CAD design work is complete, save the model as an STL file. Make sure to adjust settings like chord height so that the file has small facets (Figure 11). This will produce smooth surfaces that require less post-processing when preparing the pattern.

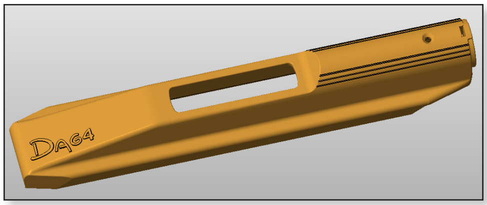

Figure 6: Start with CAD model (top view shown).

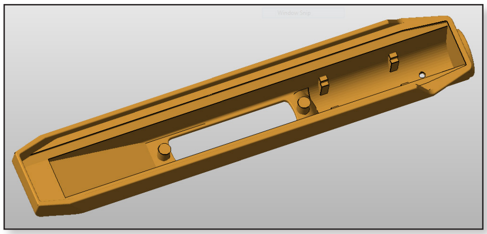

Figure 7: CAD model (bottom view) includes all design details.

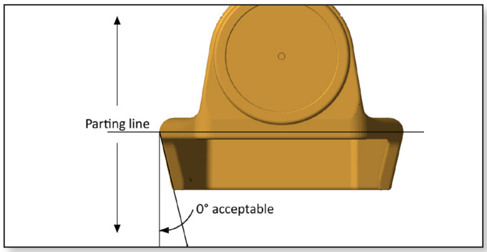

Figure 8: Flexible silicone molds do not require draft angles.

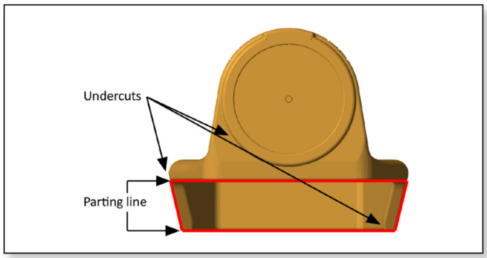

Figure 9: Small undercuts are allowable since the silicone mold will flex when extracting parts.

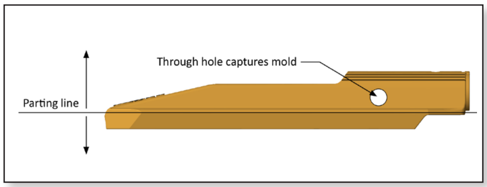

Figure 10: To simplify silicone molds, eliminate features that will prevent part extraction.

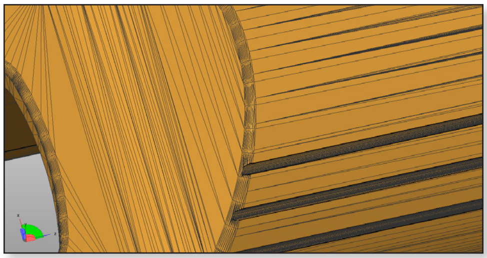

Figure 11: Export high-resolution STL files to minimize pattern finishing.

4. FILE PREPARATION

4.1. Import and orient.

Import the pattern's STL file into Objet Studio software. Then, place it on the build tray and orient (Figure 12) (Left click on part > Transform > Rotate).

4.1.1. Considerations:

When orienting the part, position it to minimize printing time and support material (Figures 13, 14 and 15).

4.2. Apply shrinkage compensation (optional).

If shrinkage compensation is required, and if it was not applied earlier (see Section 3.1.4.), adjust the pattern size using the "Transform" function (Left click > Transform > Scale).

Enter the net value — the difference between the shrinkage of the silicone rubber and cast urethane material — for the X, Y and Z axes (Figure 16).

4.3. Select surface finish.

When building silicone mold patterns, use the "Matte" finish option to create a uniform finish across the entire part (Figure 17) (Left mouse click > Matte).

4.4. Set printing mode.

Select "High Quality" for the printing mode to produce the smoothest surfaces and minimize post processing (Build > Printing Mode).

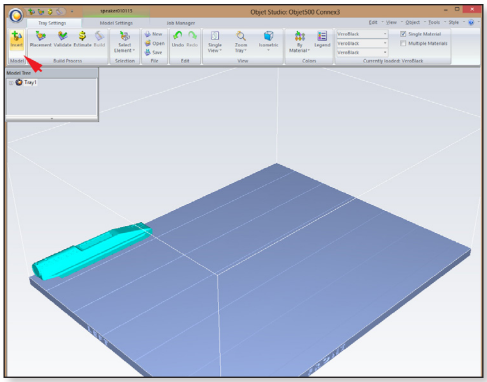

Figure 12: Import STL file into Objet Studio.

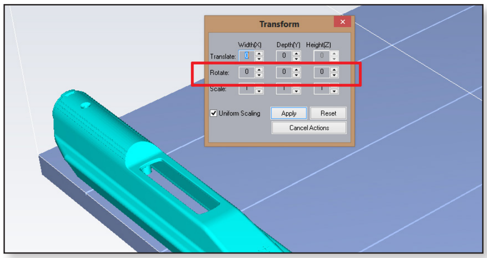

Figure 13: Orient the STL to minimize printing time. Part as shown took seven hours to build.

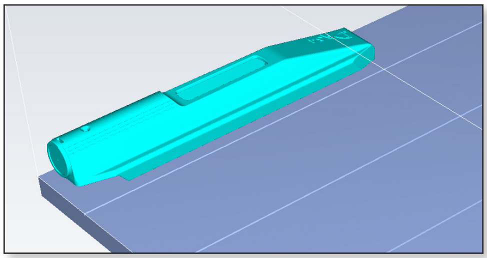

Figure 14: Two-hour print time with this orientation.

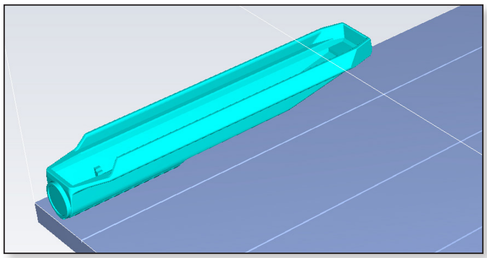

Figure 15: Orient the file to minimize support material. Best orientation for time and support material shown.

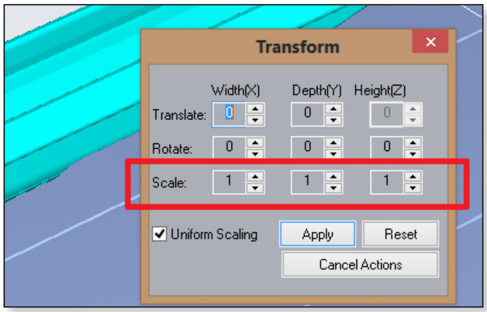

Figure 16: Option: Apply shrinkage compensation to the file.

5. MATERIALS

Most rigid PolyJet materials are suitable for creating silicone molding patterns. These include:

- FullCure™ family (Figure 18)
  - FC 720 is recommended for most applications.
- Vero™ family (Figure 19)
- Digital Materials™

5.1. Considerations:

Silicone rubber is a thermoset material that generates heat when its two components are mixed, and the reaction occurs or "kicks off." It is also heavy so it will apply a loading force on the pattern.

The heat and load may cause the pattern to deform if the mold is large or the pattern has thin, tall features. If either of these conditions exists, select a PolyJet material, like Digital ABS, that has elevated heat deflection temperatures and mechanical strength. Note, however, that the "High Quality" print mode is unavailable with Digital Materials (see Section 4.4.).

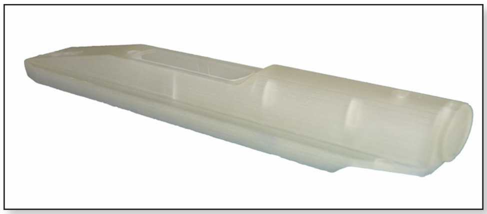

Figure 17: Use the "Matte" finish option for uniform surfaces on patterns.

Figure 18: FullCure 720 material.

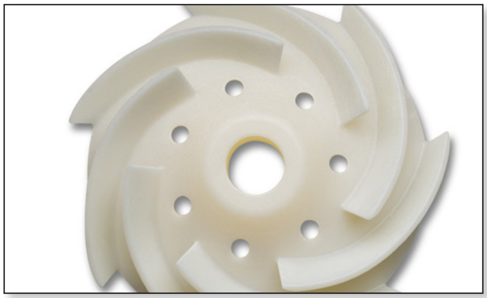

Figure 19: VeroWhite™ material.

6. PATTERN PREPARATION

After constructing the PolyJet pattern, post-process it to remove support material and finish the surfaces to the desired level of smoothness.

6.1. Remove support material.

Place the pattern in the Waterjet Station™. Using the pressurized water, separate the support material from the pattern (Figure 20).

Figure 20: Use the Waterjet Station to remove support material.

6.2. Remove support residual.

Any residual support material that remains after water-jetting must also be removed. Failure to do so will inhibit the silicone rubber from fully curing thereby creating a "sticky" surface in the mold cavity. Inhibition makes the mold unusable. To prevent inhibition, remove all of the residual support material from the pattern.

6.2.1. Prepare sodium hydroxide (NaOH) bath.

Mix water and NaOH to make a 2% NaOH solution.

6.2.2. Soak pattern.

Place the pattern in NaOH solution for two hours (Figure 21).

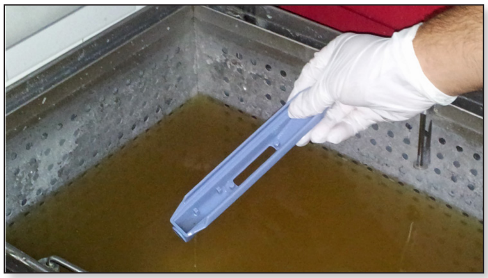

Figure 21: Soak pattern in NaOH to remove support residual.

6.2.3. Rinse thoroughly and inspect.

Rinse the pattern to remove all of the NaOH solution and then dry thoroughly. Note that moisture will also inhibit silicone curing.

Inspect the pattern to confirm that no support residual remains. If necessary, repeat step 6.2.2.

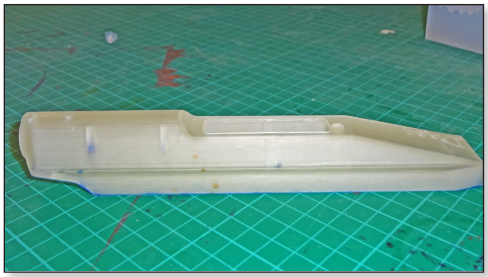

Figure 22: PolyJet pattern without optional sanding or priming is suitable for many silicone molding projects.

6.3. Surface smoothing

The silicone mold will transfer the finish of the pattern to the cast parts so it is important to have all surfaces as smooth as those needed for the intended application (Figure 22).

Surface smoothing may include any combination of sanding, filling, priming or coating. The following instructions explain the way to prepare a pattern for a high-quality finish that simulates a polished injection mold.

6.3.1. Apply primer coat (optional).

Figure 23: Apply primer to pattern (optional).

A light coating of primer will reveal surface imperfections on the pattern (Figures 23 and 24). Many find that this makes the task of filling and sanding easier by drawing attention to the areas that need work. However, this step will add several hours to the pattern preparation process.

- Option 1: Standard gray primer

  Gray is a common primer color and it works well in showing surface defects. However, most other colors will also suffice. This option is best when fillers will be applied to the pattern.

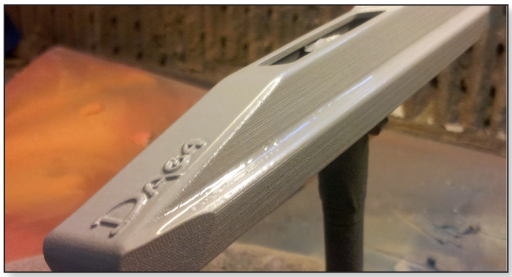

Figure 24: Primed patterns highlight areas that need additional finishing, if any.

- Option 2: Sandable primer

  Sandable primers have the advantage of self-leveling, which will aid in filling pinholes and layer lines. Use this option if the primer coat will be followed by sanding.

Using either option, apply a thin coat of primer and allow it to dry. See product instructions for drying times, which are typically 1 - 2 hours.

6.3.2. Apply body filler (optional).

There are many types of body fillers, spot putties and glazing putties, and most are suitable for pattern preparation. Select a filler for its viscosity, working time and drying time. However, for most applications, a fast-drying, one-part spot putty is preferred.

Working in small patches, spread the putty / filler on the surface of the pattern to a depth that fills surface depressions without too much buildup in thickness (Figure 25).

Allow the material to dry. Repeat this step until all areas are filled.

Figure 25: For high-gloss or clear castings, fill surface imperfections with spot putty.

6.3.3. Sand surfaces (optional).

If body filler has been applied, allow it to dry.

Sand all surfaces to a smooth finish (Figure 26). If using a power sanding tool, be cautious to avoid getting the plastic too hot.

Start with a medium-grit wet / dry sandpaper (180- to 220-grit) and sand until the surfaces are visibly smooth. Follow with fine-grit sandpaper (320- to 400-grit).

This is a good level of smoothness for most finish types.

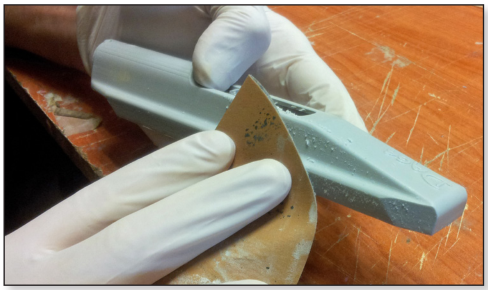

Figure 26: Sand pattern for smoother finish (optional).

6.3.4. Repeat.

Inspect the pattern. If visible depressions or defects remain, repeat the filling and sanding processes.

6.3.5. Clean pattern.

Remove dust and debris from the pattern before proceeding to the mold-making step.

6.4. Surface polishing (optional: use for high-gloss and clear parts).

Since silicone rubber picks up fine details from a pattern, and high-gloss or clear finishes highlight the tiniest flaws, the pattern finish must be taken to a polished level. Following step 6.3, polish the pattern's surfaces by wet sanding with 600-grit followed by 800-grit sandpaper. For clear casting, follow with a 1500-grit sanding.

After sanding, clean and dry all surfaces.

6.5. Apply mold release paint (optional).

A final, optional step in pattern preparation is to paint the pattern, following manufacturer's instructions, with a spray that combines a mold release and paint. This seals the pattern to eliminate silicone inhibition and the need to apply a mold release during mold making.

7. MOLD MAKING

The following procedures are intended for general information only, and they represent just one of many approaches to silicone mold making. This approach, which is called cut molds or split molds, is used for molds with complex parting lines that do not demand precision. It uses a single silicone rubber pour rather than separate pours for each mold half.

Note, this method requires that the pattern is visible when encapsulated in the silicone rubber, therefore clear or semi-transparent silicones must be used (Figure 27).

Figure 27: Use clear silicone so that the pattern is visible after mold curing.

7.1. Build mold box.

Construct a box from wood, plastic or other rigid material (Figure 28). The box should be 50 - 100 mm (2 - 4 in) larger than the pattern in all directions. For molds larger than 300 mm (12 in), increase the space between the pattern and mold box walls.

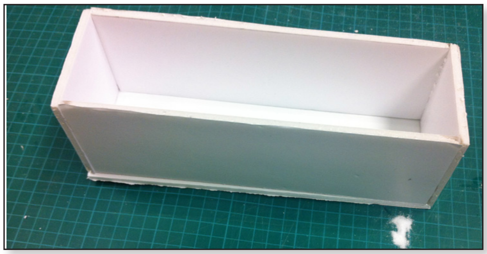

Figure 28: Construct a mold box that will be filled with liquid silicone material.

7.2. Mark parting lines and shut-offs.

After pouring the silicone rubber, the pattern will be encapsulated. To free the pattern and create the mold halves, the silicone rubber will be cut to the parting lines and shut-offs.

Establish a visual cutting guide on the pattern by marking all parting lines and shut-offs with a dark, permanent marker, such as a Sharpie® pen (Figure 29).

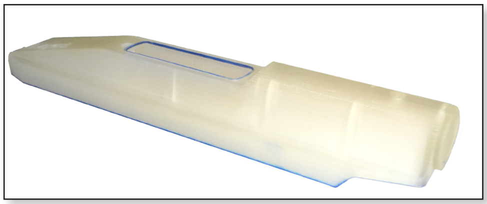

Figure 29: Mark parting lines and shut-offs on the pattern to provide a visual cutting guide.

7.3. Add gates and vents.

If gates and vents were added to the pattern's CAD model (see Section 3.1.3.), skip to Section 7.4.

The gate is the entry point for the urethane. The vents release air from pockets that would otherwise trap it.

Using rod stock (e.g., plastic, wood or metal), rigid tubing or other common shop items, attach material to the pattern to form the channels for the gate and vents (Figure 30). These components must be long enough to extend beyond the mold when the pattern is centered in the mold box. For attachment, use cyanoacrylate or other adhesive that will not inhibit the silicone cure.

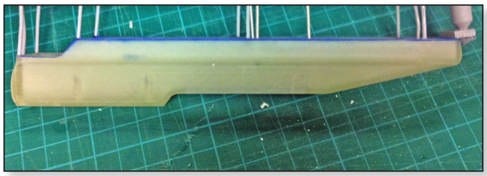

Figure 30: Attach gate- (right) and vent-forming material on pattern.

7.4. Apply mold release.

Spray the pattern and mold box interior with mold release.

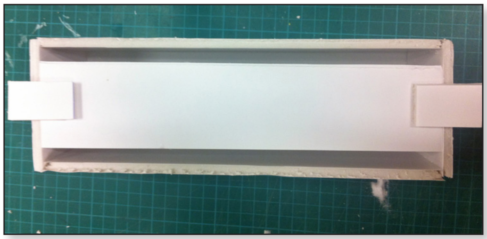

Figure 31: A suspension platform, with pattern on the underside, rests on top of mold box.

7.5. Mount pattern in mold box.

Suspend the pattern in the mold box so that it is centered in all directions. One option is to build a suspension platform that is larger than the mold box in one direction and smaller in the other to provide an opening through which the silicone is poured (Figure 31). Bond the gates and vents to the suspension platform (Figure 32).

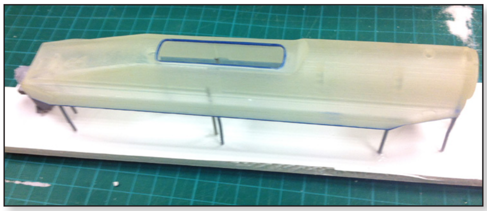

Figure 32: Attach PolyJet pattern to supporting platform using the vents and gates as attachment points.

7.6. Mix and pour silicone rubber.

Per manufacturer's instructions, weigh and mix the two components of the silicone rubber kit (Figure 33). If available, place the liquid rubber in a vacuum chamber to remove air bubbles (degassing).

Pour the silicone rubber until it fills the mold box. Do not pour directly onto the pattern. Instead, slowly pour into one corner of the mold box to avoid trapping air (Figure 34). Also, tilt the mold box to allow air to escape from any pocket in or under the pattern.

Once filled, repeat the vacuum degassing (Figure 35). Then, allow the rubber to cure, which will typically be 3 - 24 hours (Figure 36).

7.7. Extract pattern.

After the silicone rubber has cured, remove the mold box. Next, cut into the mold using a zig-zag contour to reach the marked parting lines on the pattern (Figure 37). The jagged cutting line provides locating features between the mold halves when casting parts.

Although flexible, the silicone rubber will be resistant to separation and pattern extraction. After making an initial cut, use a prying tool —ideally reverse pliers — to open the incision (Figure 38).

Once the pattern is fully exposed, carefully extract it from the mold to avoid tearing the silicone rubber. Pry the rubber, a little at a time, from around the pattern, working first around the periphery and then toward the interior (Figure 39).

Figure 33: Mix parts A and B of the silicone material.

Figure 34: Slowly pour silicone into a corner of the mold box to avoid air pockets.

Figure 35: Place filled mold box in a vacuum chamber to remove air (degassing).

Figure 36: Pattern within the cured silicone mold.

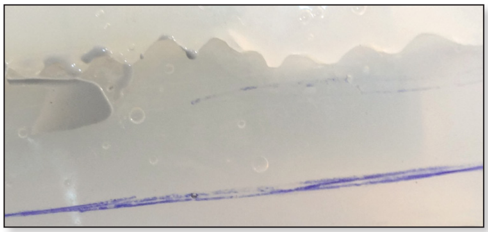

Figure 37: Cut silicone mold to create a jagged parting line for locating mold halves.

Figure 38: While cutting, pry the silicone material to open the cut.

8. PART CASTING

8.1. Assemble mold.

Spray both halves of the mold with a release agent.

Close the mold and bind it with duct tape or a similar material (Figure 40). When casting, the molds will separate so tape them tightly. Be careful, however, not to apply too much force since this will deform the mold cavity.

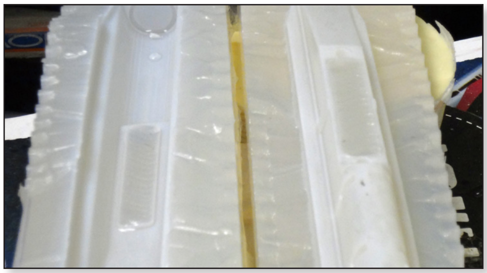

Figure 39: Silicone mold ready for part casting.

8.2. Mix urethane.

Weigh and mix the two parts of the urethane kit per manufacturer's instructions (Figure 41). If a vacuum chamber is available, and if the material's pot life is long enough, degas the liquid to remove air bubbles that could create voids on the surface of the casting.

If using a vacuum casting system, degassing occurs while the material is mixing.

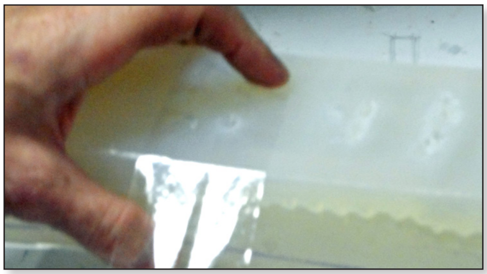

Figure 40: Spray mold with release agent and bind to prevent separation (packing tape shown).

8.3. Cast urethane into mold.

Pour or inject the liquid urethane into the silicone mold until it begins to exit from the vents. Then, place the mold into a vacuum chamber (Figure 42) or pressure pot to drive out air bubbles. Alternatively, use a vacuum casting system, which will meter, mix, degas and cast the urethane (Figures 43 and 44).

Allow the urethane to cure. Cure times vary widely so check manufacturer's instructions.

Figure 41: Weigh, mix and degas the cast urethane material.

8.4. Extract cast part.

Separate the mold halves and carefully extract the cast part (Figure 45). In many cases, the silicone rubber will grip the part. To release the part, gently pry the casting from the mold while blowing compressed air between the mold and the part (Figure 46).

Figure 42: After pouring, place the mold in a vacuum chamber (shown) or pressure pot to remove air bubbles.

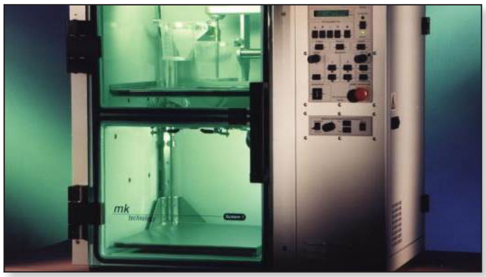

Figure 43: Vacuum casting systems meter, mix, pour and degas urethane.

9. PART FINISHING

Snip off the gate and vents from the casting and finish the part as desired (Figures 47 and 48).

Figure 44: Inside a vacuum casting system: mold with fill funnel (bottom) and unmixed urethane (black liquid in center and yellow liquid above).

Figure 45: After curing, extract cast part from silicone mold.

Figure 46: Cast part (top) and silicone mold.

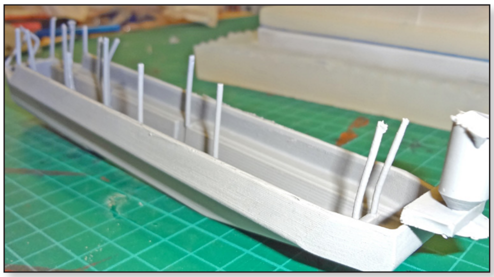

Figure 47: Raw casting before removal of gates and vents and secondary finishing.

Figure 48: Final product: painted and assembled amplifier.

10. KEY PROCESS CONSIDERATIONS

10.1. Obstacle details:

Table 1 presents common obstacles for silicone molding when using PolyJet molds along with recommended solutions.

Obstacle		Resolution				
		NaOH Soak	Sand/ Polish	Degas	Vacuum/ Pressure	Remove Undercuts/ Features
Inhibition	Silicone rubber does not fully cure in mold cavity.	✓				
Surface Imperfections	Castings have pits, flaws or layer lines.		✓	✓	✓	
Short Fill	Casting is incomplete; some areas are missing.				✓	
Trapped	Cannot extract part or pattern from the mold.					✓

Table 1: Common obstacles and resolutions.

10.2. Resolution details:

- Sodium hydroxide soak (NaOH):
  - Remove all residual support material by soaking for 2+ hours in NaOH. Rinse and dry thoroughly.
- Sand and polish:
  - Remove any imperfections in the pattern by sanding. Filling low spots with body putty is also an option.
  - Wet-sand the pattern to a polished finish when making high-gloss or clear castings.
- Degas:
  - Remove air from both the liquid silicone and urethane using a vacuum chamber.
- Vacuum or pressure:
  - Degas (above) materials to remove air.
  - Apply vacuum or pressure immediately following urethane pour to force trapped air out from the mold cavity.
- Remove undercuts and features:
  - Eliminate any features that will prevent extraction of the pattern or castings.

11. TOOLS & SUPPLIES

11.1. Required items:

- Silicone rubber (kit)
- Urethane (kit)
- Mold release
- Miscellaneous tools:
  - Knives, mixing paddles, reverse pliers, jars, etc.

11.2. Optional items:

- Sandpaper:
  - 120- to 1500-grit wet / dry
- Filler/putty:
  - 3M® Acryl-Green Spot Putty
- Primer:
  - Sandable: PlastiKote® T235
  - Standard (gray): good quality primer
- Paint with mold release:
  - Modellack Schwarz 4140 #360130000
- Vacuum chamber
- Pressure pot
- Vacuum-casting system
- Oven
  - For thermal post-cure of urethanes

11.3. Sources:

- Specialty items are available from:
  - SLM Solutions: www.slm-solutions.com
  - Smooth-On: www.smooth-on.com
  - MK Technology: www.mkt-inc.com
  - MCP Hek GmH: www.mcp-hek.de
- All non-specialty materials are available from:
  - Automotive supply/painting supply retailers
  - Hobby shops/hardware stores
  - Mold supply houses

12. RECAP - CRITICAL SUCCESS FACTORS

12.1. Actions:

- Prepare pattern to desired casting finish.
- Acquire silicone molding expertise. Mold release.

12.2. Eliminate obstacles:

- Remove all residual support material.
- Degas all materials.
- Use vacuum or pressure to fill mold cavity with urethane.
- Consider pattern extraction when preparing for mold building.

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