

BASIC LOST WAX KILNCASTING



Jim Weiler, *Bullseye Bull*.
Lost wax kilncast glass.

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 Klaus Moje Center for Research and Education (Bullseye’s R&E 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.

MATERIALS NEEDED

Glass

Bullseye billets, sheet, or frit

Wax Model

Victory Brown Wax (007064), microcrystalline, paraffin, or beeswax model, preferably hollow

Other

- Rigid plastic sheet, roughly 45.7 x 45.7cm
- Flexible metal rib, available from a ceramics supply store
- Cheap paintbrush
- Bullseye casting investment (1 part 295 mesh silica flour; 1 part #1 Casting Plaster)(008244)
- Bullseye Grog (008770)
- Black plastic investment-mixing buckets
- Lined plastic trashcan
- Bucket of water for initial clean up
- Bucket of water to rinse
- Hairspray
- Wallpaper steamer with steam paddle removed for steaming out wax
- Stand for elevating mold while steaming
- Gloves for handling hot mold
- Metric scale
- Unglazed Italian terra cotta flowerpot with a hole in the bottom (optional)



Figure 1

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.

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 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.² 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 R&E 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.



Figure 2



Figure 3



Figure 4

The second layer of the mold is called the jacket coat. Its purpose is to give the mold strength. The jacket coat is composed of the same ingredients (casting plaster and silica powder) plus a mixture of three different sizes of grog at a ratio of 1 part grog mix to 1 part water to 2 parts investment, by weight.

Measuring Investment Material

To determine the amount of investment you need, calculate the dimensions of a box large enough to hold the wax original. This will overestimate the amount you'll actually need, but it's better to have too much than to run out and have to mix more in a rush.

Our model is comprised of two rectilinear forms, the bull and the reservoir, which are roughly 25 x 7 x 12 cm and 15 x 15 x 12 cm respectively, totaling 4800 cubic cm. Divide the number of cubic cm in half and multiply by 0.64 to get the proper quantity of water required: 1536 grams. Multiply this number by 2 to get the proper amount of investment: 3072 grams. Weigh the investment materials in clean, dry buckets. (Figure 2) Be sure to work in a well-ventilated area and wear a NIOSH-approved respirator.

Mixing Investment Material

Steadily sift the investment material into the water. An island of dry material will begin to form once most of the material has been added to the water. Let the investment sit in the water until it is fully hydrated/saturated. Left alone, the investment can sit for quite some time without beginning to set up. After the material has become saturated, break up any chunks by hand. The material should have a creamy consistency.³ It can then be mixed by hand for 3–5 minutes or with an electric mixer/drill for 1–2 minutes. This mixing will cause the plaster to begin to set.

Applying the Face Coat

Drizzle a thin coating of investment over the wax model and use a paintbrush to pop surface bubbles and work the investment into fine details in the wax. (Figure 3)

After the model has a thin coating over the entire surface, thoroughly clean the brush. This short break will allow the investment to become more viscous as it begins to set.

Building up the first coat to the desired thickness becomes easier as the investment grows more viscous.

Using a flexible metal rib, lift any investment from the work surface back onto the model. Build the face coat out to the line drawn around the base of the wax model. This ensures a thickness of 15 mm. When the investment has become extremely viscous, the first coat should be finished with a rough or toothy texture to which the next layer can readily adhere. (Figure 4) Ideally, the jacket coat is applied soon after the face coat has set. But before mixing up the jacket coat, it is critical to clean the buckets and tools used for making the face coat.

Cleaning Up

The investment buckets and tools and the mold maker's hands should be thoroughly cleaned before the plaster sets and becomes more difficult to remove. Residual plaster on hands and tools will cause subsequent batches of investment to set much more quickly, making it too viscous to capture fine detail. (Tip: black mixing buckets show residual plaster well.) Investment material is never poured into a normal sink, as it will set and clog the pipes. Instead, left-over investment is poured/scooped into a trashcan with a plastic liner. Then two cleaning buckets filled with water are used to clean everything. The first bucket is for scrubbing hands, tools, and buckets completely clean and free of investment. The second bucket is for rinsing them. When these buckets become too filled with waste investment, they are allowed to settle; then the excess water is poured off and the waste investment can be collected in plastic garbage bags.

Mixing Jacket Coat Material

You'll follow the same basic steps as for the first layer of investment, except this coat includes a mixture of ceramic grog for added strength. (See Mold Material / Investment

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.



Figure 5

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 attending to surface detail is no longer necessary. 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)

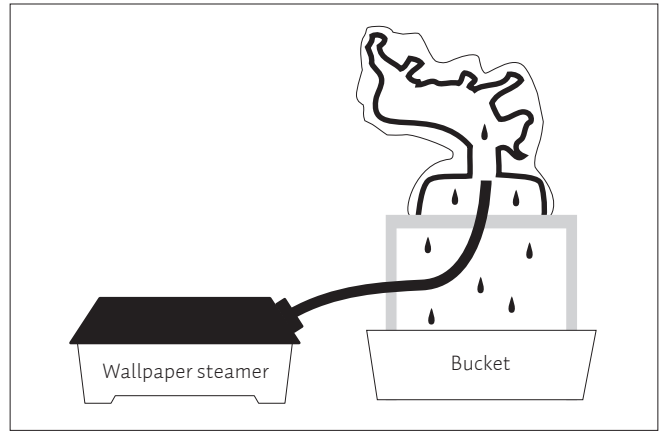


Figure 6

Fill a container with clean water to a level higher than needed to fill the mold cavity to the desired level.⁴ Weigh the water and record the weight in grams, then pour water into the mold until it reaches the level of the final casting (and then drain this water into a separate bucket or sink). Weigh the water container again and calculate the difference. The result is the amount of water needed (in grams) to fill the mold to the desired level. To translate the amount of water into glass, multiply this number by 2.5 (the specific gravity of Bullseye glass). The resulting number is how much glass you will need to fill the mold. Write this number in pencil on the lip of the mold reservoir as a reminder.

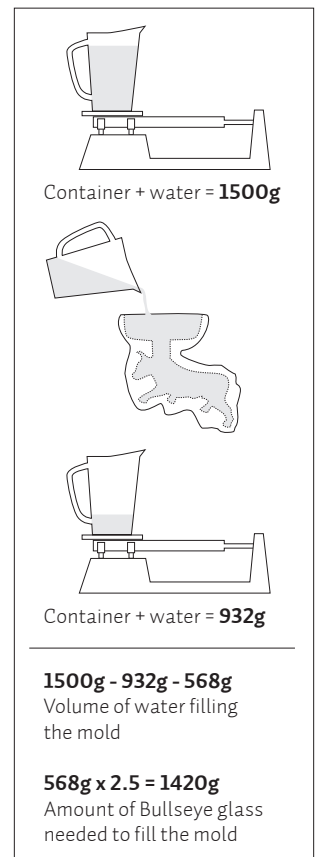


Figure 7

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.



Figure 8

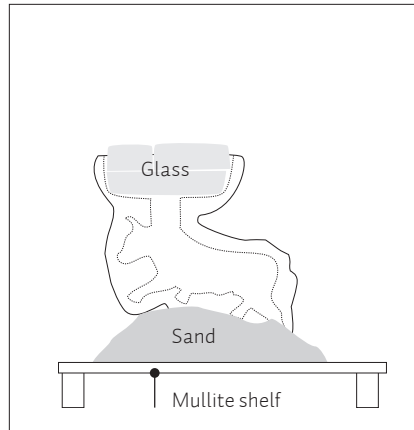


Figure 9

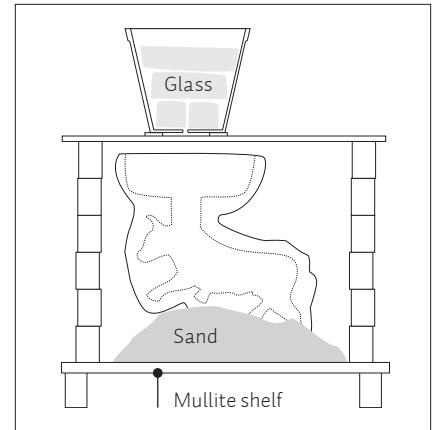


Figure 10

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 trap large numbers of air bubbles—so many 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 an ideal, affordable crucible.⁵ 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. A portion of glass will inevitably 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

5. Mexican terra cotta flowerpots have repeatedly failed when used for this purpose and are not recommended.

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 task 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 and potentially fail when the glass is flowing and exerting outward pressure on the mold wall. Boiling also seems to degrade the mold in general, producing a rougher surface in the finished casting. 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 through 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 task occurs 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 reaction 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 any unwanted visible 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

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

* 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.

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 jagged edges that can result from glass hanging up as it flows into the mold from 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 CLR⁶ breaks down residual investment material.

6. Calcium Lime Rust, commonly known as CLR, is a household product used for dissolving calcium, lime, and iron oxide deposits.



Figure 11



Figure 12

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

