

BASIC LOST WAX KILNCASTING

For Bullseye Glass



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

WHAT IS LOST WAX KILNCASTING?

Lost wax kilncasting involves creating a refractory mold around a wax model and then removing the wax to create a cavity. The mold and the amount of glass needed to fill the cavity are then placed in a room-temperature kiln and heated to temperatures at which the glass will flow into and fill the cavity. The mold and glass are then brought back down to room temperature in a controlled manner.

WHAT IS THIS TIPSHEET GOING TO TELL YOU?

This TipSheet will illustrate how to make a fully sculptural cast glass object using the lost wax process. You will see how to make a two-layer refractory mold of a wax original, safely steam the wax out, calculate the correct amount of glass needed to fill the mold, cure the mold to ensure better performance, and fire the mold and glass in such a manner to prevent the mold from cracking and/or sticking to the glass. In addition, you will learn how to remove the mold material without damaging the glass.

MEASUREMENT NOTES

All measurements of length, weight, and volume in this TipSheet are expressed in the metric system, which is superior for laboratory work. In measuring volume, 1 cubic centimeter (cm^3) of water = 1 milliliter (ml) of water = 1 gram (g) of water. The interior of a container measuring $20 \times 20 \times 2.5\text{cm}$ has a volume of $1000\text{cm}^3 = 1000\text{ml}$ of water = 1000g of water.

THE WAX MODEL

The wax model may be a fully three-dimensional object with undercuts. Ideally, this model is not made of solid wax, but rather is hollow and thus much easier

to remove from the mold and less likely to mar or break down the mold. To illustrate this TipSheet, we made a wax model of a bull. We attached a funnel made of wax to the top of the bull's back. This funnel was at the bottom of the mold during the mold making process, but in the kilncasting process, it became a reservoir at the top of the mold into which we loaded the glass necessary to fill the bull-shaped cavity. (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, they are hand-built in two or more layers: a face coat and one or more jacket coats. Our multilayered mold is light in weight with uniform wall thickness around the entire object, which allows for uniform transfer of heat through the mold wall. Multiple layers also create redundancy in the mold such that if one layer cracks or fails, there is an intact layer immediately adjacent to it. In contrast, a monolithic mold is rarely of uniform wall thickness and requires more material and introduces more water into the kiln. If such a mold cracks it is more likely to fail completely, allowing glass to flow out of the mold and into the kiln.

MATERIALS NEEDED

Glass: Bullseye billets, sheet, or frit

Wax Model: Victory Brown, 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)
- Grog mix (equal parts fine, medium, and coarse)
- 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

BUILDING THE MOLD

Preparing the Area

The mold making process involves many steps and is most cleanly and efficiently executed in a well-organized and prepared space. The area for weighing the dry materials should have good ventilation, and the person making the molds should be wearing a NIOSH approved respirator for filtering particulates. After reading through this TipSheet to gain perspective on the process, the necessary tools you will be using should be gathered.

The wax model is affixed to a clean, rigid, plastic sheet and a line is drawn around it at a distance of 13–19mm away from the base. (Figure 1) This line will serve as a guide in making the first layer of the mold, which will be 13–19mm thick. A light coating of hairspray can be applied to the wax to help the mold material adhere to its surface.

Mold Material/Investment Recipes

Kilncasting, and specifically mold making, are practiced in many different ways around the world. There is no one right way to make a mold or one correct mold recipe (often called “investment”), but in general all investment molds for kilncasting are 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 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, that can withstand high temperature. 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 in three different sizes (roughly 50, 60, and 100 mesh in equal parts) to increase the strength of the outer layer(s) of hand-built molds.

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 also compensates for the shrinkage of the plaster during firing. It expands while the plaster shrinks.

The following recipes have been used successfully in the Bullseye Research & Education studios for a number of years on a wide variety of cast objects.

The first layer of the mold, or face coat, is composed of a mixture of 50% #1 Casting Plaster and 50% 295 mesh silica flour, by weight. These ingredients are mixed with 70°F/21°C water at a ratio of 1 part water to 1.75 parts investment, by weight. The primary purpose of this layer is to pick up as much detail from the wax model as possible.

The second layer, or jacket coat, is composed of the same basic ingredients plus a mixture of three different sizes of grog at a ratio of 1 part grog mix to 1 part water to 1.75 parts investment, by weight. Whereas the first layer of the mold primarily records the fine detail of the model, the jacket coat gives the mold strength.

Measuring Investment Material

Measure the wax original and overestimate its size; it is better to make more investment than you'll actually need than to run out and have to quickly mix more material. Our model is comprised of two rectilinear forms, the bull and the reservoir, which are roughly 25 x 7 x 12cm and 15 x 15 x 12cm respectively, totaling 4800 cubic cm. Divide the number of cubic cm in half and multiply by 0.63987 to get the proper quantity of water required: 1535.69 grams of water for our model. Multiply this number by 1.75 to get the proper amount of investment: 2687.46 grams of investment for our model. Weigh the investment materials in clean, dry buckets. (Figure 2) Remember to work in a well-ventilated area and wear a NIOSH approved respirator when working with powdered materials.

Mixing Investment Material

The investment material should be steadily sifted into the water. An island of dry material will often begin to form once most of the material has been added to the water. The investment should be allowed to sit in the water until it is fully hydrated/saturated (two minutes minimum). If left alone, the investment can sit for quite some time without beginning to set up. After the material has become saturated, any chunks should be broken up by hand so that the material has 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, which will cause the plaster to begin to work or set.



Figure 2



Figure 3



Figure 4



Figure 5

Applying the Face Coat

The mixed investment is drizzled or scooped onto the top of the wax model, and a cheap paintbrush is used to pop surface bubbles and break the surface tension of the mold material while working it into fine detail in the wax. (Figure 3)

After the model has a thin coating over the entire surface (6mm minimum, 12mm maximum), the brush can be thoroughly cleaned. 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. The flexible metal rib is an ideal tool for lifting investment that has run off of the model and onto the work surface back onto the model. This first coat should be built out to the line that was drawn around the base of the wax model to ensure the correct thickness of 13–19mm. 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.

³ Plaster has a shelf life after which point it may be less effective. If there are hard, sharp chunks in the investment recipe after it has been added to the water, it is quite likely the plaster has been previously exposed to moisture and may not be viable for mold making. It should be discarded and the investment remade with fresh plaster.

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

The same steps are followed as for the first layer of investment, except this coat includes a fired ceramic grog mixture for added strength. (See Mold Material/Investment Recipes, page 2.) The grog is blended into the dry plaster/silica mixture before sifting into the water. When sifting in the material for this layer, 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. This layer should be built up until it covers the first layer by roughly 13–19mm all around. The surface is finished by smoothing with the flexible metal rib, making the mold easier to handle and less likely to break. (Figure 5) Cleanup should proceed as before.

Loosening/Removing the Wax

Once the mold has been built, the wax needs to be removed to leave a cavity into which the glass can be

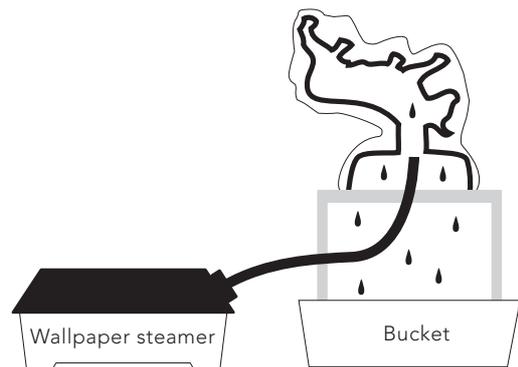


Figure 6

cast. Wait at least one hour after completing the jacket coat of the mold before removing the wax. In casting metal, wax is often burned out of the mold in an outdoor kiln, which causes the wax to volatilize, produce carcinogenic smoke and toxins, and be driven into the mold—where it would affect the surface if used for casting glass. For kilncasting glass, we recommend steaming the wax out of the mold using a wallpaper steamer. The mold is elevated 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, allows wax to drip freely, and allows us to view the inside of 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 cause wax to be driven into the investment. When no more wax runs out of the mold, the mold can be removed from the stand and flushed with water. Care should be taken as the mold may have become quite hot.

Measuring the Mold Cavity Volume

Once the wax has been removed, the volume of the mold cavity should be measured before the mold is cured.⁴ (Figure 7) A container is filled with clean water to a level higher than needed to fill the mold cavity to the desired level. The water is weighed on a gram scale and the weight recorded. Water is poured into the

⁴ At Bullseye we typically plan to fill the mold in a fashion that the mold reservoir will be the thickest area of the casting. We have observed that this helps reduce the incidence of suckers, areas in which it appears that glass has taken on detail from the mold and then contracted away from it, forming depressions in the final object that were not present in the wax model. Suckers usually form in the area of the glass that remains the hottest for the longest during the cooling cycle, which becomes 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.

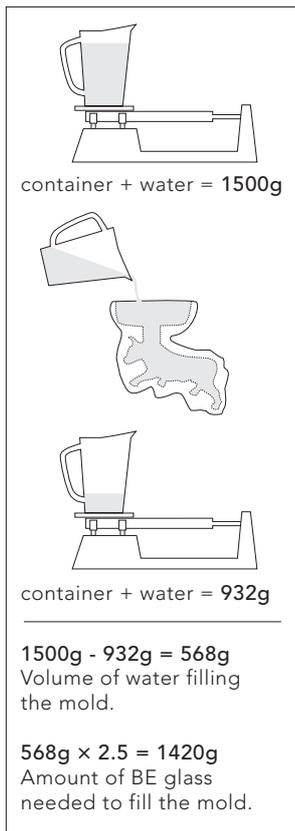


Figure 7



Figure 8

conditions. We have observed that this practice often results in a finished casting with an extremely lucid surface. It is better to load pre-dried molds into the kiln because firing wet molds releases a lot of water that will attack/rust the structure of the kiln and deposit contaminants on the glass. When there is not sufficient time to dry the mold before loading it into the kiln, the drying step is incorporated into the firing program.

SELECTING THE GLASS

Any form of Bullseye glass (billet, cullet, sheet, frit, etc.) may be used to fill the mold, but the form selected will have a direct impact on the clarity of the casting.

mold until it reaches the desired level, and then is poured out into a bucket or sink. The container of remaining water is then weighed again and the difference in weight is calculated. The resulting calculation is the amount of water needed to fill the mold to the desired level. To translate the amount of water into glass, this number is multiplied by 2.5, the specific gravity for Bullseye glass. This final number is written in pencil on the lip of the mold reservoir as a reminder of how much glass will be needed to fill the mold.

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 in a mold dryer or ambient conditions.

When smaller forms of glass are used, they will trap more air bubbles in the finished piece, resulting in less clarity. Powders and fine frits create so many bubbles that even our Crystal Clear 001401 will appear milky white and opalescent when cast in those forms. Billets, on the other hand, trap many fewer air bubbles and therefore 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 3-6mm. Many of these colors, when used at full strength in thicker works, appear very dark; others, such as 001120, 001122 and 001125, may opalize during the longer hold times at higher temperatures required for kilncasting.

Our 001800 series of casting tints was developed precisely to create colors that would be of lighter saturation and greater stability at these thicknesses and temperatures. Likewise our standard palette can be used to tint 001101 Clear as described in our product sheet, *Frit Tinting*.

FIRING THE MOLD AND GLASS

Loading the Kiln

To aid in even heating and cooling, the mold is fired on 15mm thick mullite shelf that is elevated on 50mm posts. The mold is stabilized and leveled by nesting it in a mound of sand on the shelf. Torpedo levels are placed along the top of the mold and it is adjusted until level, at which point it is ready to be loaded with glass. (Figure 9) The height of some kilns makes it difficult to load the mold with glass once it is in the kiln. In that case the mold is loaded with glass outside the kiln and then the mold and glass are placed in the kiln together and leveled. The glass should be thoroughly cleaned before loading.

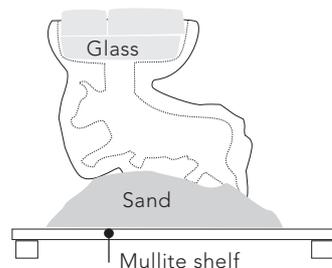


Figure 9

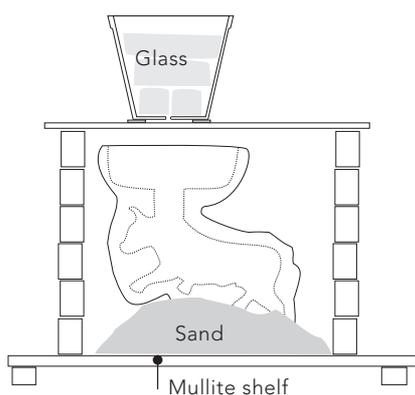


Figure 10

An alternative to loading glass directly into the mold is to load it into a crucible above the mold. (Figure 10) An unglazed Italian terra cotta flowerpot makes an ideal, affordable crucible.⁵ Before loading the pot with glass, the hole in the bottom is enlarged to about 16mm and filed to remove small shards that could flow into the casting, and the pot is wiped with a damp cloth to remove dust. If a crucible is used, an additional 10% should be added to the total weight of glass to account for material that will stick to the crucible.

The advantage of loading the glass into a crucible is that it will not be in contact with the mold during the heating process, when water vapor, which might carry contaminants, will be leaving the mold. Such contaminants can cause the glass to haze, can seed devitrification, and/or can change the surface tension of the glass and make it flow more slowly. Furthermore, glass is heavy and may have sharp edges. Loading it directly into a mold (especially if freshly made) can damage details and break off small pieces of mold material that may 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 topic of the firing cycle as it relates to the glass and kiln conditions is covered in depth in *TechNotes 4: Heat and Glass*. One area not fully addressed there, however, is the issue of adding glass to a hot mold, or charging, which is sometimes necessary if it has not been possible to load all of the glass needed for the casting at the beginning of the firing. The primary concern here is that certain glasses, such as 001824 and other gold-bearing glasses, if heated too rapidly, will develop a sapphirine quality instead of their intended color. If such glasses are to be charged into the mold, they should be preheated to 1250°F/677°C in a separate kiln 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. Remove interstitial water, which occurs from room temp to 212°F/100°C. During this phase of the firing we are trying to drive water out of the mold without boiling it. Boiling the water may create small fractures throughout the mold and subsequently cause it to fail at temperatures at which the glass is flowing and exerting outward pressure on the mold wall. To avoid boiling the water we hold at 200°F/93°C, below the boiling point, until we are confident that we have removed all of the interstitial or free water from the mold. The kiln should be vented during this phase (and until 1100°F/593°C) to make certain that water vapor can easily escape the kiln and will not attack the frame (causing rust) or deposit contaminants on the glass.
2. Remove chemical water 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 this water, fire at a slow rate of 100°F/55°C per hour from 200°F/93°C to 1250°F/677°C.
3. Heat evenly through "Quartz Inversion," which 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 or else strain can develop that results in the mold cracking. Fire as suggested above at a slow rate of 100°F/55°C per hour to achieve the necessary uniform heating.

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

4. Fire to a low process temperature. The plaster loses much of its integrity after 1100°F/593°C, and therefore the mold becomes progressively weaker as it is fired hotter. Furthermore, 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 than firing at temperatures below this point. The reason: the hotter the mold and the glass are fired, the more they will react with one another, which can cause the surface tension of the glass to change/increase.

Timing the firing

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

1. At 1100°F/593°C, to close the vents. Up to this point the vents will need to be open to allow various forms of water and organic materials burning out of the mold to exit the kiln. After this point all water and burned-out materials should have left the kiln, and vents should be closed for better efficiency.
2. At 1250°F/677°C, to confirm that mold(s) are stable, not rupturing/cracking. Open the kiln enough to take a quick look; then close it and think about what

you've seen (as opposed to holding the door open for a long period of time, which could thermal shock and crack the mold). Check the mold several times at this temperature. If it is stable/un-cracked and remains so throughout the hold at this temperature, it is safe to proceed to the casting/process temperature. If the mold is cracking, it may fail at process/casting temperature, and you may consider aborting the firing at this point.

3. At process temperature, to 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 into the bottom of the kiln, potentially damaging or destroying it. As above, you should 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, or will not compromise the piece.

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" will be whatever cooling rate results from the kiln power being cut by the controller. We do not advocate crash cooling. Leave your kiln closed, allowing it to cool naturally.

*** 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.



Figure 11



Figure 12



Figure 13

Divesting and Cleaning the Glass

We recommend leaving the piece in the kiln at room temperature for at least a day (once the entire firing cycle is complete) before taking it out to divest it.

After firing, the mold will be considerably weaker than it was at the beginning of the firing and no longer structurally sound, so it must be removed from the kiln carefully. Gloves are recommended while handling the fired mold and divesting the casting, which may have sharp areas, and an approved dust mask or respirator should be worn. Ideally, the casting is divested in an area with local ventilation, as many of the finer dusts generated may remain airborne for hours.

The investment can be removed from the glass with a variety of tools, such as dental instruments, wooden picks, nylon brushes, and wood carving tools. (Figure 11) Wooden tools are ideal for carefully removing broad areas of investment, and metal tools should be used delicately to clean fine details. 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 the investment material.

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. While this document cannot begin to address the myriad of possibilities presented by coldworking, it can provide these important words of caution: the casting should be at room temperature for a day before any coldworking is attempted. This is because a casting that feels cool on the exterior may be considerably warmer on the interior. If subjected to cold water, the exterior will try to contract around the interior, which will not be able to yield, and the piece may crack.

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