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Kiln casting: What can go wrong and how to fix it?

A visual journey through the kiln casting process, Brachlow presents her making methods from initial model to finished glass sculpture. The second section of this lecture focuses on problem solving: It's cracked – what went wrong? How can bubbles on the edges be avoided? Why did my mould break?

Introduction to Heike Brachlow's work, inspiration and process.

Figure 1: Heike Brachlow in her studio, 2016, photo by Roger Lee

Figure 2: Heike Brachlow, Apagogue 2016, photo by Ester Segarra

My current body of work is based on a concept called D-form, a three-dimensional form created by joining the edges of two flat shapes with the same perimeter length. Results are wildly different depending on at which point the shapes are joined. I have been exploring these shapes since 2015; they have been changing slowly, elongating, thinning. I aim at a colour fade from almost black in the more solid parts to almost nothing along the edges; polished surfaces let the light in and matt surfaces capture and diffuse it. The initial model is made from polypropylene sheet material. From this, a 3-part plaster mould is made, to be able to cast multiple waxes. The wax model is cleaned and bubbles and deviations in the form are filled with warm, soft wax. Next, a three-layer refractory mould is made. I use Crystalcast, a British readymade refractory material, for the first two layers, and Wrightcast LC16AC refractory cement, mixed with 20% plaster, for the outer layer. After one or two days, the wax is steamed out, the mould volumised with water, and left to dry. I pre-fire my moulds in the kiln to 428ºF (220ºC) for about 12 hours, then blow out the moulds with compressed air, place large terracotta flower pots filled with slightly more glass than necessary on top of kiln-washed shelf strips on top of one of the mould openings, and program the kiln with a time delay so I can check at top temperature. I try to pull off the flower pots when the mould is full, but before it runs over too much, trying to prevent all glass from the pot running into the mould as the last bit often contains a devitrification or colour trails. When the kiln has completed its process hold at top temperature, I place fibre blanket on top of the mould to encourage even cooling.

After the glass is annealed and completely cooled, the outer mould is chiselled off, and the softer inner mould removed. The sprues are cut off with a brick saw with continuous rim diamond blade, and the whole shape is ground and polished with a water fed angle grinder. Only the matt surfaces are hand-rubbed after having been finished to 400 grit with the angle grinder. I can make 1-2 pieces per month, depending on size, and sometimes, everything works perfectly. Quite often, it doesn't…

Problem solving (What can go wrong and how can it be fixed?)

"I have not failed. I've just found 10,000 ways that won't work."

Thomas Edison

Kiln casting is a long and complicated process, with lots of potential for things going wrong. This section looks at a series of problems, along with preventative measures and/or remedies. There are many approaches to all aspects of kiln casting, and many problems and solutions. Here are some of mine:

Wax

Lots can go wrong when working with waxes. Cooling lines in the wax, bubbles and divots can all be fixed fairly easily (although maybe not speedily). The following issue is fatal if it occurs and needs to be addressed during mould making. When using clay as a reservoir for making a mould of a delicate wax, great care should be taken that all the clay is removed either before or while steaming out the wax. The mould needs to stay upside down until the removal of clay is complete, because if a small bit of clay falls into the mould and lodges in a delicate connection or thin part of the shape, it is likely to crack the glass.

Mould

Mould material failure

My moulds for wax are mostly 3-part plaster moulds – I rarely make silicone moulds because of time and expense. The main disadvantage of plaster moulds is that they deteriorate relatively quickly. My moulds often warp slightly, causing wax to leak our, and sometimes break. Wax leaks can easily be contained by using clay to seal the seams. I have had a large plaster mould break into seven pieces, but I urgently needed another wax from it. With a combination of clay to seal the gaps and duct tape, packing tape and tie-down straps to hold it together I managed to pour a reasonable wax model.

Figure 3: Broken plaster mould for wax, 2018, photo by artist

Figure 4: Broken plaster mould repair, 2018, photo by artist

Moulds for glass made from just plaster and silica are often not very strong at high temperatures. This can lead to mould failure, especially when scaling up or using unfamiliar materials, for example while doing residencies in other countries.

Possible fixes include changing the ratio of plaster to silica, with more silica making the mould stronger at high temperatures, but also softer at room temperature; changing the water to powder ratio (more powder means stronger), and adding fiberglass needles or inert materials with different particle sizes into the outer layer(s), such as grog, sand or perlite. An outside layer of refractory cement mixed with approximately 20% plaster is very effective, especially for larger moulds.

Alternatively, a good commercial mould mix such as Crystalcast from Goodwin Refractory Services can be used. Crystalcast is extremely strong if poured with an appropriate wall thickness. Wall thickness depends on the size of the model and the weight of glass.

Poorly made mould

Hand building generally results in a stronger mould than pouring (except when a commercial mould mix such as Crystalcast is used), and gives the opportunity to add grog or sand into the outer layer. The mould should be of even thickness, which can be difficult to achieve over sharp corners. When hand-building a mould, I always identify the areas I need to focus on, and make sure I add lots of material to the problem areas. Commercial mould mixes such as Crystalcast generally work better for poured moulds. However, I do use Crystalcast for hand building, but add an outer layer of refractory cement for strength.

Firing

Setting up

When setting up for firing, moulds should not be touching each other. They should be levelled, if necessary on a bed of sand. If glass is stacked directly into the mould, it should not protrude too much to avoid the glass slumping and landing outside of the mould. Shelf strips coated in shelf primer/kiln wash can be arranged on top of the mould to contain and guide the glass.

When terracotta flower pots are used as reservoirs, they need to sit above the mould. Placing the flower pot straight on the mould can cause problems – if the mould fills with glass to the top, and the glass touches the terracotta, it will crack (the glass, not the pot). Normally, I use kiln shelf strips to support the reservoir on top of the mould. I prime these with shelf primer to prevent the glass from sticking.

For large moulds, I sometimes suspend the reservoir with kiln furniture or bricks above the mould, rather then place it straight on top.

Issues relating to the firing cycle

Mould temperature

During the ramp up to process temperature, a hold at approximately 1250ºF (680ºC) can be incorporated to even out the temperature throughout kiln, mould and glass. This serves the dual purposes of gently slumping the glass (bubble squeeze) and avoiding cold spots within the mould, which could cause the glass pouring into the mould from the reservoir to become more viscous on contact, which may, in extreme cases, cause the mould to overflow.

Uneven shrinkage

When glass cools, it shrinks. If it cools too quickly through its liquid-to-solid transformation, the exterior of the glass will solidify first, while the interior is still hotter and liquid. When the interior solidifies, it needs to shrink, but is stopped by the outer solid shell. This results in small or larger craters in the surface, similar to bubbles in appearance, but retaining the mould surface on the inside.

Avoiding uneven shrinkage ("suckers")

These shrink pockets are called "suckers" (technical term for uneven shrinkage). This can easily be avoided by evening out the temperature during the transformation from liquid to solid, essentially pre-annealing the glass. I add a hold at 150-180ºC (300-350ºF) above annealing temperature (at 1200ºF (650ºC) for Bullseye and most other soda-lime glasses), then ramp slowly to annealing temperature. The hold time and ramp depend on the shape and size of the piece – it should be long enough to even out the temperature within the glass. For my current work, I hold for approximately 6 to 8 hours and ramp at about 4-8ºC (7-14ºF) per hour. For very large moulds it may be necessary to go slower and/or have several soaks on the way down.

Shape induced stress

Another issue can arise from shrinkage during the cooling, in the form of shape-induced stress. If the object to be cast has sharp angles, and the glass is fairly thin, it might not be possible to cast, unless some adjustments are made, such as adding more glass (thickness) to problem areas. This can be ground off after annealing to achieve the intended form. To reduce shape-induced stress, follow the firing instructions for uneven shrinkage, described above. In the case of shrinkage around a refractory core, it is highly advisable to weaken the core, to make it softer. This can be done by adding modifiers to the mould mix, such as diatomaceous earth, sawdust, paper pulp, or similar. The mould mix can be made weaker by adding more water or less powder, or by mechanically weakening the mould after it has set, for example by cutting slots into a hollow core from the inside. It is better to plan for a hollow core rather than a solid one, to aid even cooling.

Annealing

Having already discussed uneven shrinkage and shape induced stress, I just want to add a few words on annealing.

Glass as a substance is very slow to transfer heat. It is important to keep the mass of glass even in temperature as it passes through the annealing range to avoid stress being created in the glass. In thicker glass, the transfer of heat is slower, and therefore the cooling needs to be slower.

While it is hard to find instructions on a complete firing program, we all know about and use annealing charts. However, have you ever read the small print on an annealing chart? It says something like “these charts have been based on a flat slab of uniform thickness which is set up so it can cool equally from all sides. If your work is not set up in such a way, please select an annealing cycle for twice the thickness of your piece”. I don’t quite do this, but I do anneal on the cautious side.

For large works, I normally cover the top of my mould with fiber blanket to facilitate a more even cooling. I usually open the kiln after the process hold, when it is on its way down, between 1500º and 1300ºF (815º - 700ºC), to remove the flower pots and add the fiber blanket.

Bubbles

It is fairly difficult to kiln cast a form without any bubbles. While most kiln casters like bubbles – they add liveliness and interest - there are areas where bubbles are not welcome. On edges and high points, a burst bubble can give a frayed appearance.

To control bubbles, one needs to know or guess where the bubbles will be. Bubbles will rise during the process soak at top temperature, taking the path of least resistance. If the mould is open-faced, bubbles will sit on the surface and eventually burst and vanish. If it is a closed mould, bubbles will sit against the inner mould surface at the highest point they can reach. I always think about bubble behavior when choosing a point for the sprue, where the glass enters. I have found that a symmetrical setup works better than an asymmetrical set up.

If I think bubbles may be caught against the mould on an edge or high point, I add wax fins to the model, so bubbles rise into the fins, which can be ground off the glass form as part of the cold working process.

Figure 5: added wax fins to catch bubbles, 2016, photo by artist

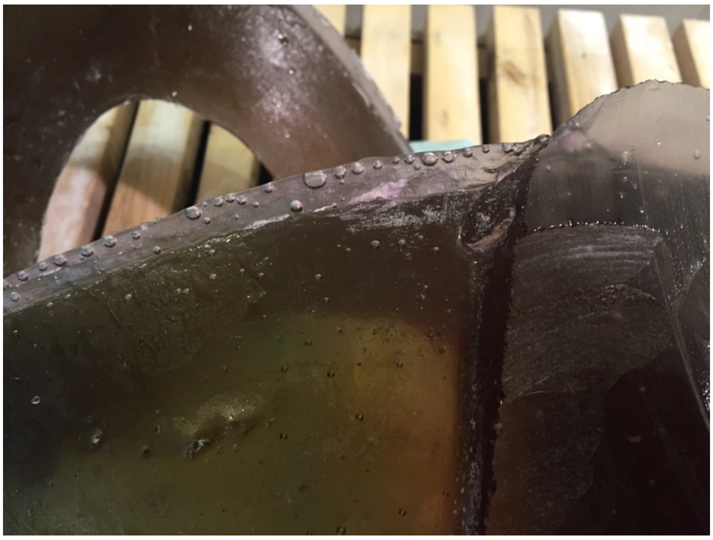

Figure 6: Bubbles caught in added fin, 2016, photo by artist

A lot of the failures discussed above are mine, but I have also borrowed some from students and colleagues (thank you!). Many thanks to Richard Whiteley, for generously sharing his research on firing and annealing. And thanks to GAS, for the invitation to give a LecMo!