

LOST-WAX CASTING GLASS

An introduction

by Shelley Doolan

Modelling

There are many, many materials from which models can be created, they can be made by you or they can be 'found' objects (natural or man-made).

Depending on the material used for your model and its shape, you can either make the refractory¹ mould directly from the model or, for more complex shapes, use extra processes such as making a rubber mould of your form from which wax replicas can be created.

When learning the casting process, start simple and create a model using a material from which you can make a direct refractory mould.

Modelling materials suitable for direct refractory mould making

Clay

Clay is relatively cheap, re-usable and versatile and is a good material to start with. It is good for fine detail work and can be removed easily from the mould. Keep the clay wet, if it becomes leather hard it is more difficult to remove it from the mould.

When your refractory plaster mould has set (this will be explained later), the clay can be carefully picked out of the mould, and the cavity washed with care.

Clay models can have a degree of undercutting but bear in mind that you will have to be able to reach the clay to pick it out of the hard and inflexible mould.

If you do get carried away and model something in clay that has too many undercuts to remove from a refractory plaster mould, you can still use it, but it will involve more work and processes such as creating a flexible rubber mould and wax replica (this will be explained later).

¹ In this context, refractory refers to the material's ability to withstand heat.

A note on undercuts

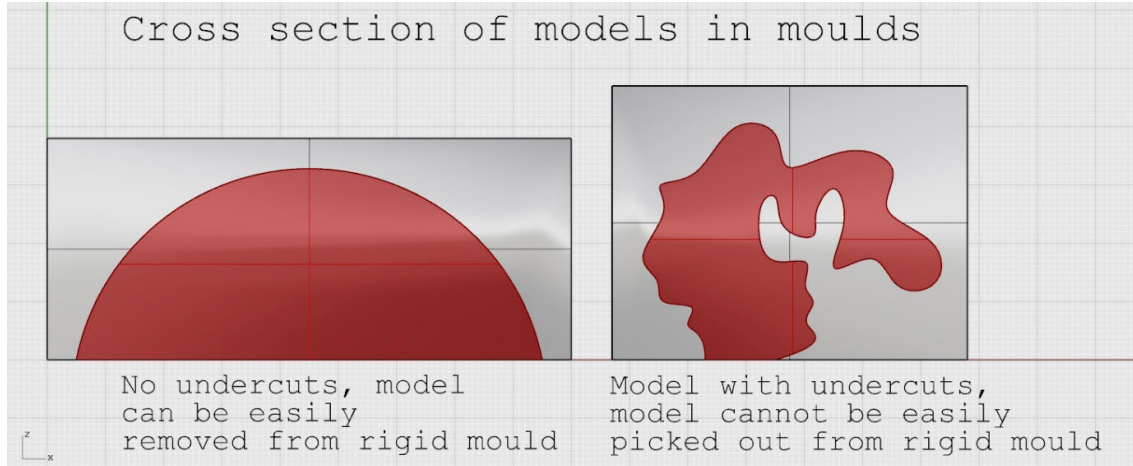


Figure 1. Undercuts

Polystyrene

This is a good material for making large scale models, it can be sculpted with a surform, cut with a hot-wire cutter and joined with a hot glue gun. The disadvantage is the texture of the material. When combined with clay, polystyrene can be used to make the bulk of the model (saving on clay) with clay used for the final finish layer.

The blue foam stocked in the workshop has a denser structure and gives a better finish than standard polystyrene.

Check with your technician for health and safety when working with this material.

Less common options:

Sand: Think sand-castle! Keep it damp so it keeps its shape and pour your refractory material in a corner not directly on the model.

Ice: Artists including Joseph Harrington have made refractory moulds directly from ice...

Organic material: Some artists cast directly from organic material such as fruit and veg, burning it out of the mould to leave a cavity. Please don't do this without consulting your technician!

Wax

Wax is wonderfully versatile, relatively inexpensive and endlessly recyclable. It can be used to create highly intricate models with fine detail and undercuts as the wax is usually steamed out of the mould (so you don't have to be able to reach it to pick it out).

The wax most commonly used is called microcrystalline and is pretty hard. To make it softer and easier to model it is blended with petroleum jelly (aka Vaseline) to approx 10-15% by volume. (Modelling wax is available to buy but it will be more expensive than blending your own). It can be carved and sculpted and can translate very fine detail into the glass – even down to a fingerprint.

As well as modelling by hand, the wax can be melted and poured into a mould. This is a useful way of working if you want multiples. The wax can be poured into rubber moulds (materials such as Gelflex or RTV); sand or clay negatives, or plaster moulds. When pouring into plaster moulds, the plaster must be fully saturated with water otherwise the wax will become stuck to the plaster. The plaster mould must also allow the wax to be removed, i.e. no undercuts.

Notes on working with wax

- Your Technician will advise you on health and safety when working with wax.
- **Wax is flammable** so must not be left unattended while heating it.
- When pouring wax into a rubber mould, it is best to use 100% microcrystalline wax as it will be less prone to marking when removing from the mould.
- The pouring temperature is 70-80°C
- For modelling, the wax can be blended with 10-15% petroleum jelly to make it softer. To do this, melt the wax add the petroleum jelly and mix. Pour it into suitably-sized containers and allow it to cool.
- The specific gravity for microcrystalline wax is in the region of 0.89 but check with the supplier.

Setting up your model to make a refractory mould

Considerations:

Reservoir to hold glass prior to melting

Securing the model

Sprues

Mould making and steaming

Weight of glass needed

Type of glass i.e. lead glass or soda lime glass / format of glass i.e. single billets through to finely crushed frit

Reservoir

In most circumstances, when casting, you will need to use a reservoir to contain the cold, un-melted glass prior to kiln-firing. A common mistake is to underestimate the size of the reservoir needed. The glass must not melt and pour over the top edge of the reservoir as it may damage the kiln and waste materials.

The reservoir can be integral to your mould or it can be made separately and placed on top. There may be times where it is preferable to make a separate reservoir collar, for example on very large scale work where the extra weight would be an issue. Either way, it must be made from refractory material. Usually it is either made from the same refractory plaster mix used for the mould, alternatively unglazed terracotta flower pots can be used.

For small moulds, the simplest way is to make the reservoir integral to the mould. To do this you would place your model on clay or polystyrene of the appropriate size to form the reservoir before pouring the refractory material (as illustrated). It is useful if your reservoir has sloped sides to aid the flow of glass into the mould.

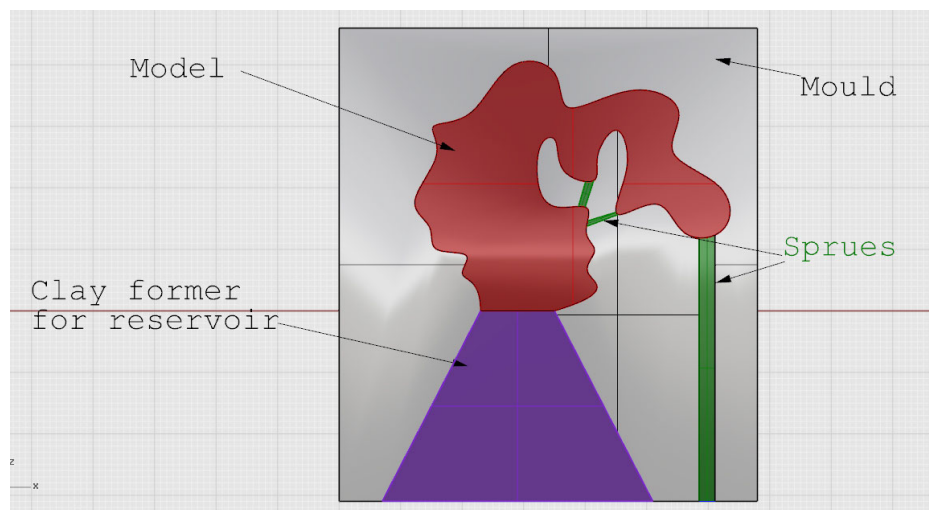


Figure 2. Reservoir and sprues

'Dribble' cast

In this set-up the glass is suspended in a reservoir / crucible (often ceramic flowerpots) above the mould; when molten, the glass flows through the aperture in the base of the pot. This method is useful where the inside of the mould is fragile and you do not wish to have the chunks of glass loaded into the mould prior to firing.

Securing the model to the base board

- Wax is less dense than water – it floats! Make sure it is stuck down to the base board.
- Make sure that no mould mix can get under your model by thoroughly securing it to the board.
- Polystyrene can be glued to the base board.

Sprues

Before making your mould, have a good look at the model. Look at where the entry point for the glass will be and how the glass will flow.

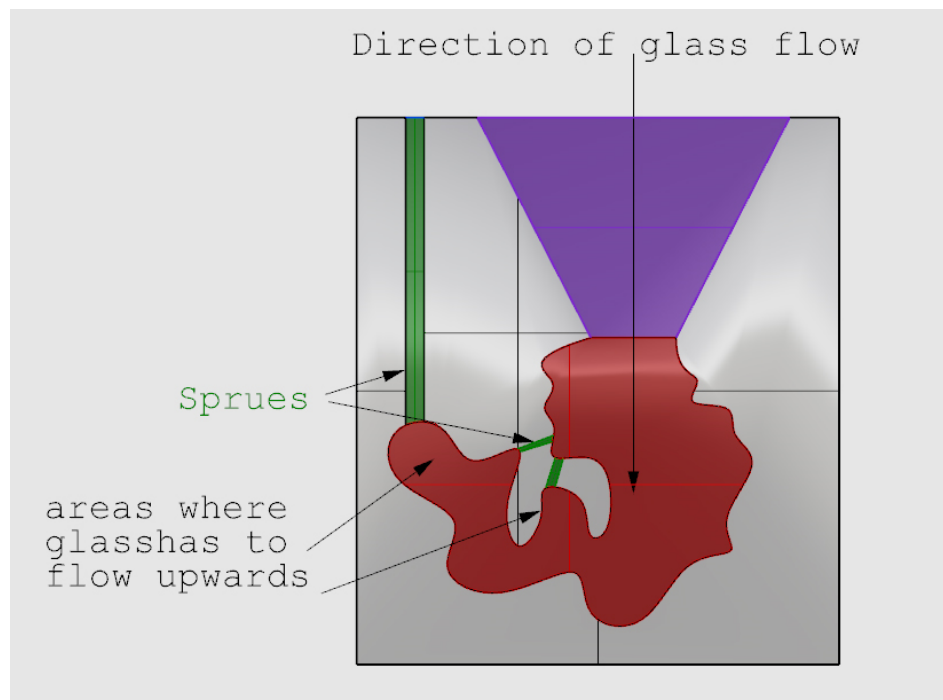


Figure 3. Sprues

Generally given adequate time and heat, casting glass will flow with gravity to reach all parts of the mould. If, as shown in Figure 3 the model has areas where the glass is required to flow upwards, against gravity, sprues should be added to the model. These can be made from sticks of wax which will steam out of the mould along with the model, or from cocktail or bbq skewers which will burn out of the mould. The sprues when steamed or burned out

leave behind a channel in the plaster mould which allows air to escape, enabling the glass to flow upwards unhindered by an air pocket.

Before you start, weigh your wax model and make a note. If possible, take a photograph of the wax model too.

Cottling up

We will be making block moulds. Cottling refers to the container for your mould. The material used must be strong enough and sufficiently well-secured to contain the liquid refractory plaster mould mix whilst it sets. It is a common mistake to underestimate the hydrostatic pressure of mould mix and the need to make sure that your cottling will not fall apart: resulting in a huge plaster mess to clear up. Use clay and if need-be clamps to hold the boards securely.

Where possible, try to create an even wall thickness to your plaster mould. The mould should have a wall thickness in the region of 4-5cm. Don't make the walls too thin, or too thick. Huge mould walls do not stop the mould cracking but waste material and take longer to dry out and adds to the annealing time of the glass in the kiln.

The moulds must be well-made and strong, this is down to the correct ratio of ingredients and the mixing and pouring.

If you're making your mould on melamine or onto glass, the plaster will not stick. If you're working directly on the table, the plaster may stick temporarily to the surface making it difficult to move. (In time it will release). To overcome this, you can brush the table with soft-soap aka mould-makers size.

Refractory mould making for glass casting

The recipe

There are many recipes for mould mixes, some more successful than others. This is a tried and tested recipe used by many professional glass artists. I have used it successfully for moulds weighing in the region of 75Kg.

1 litre of water

700 grams of plaster

700 grams of quartz (or flint)

21 grams of glass fibre chopped strands

- The plaster binds the mix allowing it to set,
- The quartz is the refractory element, preventing the mould from falling apart at high temperatures. There are specific health and safety considerations when working with quartz and flint (your technician will advise) – **always wear a dust mask and handle dry ingredients under extraction**
- The fibre-glass strands add mechanical strength to the mould and also aid the release of moisture by capillary action. They may not be necessary for small moulds.

How much mould mix?

It is good practice to calculate the amount of mould mix you will need to avoid waste and to avoid having to mix up more than one batch.

Measure the volume of the mould box (length x width x height [height to 4-5cm above highest point of model]) in centimetres. Subtract the volume of your model.

The result is the measurement in cubic centimetres. 1000cc = 1 litre. This is the total volume of mould mix needed to fill the void i.e. the water, quartz and plaster.

You need to subtract 30% from this figure. This leaves you with a figure which is the amount of water needed in your mould mix. You need to do this as the recipe is given per litre of water.

Example

If the inside of your mould box measures 10cm x 10cm x 8cm, the volume = 800cc

If the model measures 4cm x 4cm x 5cm, the volume = 80cc

Subtracting the volume of the model from the volume of the mould gives you the volume of mould mix needed

$$800 - 80 = 720\text{cc}$$

Subtract 30% to give you the required litres of water:

$$720 \times 0.7 = 504\text{cc} = 0.504 \text{ litres (round down to } \frac{1}{2} \text{ litre).}$$

So, using the mould-mix recipe:

$\frac{1}{2}$ litre of water

350 g of plaster

350 g of quartz

10.5g of chopped fibre glass strands

Mixing your mould-mix

1. Your technician will advise on health and safety for this process. Wear an apron – it's messy. You **MUST** wear a proper dust mask when exposed to plaster and quartz/flint in their dry form, use extraction if it's available. When mixing and pouring, avoid getting the mix in your eyes, it will sting and burn – wear goggles. If you need help lifting, ask a member of staff. If you have sensitive skin, ask for gloves.
2. Give yourself enough time. Get everything you need together: clean buckets, measuring jugs, weighing scales and materials, dust mask etc.
3. Measure out the volume of water required and pour into a bucket
4. Weigh the correct amount of quartz, plaster and chopped strands in separate containers.
5. For small moulds, mix the dry ingredients together before adding to the water.
6. For large moulds it can be useful to add the quartz to the water first. Quartz is inert i.e. the mix will not start to set. This is of value when you're mixing large quantities.
7. Next add in the plaster. Mix thoroughly, breaking down any lumps. Keep mixing vigorously, then add in the chopped strands, mixing all the time. The strength of your mould will rely on the mould mix having been thoroughly mixed.
8. You will feel the liquid change from a milk through to single cream then double cream consistency. If you leave it too long before pouring, it'll go through to cream cheese and then rock hard stone! You will tune into this change in consistency and come to recognise it. Try to pour the mix when it is a thick double cream.
9. If you pour too early when the mix is still too runny, the mould will be weak as the different ingredients separate
10. **Do not, ever, leave your hands** (or any other body part!) **in a bucket of plaster while it sets**. As plaster sets it undergoes an exothermic reaction (it heats up) and it sets rock hard. It will not end well! It's unlikely I know but in 2007 there was a horrible incident in the art dept. of a school which left a 16-year old with severe injuries. If you want to make a life cast, speak to a member of staff about the safe way to do this.

Steaming wax from your mould

Remove any polystyrene or clay which you may have used as a reservoir. Clean the opening to the mould, making sure there's no loose plaster or residual clay.

Your technician will advise on the safe set-up and use of the steamers. Do not let them run dry.

Be careful to not burn yourself. Wear gloves, cover your arms and wear eye protection.

With complex shapes when it's not possible to see inside the mould it can be hard to tell if you've removed all the wax.

There are a couple of ways to check.

1. Wearing your PPE (gloves and eye/face protection) hold a clean piece of glass under the mould opening while it's steaming. You'll soon see if there's wax still coming out.
2. Take the mould off the steamer and carefully pour in cold water. If wax is still present you will see it floating up in the mould cavity.

Calculating weight of glass needed

Water displacement of mould

- Make sure plaster mould is fully saturated and empty before starting (best done after steaming before drying).
- Pour water into a jug and mark or record the level.
- Pour water from the jug into the mould up to the desired level.
- Mark or record this new level
- The difference between the two is the volume of the mould.
- To work out how much glass, you can *either*:
- Place glass into the jug until the level rises to the first mark; **or**
- Multiply the volume by the specific gravity of glass (3.6 for Gaffer, 2.5 for Bullseye); for example: $100\text{ml} \times 3.6 = 360\text{g}$ of glass needed.
- NOTE: in some instances, you may prefer to have a little extra glass but this will depend upon the type of casting and is a matter of judgement.

Wax weighing method for models

If you have a complex wax model you can calculate volume of glass needed by weighing the wax model.

- Weigh the wax model
- Then divide this by the specific gravity of the wax (0.89) to give you the volume of the model.
- Multiply the volume by the specific gravity of glass (3.6 for Gaffer, 2.5 for Bullseye); for example: 100ml x 3.6 = 360g of glass needed.

Water displacement of model

- Pour water into a jug and mark or record the level.
- Place the model into the jug (if it is wax you will have to stop it floating by lightly touching the top, taking care to not displace water with your fingers).
- Mark or record this new level
- The difference between the two is the volume of the model.

Bullseye's Rice method for displacement if you don't want to re-wet your mould

- Fill your mould with rice to the desired thickness of the casting.
- Then remove the rice and decant it into a container.
- Level the rice, and then mark the level.
- Remove the rice from the container, and weigh the container.
- Then fill the container with water up to the former level of the rice, and weigh it again.
- Subtract the weight of the container to get the weight of the water (the volume of the mould)
- Multiply the volume by the specific gravity of glass (3.6 for Gaffer, 2.5 for Bullseye); for example: 100ml x 3.6 = 360g of glass needed.

Selecting glass type

Using larger chunks / billets of glass will give a clearer cast. Using small glass pieces will create more bubbles in the cast. This effect can be used creatively by controlling the particle size to create a translucent almost opaque quality. Glass cast in this way often has a luminous quality caused by the air that is trapped between the glass particles.

Different glass types have different properties, with some better suited to casting. A lead-based glass such as Gaffer casting crystal (40% lead), is ideal for casting. Soda lime glass that has been formulated for casting, such as Bullseye casting glass also works well. Window (float glass) can be used for some forms but it is generally less suited to casting as it requires

higher casting temperatures and does not 'flow' as readily, it is also prone to devitrification. It can however be used creatively in casting to exploit its tendency to devitrify.

Kiln firing

Initial ramp

The mould has to lose its water content. The kiln is vented during this phase. The temperature is raised typically between 50 and 100°C per hour up to 600°C. At this temperature the plaster loses its chemically bonded water.

If the mould is wet, an extra stage for drying the mould can be used.

Soak

The moulds are held at 600°C to fully remove the water. This depends on the size of the mould, the thickness of its wall and the number of moulds in the kiln etc...

Having lots of moulds in a kiln will increase the humidity and require a longer soak time. At the end of the soak time, the vents in the kiln are closed.

Ramp to top temperature

The rate of climb to top temperature is typically 50 to 100°C per hour.

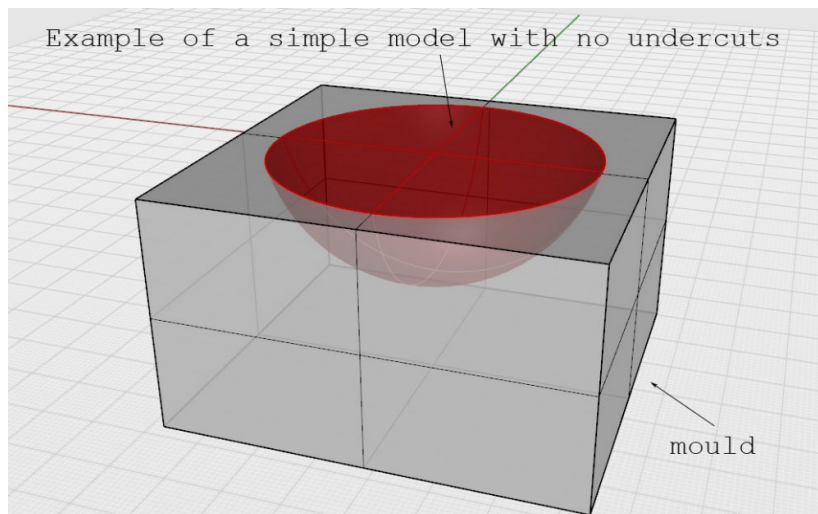
Top temperature

The top temperature depends on a number of factors:

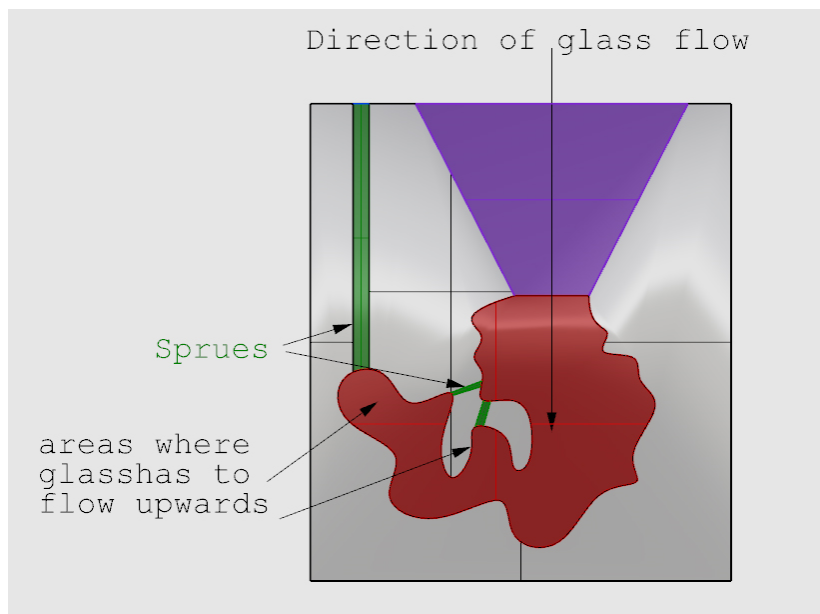
1. Mould thickness and type
2. Glass type
3. Where the elements are in the kiln and their relative position to the moulds
4. Type of casting
5. The complexity of the form

1. Mould thickness and type

In a mould with an open cavity, heat gets to the mould quickly



For a more complex form the heat will take longer to reach the cavity.



2. *Glass types*

There are a number of different types of glass, all of which have different properties and casting temperatures. For example, a lead-based glass will cast at a lower temperature to float or borosilicate glass. The supplier will be able to provide literature to give an indication of the casting temperature range.

3. *Element position*

Ideally the kiln would have all round elements so that the mould gets an even heat. In practice this may not be possible as some kilns have only top elements. The 'ideal' position is central in the kiln to ensure even heating.

4. *Type of casting*

Open / static cast

The glass has less to do, it has to melt and find its own level

In a 'dribble' cast, the glass in the reservoir has to liquefy and fill the mould which may consist of narrow channels. The glass therefore needs to be hotter and less viscous in order to flow into the mould.

5. *Form*

Casting a simple open form will typically require a shorter cycle and a lower temperature than a complex form with lots of undercuts or a very fine, thin form. To fill complex moulds or thin channels the glass has to get hot enough to reduce the viscosity so it will flow to fill the voids.

Cooling

Initial cooling from top temperature is usually done as fast as possible and may include crash cooling by opening the kiln.

ANNEALING

Details of the Annealing and Strain points will be available from the glass manufacturer. I've attached the annealing charts for Gaffer and Bullseye to this document.

Glass has an irregular non-crystalline structure, if it is cooled too fast through the annealing range, the molecules will not settle properly and stress will be introduced into the glass. Stress can cause cracking, either immediately or years later. The majority of stress can and should be released at the annealing point.

Soaking

Therefore, the glass is soaked at the annealing point to equalise the temperature throughout the glass and to allow the molecules to settle. The glass should reach an even temperature throughout its mass; this will take longer depending on the thickness of the glass and the difference in glass thickness throughout the casting.

Controlled cooling to strain point

From the annealing point, the temperature is gradually reduced to the strain point. The idea is to maintain a consistent temperature throughout the body of glass, the rate of cooling will therefore depend on the thickness of the form and difference between thick and thin areas.

Controlled cooling past strain point

The temperature is dropped twice as fast as through the annealing range for 50 to 100°C below the strain point. Below the strain point, a slow cool for a further 100°C prevents thermal shock to the glass.

The glass is then cooled to room temperature at a suitable rate i.e. a large thick piece may require slower cooling to avoid thermal shock.

De-moulding

PPE must be worn when de-moulding. The silica in the mould is harmful and must not be breathed in – your technician will advise. Dispose of the used plaster as requested by your technician.

Take care when de-moulding that the glass is properly cool. Bear in mind that the plaster mould may be insulating the glass so although cold on the outside the glass may be warm inside. If the glass is still warm, avoid getting it wet as this may cause thermal shock. Also watch out for any sharp areas of glass, Kevlar cut-resistant gloves are available from your technician.

The fired plaster can be removed by carefully scraping to reveal the glass. If your object was thin and fragile take extra care...

Finishing

A variety of finishing and cold-working techniques await!

The casting reservoirs and sprues can be removed by grinding or cutting using a diamond saw. Depending on the form, options include using a lathe with water-cooled stone or diamond wheels to grind and smooth the glass; felt wheels for pumice and cerium polishing. For flat surfaces a flat-bed grinder, reciprolap or hand-lapping can be used. Other options include burs on a flexi-drive (similar to a Dremel tool); water-cooled angle grinders....

As well as mechanical finishing options, the glass can be chemically treated. It is possible to acid polish glass. A lead-based glass works particular well with acid. The acid only polishes the glass, so any tidying up or smoothing must be done prior to polishing.

Finishing processes can add a great deal to the work. They can be used creatively to vary the surface finish, adding textures by carving using stone, copper or diamond tools. The transparency can be varied by grinding with different grades of grit or by sand-blasting. Areas of the glass can be masked prior to grinding or blasting to vary the surface across the glass.

A Note on Materials

For health & safety matters ask your Technician...

Wax

The wax most commonly used for lost-wax casting is microcrystalline wax. This wax is non-toxic, and very fluid when melted. The melting point is approximately 71°C. It can be blended with petroleum jelly to make it more malleable for modelling.

Microcrystalline wax has a 'flash point' of approximately 150°C and must not be left unattended.

It is possible to buy ready blended modelling wax which can be useful for modelling. It is useful as a means of bonding wax components together.

There are a number of suppliers including Tiranti who sell small quantities.

When melting wax to pour into a Gelflex mould, avoid over-heating the wax as this may prematurely cause a deterioration of the surface of the mould.

Wax / separator

Wax can be used with plaster moulds. The wax will stick unless the plaster is first saturated with water. Dried plaster slabs or moulds should be first soaked and time allowed for the surface to dry to avoid water marks on the wax.

Other materials can be used with wax but may require the use of a separator such as mould-maker's size aka 'soft-soap' (not to be confused with sugar-soap); or petroleum jelly.

Gelflex

Gelflex is a hot melt reusable vinyl rubber material. It is typically available in soft and hard formats (the soft variety is used in college).

It should be melted between 150 and 165°C. **Do not overheat.** When overheated it turns orange, smells appalling and is not usable.

It should be allowed to cool to approx 140-150°C before pouring to allow bubbles to settle.

Gelflex can be used with a variety of model materials (provided they can withstand the heat). Some materials such as wood or plaster may require sealing. Gelflex sealers are available, alternatives such as petroleum jelly may be a suitable substitute.

There are a number of suppliers including ACC Silicones.

RTV Silicones

Models that cannot withstand Gelflex may be suited to RTV silicones. These are room temperature curing 2-part materials available in a range of different shore hardnesses. Different manufacturers will have different mixing requirements / ratios.

These are expensive materials and cannot be re-melted or reconfigured.

It is possible to add a thixotropic additive to the 2-part rtv to change its consistency. This will make it possible for the material to be brushed onto a model (it can then be backed up with plaster to save materials).

There are a number of suppliers including ACC Silicones and Jacobsons Chemicals.

Mould-makers size / soft-soap

This is a useful and cheap separator when working with wax and with plaster.

It is usually available from ceramics suppliers but is also available from Tiranti.

Basic Refractory Glass Casting Recipe

Water	Flint or Quartz	Plaster	Chopped strands
1 litre	0.7 Kg	0.7 Kg	21 grams
2 litre	1.4 Kg	1.4 Kg	42 grams
3 litre	2.1 Kg	2.1 Kg	63 grams
4 litre	2.8 Kg	2.8 Kg	84 grams
5 litre	3.5 Kg	3.5 Kg	105 grams
6 litre	4.2 Kg	4.2 Kg	126 grams
7 litre	4.9 Kg	4.9 Kg	147 grams
8 litre	5.6 Kg	5.6 Kg	168 grams
9 litre	6.3 Kg	6.3 Kg	189 grams
10 litre	7.0 Kg	7.0 Kg	210 grams

Annealing Schedule for Casting Crystal

Gaffer® Casting Crystal Annealing Schedules. Semi-Open and Open Forms *

Thickness (inches) (mm)	Anneal Soak Time @ 806°F @ 430°C	Initial Cooling Rate °F/Hr °C/Hr	Initial Cooling Range °F °C	Second Cooling Rate °F/Hr °C/Hr	Second Cooling Range °F °C	Final Cooling Rate** °F/Hr °C/Hr	Final Cooling Range °F °C	Total Elapsed Time
.5 in 12 mm	2 hr	120 67	806 - 680 430 - 360	240 133	680 - 590 360 - 310	720 402	590 - 70 310 - 21	4hrs 10mins
.75 in 19 mm	3 hr	52 29	806 - 680 430 - 360	104 58	680 - 590 360 - 310	312 174	590 - 70 310 - 21	8hrs
1.0 in 25 mm	4 hr	29 16	806 - 680 430 - 360	58 32	680 - 590 360 - 310	174 96	590 - 70 310 - 21	13hrs
1.5 in 38 mm	6 hr	13 7.2	806 - 680 430 - 360	26 14.4	680 - 590 360 - 310	78.0 43.0	590 - 70 310 - 21	26hrs
2.0 in 50 mm	8 hr	7.8 4.3	806 - 680 430 - 360	15.6 8.6	680 - 590 360 - 310	46.8 25.8	590 - 70 310 - 21	41hrs 30mins
2.5 in 60 mm	10 hr	5.2 2.9	806 - 644 430 - 340	10.4 5.8	644 - 554 340 - 290	31.2 17.4	554 - 70 290 - 21	2 days 17hrs
3.0 in 75 mm	12 hr	3.3 1.8	806 - 644 430 - 340	6.6 3.6	644 - 554 340 - 290	19.8 10.8	554 - 70 290 - 21	4 days 5hrs
3.5 in 88 mm	14 hr	2.5 1.4	806 - 644 430 - 340	5.0 2.8	644 - 554 340 - 290	15.0 8.4	554 - 70 290 - 21	5 days 12hrs
4.0 in 100 mm	16 hr	1.8 1.0	806 - 644 430 - 340	3.6 2.0	644 - 554 340 - 290	10.8 6.0	554 - 70 290 - 21	7 days 8hrs
4.5 in 113 mm	18 hr	1.6 0.9	806 - 644 430 - 340	3.2 1.8	644 - 554 340 - 290	9.6 5.4	554 - 70 290 - 21	8 days 5hrs

5.0 in 125 mm	20 hr	1.3 0.7	806 - 644 430 - 340	2.6 1.4	644 - 554 340 - 290	7.8 4.2	554 - 70 290 - 21	10 days 9hrs
5.5 in 138 mm	22 hr	1.1 0.6	830 - 644 430 - 340	2.2 1.2	644 - 554 340 - 290	6.6 3.6	554 - 70 290 - 21	11 days 20hrs
6.0 in 150 mm	24 hr	0.9 0.5	806 - 608 430 - 320	1.8 1.0	608 - 518 320 - 270	5.4 3.0	518 - 70 270 - 21	16 days
6.5 in 165 mm	26 hr	0.7 0.4	806 - 608 430 - 320	1.4 0.8	608 - 518 320 - 270	4.2 2.4	518 - 70 270 - 21	19 days 20hrs
7.0 in 175 mm	28 hr	0.6 0.33	806 - 608 430 - 320	1.2 0.66	608 - 518 320 - 270	3.6 2.0	518 - 70 270 - 21	23 days 19hrs
7.5 in 190 mm	30 hr	0.5 0.3	806 - 608 430 - 320	1.0 0.6	608 - 518 320 - 290	3.0 1.8	518 - 70 270 - 21	26 days 6hrs
8.0 in 200 mm	32 hr	0.47 0.26	806 - 608 430 - 320	0.94 0.52	608 - 518 320 - 270	2.8 1.56	518 - 70 270 - 21	30 days 4hrs
8.5 in 215 mm	34 hr	0.41 0.23	806 - 608 430 - 320	0.8 0.46	608 - 518 320 - 270	2.4 1.4	518 - 70 270 - 21	33 days 21hrs
9.0 in 225 mm	36 hr	0.35 0.2	806 - 608 430 - 320	0.7 0.4	608 - 518 320 - 270	2.1 1.2	518 - 70 270 - 21	38 days 22hrs
9.5 in 242 mm	38 hr	0.32 0.18	806 - 608 430 - 320	0.64 0.36	608 - 518 320 - 270	1.9 1.1	518 - 70 270 - 21	42 days 6hrs
10.0 in 254 mm	40 hr	0.29 0.16	806 - 608 430 - 320	0.58 0.32	608 - 518 320 - 270	1.74 0.96	518 - 70 270 - 21	47 days 15hrs

* Based on: Schedules for commercial annealing of ordinary ware. Corning Glassworks. Corning N.Y. 1950. **For forms that are able to cool reasonably equally on all sides.**

** Obviously cooling rates of thinner pieces are faster than ordinary kilns would lose heat. In those cases the kiln can be allowed to cool at its normal rate.

Revised schedules August 2010.

ANNEALING THICK SLABS

This annealing chart has been formulated for use with Bullseye clear glass. It is derived from Corning's method as shown in McLellan and Shand.* It is based on a flat slab of uniform thickness that is set up in such a fashion that it can cool equally from top and bottom.

If the piece is not set up in such a fashion that it can cool equally from top and bottom or is anything besides a flat slab of uniform thickness, select an annealing cycle for a piece that is twice the thickness of the thickest area of the piece. Even a very conservative annealing cycle may not work if the kiln is not capable of cooling the work uniformly.

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THICKNESS	ANNEAL SOAK TIME	INITIAL COOLING RATE	INITIAL COOLING RATE	2nd COOLING RATE	2nd COOLING RATE	FINAL COOLING RATE	FINAL COOLING RATE	TOTAL MINIMUM TIME
inches	@ 900 °F	°F/hr	°F	°F/hr	°F	°F/hr	°F	Hours
mm	@ 482 °C	°C/hr	°C	°C/hr	°C	°C/hr	°C	Hours
0.5 in	2 hr	100	900–800	180	800–700	600	700–70	~5 hr
12 mm		55	482–427	99	427–371	330	371–21	
0.75 in	3 hr	45	900–800	81	800–700	270	700–70	~9 hr
19 mm		25	482–427	45	427–371	150	371–21	
1.0 in	4 hr	27	900–800	49	800–700	162	700–70	~14 hr
25 mm		15	482–427	27	427–371	90	371–21	
1.5 in	6 hr	12	900–800	22	800–700	72	700–70	~28 hr
38 mm		6.7	482–427	12	427–371	40	371–21	
2.0 in	8 hr	6.8	900–800	12	800–700	41	700–70	~47 hr
50 mm		3.8	482–427	6.8	427–371	22	371–21	
2.5 in	10 hr	4.3	900–800	8	800–700	26	700–70	~70 hr
62 mm		2.4	482–427	4.3	427–371	14.4	371–21	
3.0 in	12 hr	3	900–800	5.4	800–700	18	700–70	~99 hr
75 mm		1.7	482–427	3.1	427–371	10	371–21	
4.0 in	16 hr	1.7	900–800	3.1	800–700	10	700–70	~170 hr
100 mm		0.94	482–427	1.7	427–371	5.6	371–21	
6.0 in	24 hr	0.75	900–800	1.3	800–700	4.5	700–70	~375 hr
150 mm		0.42	482–427	0.76	427–371	2.5	371–21	
8.0 in	32 hr	0.42	900–800	0.76	800–700	2.5	700–70	~654 hr
200 mm		0.23	482–427	0.42	427–371	1.4	371–21	

* McLellan and Shand (1984), *Glass Engineering Handbook*, 3rd Edition, New York, McGraw Hill.

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