BASIC LOST WAX KILNCASTING

Lost wax kilncasting is a versatile method for making glass pieces in almost any form imaginable. The process involves creating a refractory mold around a wax model. The wax is then removed—or “lost”—creating a cavity. Glass is cast into the cavity, resulting in a fully sculptural finished piece.

What This Tipsheet Covers
This Tipsheet covers the steps involved in making a fully sculptural cast glass object using the lost wax process.
• Making a two-layer refractory mold of a wax original
• Steaming out the wax
• Calculating the amount of glass needed
• Curing the mold to ensure better performance
• Preparing the kiln for firing
• Casting the glass into the mold
• Divesting the piece from the mold materials
• Coldworking the finished piece

Measurement Note
All measurements of length, weight, and volume in this Tipsheet are metric, a superior system for laboratory work. In measuring volume, 1 cubic centimeter (cm³) of water = 1 milliliter (ml) of water = 1 gram (g) of water. Thus the interior of a container measuring 20 x 20 x 2.5 cm has a volume of 1000 cm³ = 1000 ml of water = 1000 g of water.

The Wax Model
The wax model may be a fully three-dimensional object with undercuts. Ideally, this model is hollow and thus much easier to remove from the mold and less likely to mar or break down the mold. For this Tipsheet, we made a wax model of a bull and attached a “funnel” made of wax to the top of the bull’s back. During the mold making process, this funnel was at the bottom of the mold. For the kilncasting process, the mold was inverted, the funnel becoming a reservoir into which we loaded the glass. (Figures 1, 9, 10 and footnote 4)

Monolithic vs. Multilayered Molds
Historically, molds for lost wax kilncasting have been “monolithic,” or made/poured in one piece. In the Bullseye Research & Education studios, we hand-build molds in two or more layers: a face coat and one or more jacket coats. These multilayered molds are light in weight, with uniform wall thickness around the entire object. This allows for uniform transfer of heat through the mold wall. Multiple layers also create redundancy in the mold: if one layer cracks or fails, there is an intact layer immediately adjacent to it. In contrast, a monolithic mold rarely has uniform wall thickness, requires more material, and introduces more water into the kiln. If a monolithic mold cracks it is more likely to fail completely, allowing glass to flow out of the mold, potentially damaging the kiln.
BUILDING THE MOLD

Preparing the Area
The mold making process involves many steps and is most efficiently executed in a well-organized space. The area for weighing the dry materials should have good ventilation, and you should wear a NIOSH-approved respirator for filtering particulates when working with dry investment.

After reading through this TipSheet to gain perspective on the process, gather the necessary tools.

Affix the wax model to a clean, rigid, plastic sheet and draw a line around it at a distance of about 15 mm from the base. (Figure 1) This line will serve as a guide in making the first layer of the mold, which will be 15 mm thick. A light coating of hairspray can on the wax can help the mold material adhere.

Mold Material / Investment Recipes
Kilncasting and mold making are practiced in different ways around the world. There is no one right way to make a mold or one correct recipe for the mold material, or “investment.” However, all investment molds for kilncasting are generally composed of three basic ingredients: a binder, a refractory, and modifiers.

A binder is a material used to unite two or more other materials in a mixture. Its principal properties are adhesion and cohesion. At Bullseye we frequently use #1 Casting Plaster as the binder.1 A refractory is a material that is difficult to melt or work, and that can withstand high temperatures. At Bullseye we use 295-mesh silica flour as our primary refractory material.

A modifier is a material used to change the characteristics of the mixture into which it is introduced. Different materials are used as modifiers to serve different purposes. Perlite can be added to a mold recipe to reduce the weight of a large mold. Fiberglass strands are sometimes used to increase the tensile strength of an unfired mold and may allow water to wick out of the mold. Ground up ceramic grog, as an aggregate material, can increase the mechanical strength of the mold. Grog also has refractory properties. At Bullseye, we use grog mixture with particle sizes ranging from 25- to 80-mesh to increase the strength of the outer layer (or layers) of hand-built molds.

We’ve successfully used the following recipes in Bullseye’s Research & Education studios on a wide variety of cast objects.

The first layer of the mold is called the face coat. The primary purpose of this layer is to pick up as much detail from the wax model as possible. The face coat is composed of a mixture of 50% #1 Casting Plaster and 50% 295 mesh silica flour, by weight. We mix these ingredients with water 70°F (21°C) at a ratio of 1 part water to 2 parts investment, by weight.

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1. Plasters can be very different in different parts of the world, and this can radically affect the investment recipe and performance.

2. Silica flour expands during firing. This compensates for the plaster, which shrinks during firing.
3. Be sure to work with fresh plaster. Plaster has a shelf life after which it may be less effective. If there are hard or sharp chunks in the investment recipe after it has been added to the water, the plaster has likely been exposed to moisture and may not be viable for mold making. If so, discard the plaster and remake the investment with fresh plaster.
4. At Bullseye, we generally plan to fill the mold so the reservoir will be the thickest area of the casting. This helps reduce the incidence of “suckers,” or scars that form when the glass pulls away from the mold forming depressions in the final object. Suckers usually form in the area of the glass that remains the hottest for the longest during the cooling cycle, becoming a focal point for shrinkage in the material. The thickest and/or most heavily insulated area of the casting is usually where the glass remains the hottest during the cooling cycle. Since the reservoir is typically cut off or removed from the finished casting, it is the ideal place for such shrinkage to concentrate, often forming a meniscus. Filling the reservoir with glass to a certain point also has the added benefit of providing increased head pressure that will help glass flow completely into the mold during process temperature.

Recipes, page 2.) Blend the grog into the dry plaster/silica mixture before sifting all the dry material into the water. A larger island will form because of the grog, but the material must still become fully saturated before mixing. This investment batch will initially be much thicker than the first batch, but will loosen up and homogenize considerably during mixing.

**Applying the Jacket Coat**
The second layer can be added much more quickly than the first because the investment material is more viscous and will adhere more readily and because surface detail is no longer an issue. Build this layer up until it covers the first layer by roughly 15 mm all around. Finish the surface by smoothing it with a flexible metal rib. This will make the mold easier to handle and less likely to break. (Figure 5) Clean up as before.

**Losing/Removing the Wax**
Once the mold is built, you’ll remove the wax to leave a cavity into which the glass can be cast. Wait at least one hour after completing the jacket coat before removing the wax. For kilncasting glass, we recommend steaming the wax out with a wallpaper steamer. Elevate the mold with the reservoir facing down and the end of the steam hose inserted into the mold reservoir. (Figure 6) At Bullseye we use a stand that holds the steamer tube in place and allows wax to drip freely. It also provides a view inside the mold. As soon as steam starts coming from the tube, wax will run out of the mold.

The thinner the original wax, the faster the melting process will be. The tube should never touch the surface of the mold, as this could damage the surface and/or drive wax into the investment. Wearing gloves to avoid steam burns, rotate the mold to help wax escape. When no more wax runs out of the mold, remove it from the stand and flush it with water.

**Measuring the Mold Cavity Volume**
Once the mold is cool to the touch but before it has cured, calculate the volume of the cavity. (Figure 7)
Curing the Mold
Much like concrete, plaster in the investment needs to remain moist while setting up. At Bullseye we wrap our molds in plastic for 24-48 hours, which gives the plaster a chance to cure and increases the green or unfired strength of the mold. (Figure 8)

Drying the Mold
Before the mold is fired, it should be dried either in a mold dryer or ambient conditions. We have observed that this practice often results in a finished casting with an extremely lucid surface. Also, firing wet molds releases a lot of water that will attack/rust the structure of the kiln and deposit contaminants on the glass. If there is not sufficient time to dry the mold before loading it into the kiln, incorporate the drying step into the firing program.

SELECTING THE GLASS
You can cast with any form of Bullseye glass (billet, cullet, sheet, frit, etc.), but the form selected will have a direct impact on the clarity of the casting.

Powders and fine frits will trap more air bubbles, so many bubbles that even our Crystal Clear (001401) will appear milky white and opalescent when cast. Billets, on the other hand, trap fewer air bubbles and result in castings of greater clarity and transparency.

Color is another major consideration when selecting glass. Most of Bullseye’s original transparent colors were developed to have their full color intensity at thicknesses of 3–6 mm. Many of these colors, when used at full strength in thicker works, appear very dark. Others, such as Yellow (001120), Red (001122), and Orange (001125), may opalize during the longer hold times at higher temperatures required for kilncasting.

Our 001800 and 001900 series of casting tints were specifically developed to create colors that would be of lighter saturation and greater stability at these thicknesses and temperatures. Or our standard palette can be used to tint Clear (001101) as described in our technical article Frit Tinting (available on bullseyeglass.com).

FIRING THE MOLD AND GLASS

Loading the Kiln
To aid in uniform heating and cooling, place the mold on a 15-mm-thick mullite shelf elevated on 50-mm posts nestled in a mound of sand. The sand will stabilize the mold and make it easier to level. Once the mold is level, it is ready to be loaded with glass. (Figure 9) The height of some kilns makes it difficult to load the mold once it is in the kiln. In that case, load the glass outside the kiln and then level the mold in the kiln. The glass should be thoroughly cleaned before loading.

An alternative to loading glass directly into the mold is to load it into a crucible above the mold. (Figure 10) An unglazed US- or Italian-made terra cotta flowerpot makes the ideal, affordable crucible. Before loading the pot with glass, use a rattail file to enlarge the hole in the bottom to about 16 mm. Remove small shards that could flow into the casting, and wipe the pot with a damp cloth to remove dust. Some glass will stick to the crucible, so you’ll need to increase the amount of glass by 10 percent.

The advantage of casting through a crucible is that it keeps the glass away from the mold during the heating process, when water vapor is being driven out of the mold. Contaminants in this vapor can seed devitrification or cause the glass to haze. It can also change the surface tension of the glass, making it flow more slowly or not at all. Furthermore, glass is heavy and may have sharp edges. Loading glass directly into a mold (especially if freshly made) can damage details and break off small pieces of...
mold material that can become trapped in the finished casting. The primary disadvantages of working with a crucible are the loss of some material in the crucible and the added height required in the kiln.

At Bullseye, we have successfully cast objects using both the crucible and non-crucible methods.

**Firing**

There are three major considerations when developing a firing cycle for lost wax kilncasting:

- Glass and kiln conditions
- Mold materials
- Timing the firing

**Glass and Kiln Conditions**

The firing cycle as it relates to glass and kiln conditions is covered in depth in TechNotes 4: Heat and Glass. We recommend reviewing that article.

One additional consideration area not fully addressed in TechNotes 4, however, is the issue of “charging,” or adding glass to a hot mold. This is sometimes necessary if you aren’t able to load all of the glass at the beginning of the firing. The primary concern here is that certain glasses—such as Ruby Red Tint (001824) and other gold-bearing glasses—if heated too rapidly, will develop a sapphirine quality instead of their intended color. If you need to charge such a glass into the mold, it should be preheated in a separate kiln to 1225°F (663°C), held for two hours, and transferred hot into the mold or crucible.

**Mold Materials**

The firing cycle as it relates to the mold materials involves four basic tasks.

1. Removing interstitial water. This occurs from room temp to 212°F (100°C). During this phase of the firing, you’re trying to drive water out without boiling it. Boiling the water may create small fractures throughout the mold, causing it to weaken fail when the glass is flowing and exerting outward pressure on the mold wall. To avoid boiling the water, hold at 200°F (93°C) (below the boiling point) until you’re confident all of the interstitial or free water has been driven from the mold. Vent the kiln during this phase and though 1100°F (593°C) to make certain that water vapor can easily escape the kiln and will not attack the kiln’s frame (causing rust) or deposit contaminants on the glass.

2. Removing chemically bound water. This happens from 212°F (100°C) to around 350°F (177°C). During this phase of the firing we are trying to drive out chemically bound water, again without boiling it. To avoid boiling, fire at a slow rate of 100°F (55°C) per hour from 200°F (93°C) to 1225°F (663°C).

3. Heating evenly through the quartz inversion zone. This occurs at about 1100°F (593°C). At this point in the firing the silica and the grog (and possibly other modifiers in the mold) suddenly expand in size. It is important that all of these materials go through this sudden change at the same time. If not, strain can develop that may result in the mold cracking. Again, fire at a slow rate of 100°F (55°C) per hour to achieve uniform heating.

4. Employing a low process temperature. The plaster loses much of its integrity above 1100°F (593°C), making the mold progressively weaker the hotter it’s fired. Also, the hotter the mold is fired the more likely it is to stick to the glass. Finally, though it seems somewhat counterintuitive, firing to temperatures higher than 1550°F (843°C) can, in some instances, actually make the glass flow more slowly. This is because the hotter the mold and the glass are fired, the more they react with one another. This can cause the surface tension of the glass to increase.

**Timing the Firing**

In timing the firing, plan to be present at the following key times.

1. At 1100°F (593°C), close the vents. Up to this point, the vents will need to be open to allow water and organic materials burning out of the mold to exit the kiln.

2. At 1225°F (633°C), confirm that the mold is stable and no cracks have formed. To do this, open the kiln enough to take a quick look, then close the door and think about what you’ve seen (holding the door open for a long time could thermal shock and crack the mold). Check the mold several times at this temperature. If it remains stable and no cracks have formed, it is safe to proceed to the casting/process temperature. If the mold is cracking, however, it may fail at casting/process temperature, and you may need to consider aborting the firing at this point.

3. At process temperature, confirm:

   - The integrity of the mold. If the mold fails seriously at this temperature you have limited time to halt the firing to prevent the glass from flowing out of the mold. This could potentially damage or destroy your kiln. Again take quick looks, close the door, and think about what you have seen.
   - That the glass has flowed and filled the mold cavity.
   - That unwanted bubbles have risen, popped, and healed.

4. Throughout the annealing process, to monitor and record multiple thermocouples and make adjustments. For more information see TechNotes 7: Monitoring Kiln Temperatures for Successful Annealing.
**Typical Cycle**

<table>
<thead>
<tr>
<th>STEP</th>
<th>PURPOSE</th>
<th>RATE (degrees per hour)</th>
<th>TEMPERATURE (degrees Fahrenheit)</th>
<th>HOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial heat, remove physical water</td>
<td>100°F (55°C)</td>
<td>200°F (93°C)</td>
<td>6:00</td>
</tr>
<tr>
<td>2</td>
<td>Initial heat, remove chemical water, Quartz Inversion, pre-rapid heat soak</td>
<td>100°F (55°C)</td>
<td>1250°F (677°C)</td>
<td>2:00</td>
</tr>
<tr>
<td>3</td>
<td>Rapid heat, process hold</td>
<td>600°F (333°C)</td>
<td>1525°F (830°C)</td>
<td>3:00*</td>
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<tr>
<td>4</td>
<td>Rapid cool and anti-sucker soak</td>
<td>AFAP**</td>
<td>1150–1250°F (596–677°C)</td>
<td>4:00***</td>
</tr>
<tr>
<td>5</td>
<td>Anti-sucker cool, anneal soak</td>
<td>50°F (27.7°C)</td>
<td>900°F (482°C)</td>
<td>6:00</td>
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<tr>
<td>6</td>
<td>1st anneal cool</td>
<td>12°F (6.7°C)</td>
<td>800°F (427°C)</td>
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<tr>
<td>7</td>
<td>2nd anneal cool</td>
<td>22°F (12°C)</td>
<td>700°F (371°C)</td>
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<td>8</td>
<td>Final cool</td>
<td>72°F (40°C)</td>
<td>70°F (21°C)</td>
<td>:01</td>
</tr>
</tbody>
</table>

* Visually confirm process hold time.
** "As Fast As Possible" Specifically: allow the kiln to cool at its natural rate with the door closed. Do not crash cool by opening the kiln door.
*** The anti-sucker processes can be performed in a variety of methods and through a range of temperatures; however, the most important aspect of this step is to cool the glass uniformly while it is experiencing its most dramatic rate of shrinkage/contraction.

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**Divesting and Cleaning the Glass**

Once the entire firing cycle is complete, we recommend leaving the piece in the kiln at room temperature for at least a day before divesting. Remove it from the kiln carefully. After firing, the mold will be considerably weaker and no longer structurally sound.

Be sure to wear proper safety equipment, including a respirator to protect you from the plaster and silica particles. Ideally, you should divest the casting in an area with local ventilation, as many of the finer dusts generated may remain airborne for hours. Safety glasses and gloves will protect you from the thin, sharp flashing that results from glass dragging into the mold form the reservoir.

You can remove the investment material with a variety of tools, including dental instruments, wooden picks, nylon brushes, and wood carving tools. (Figure 11) We recommend wooden or hard plastic tools. Metal tools should be used carefully, as they can scratch or chip the casting. A nylon bristle brush and forced air are also great tools for cleaning areas of residual investment. Most of the investment should be removed from the glass before submerging it in or scrubbing it with water. (Figure 12) While water can be used to rinse away residual investment, we have found that scrubbing the glass with vinegar and/or CLR® breaks down residual investment material.

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6. Calcium Lime Rust, commonly known as CLR, is a household product used for dissolving stains such as calcium, lime, and iron oxide deposits.
Coldworking
If the cast glass object includes a reservoir that needs to be removed (Figure 13), this can be taken off with a wet tile saw with a diamond blade, or it can be ground off using rotary tools.

Coldworking presents a myriad of possibilities, but first a word of caution: the casting should be at room temperature for a day before attempting any coldworking. A casting that feels cool on the exterior may be considerably warmer on the interior. If subjected to cold water, the exterior will contract around the interior, which will not be able to yield, and the piece may crack.

Figure 13