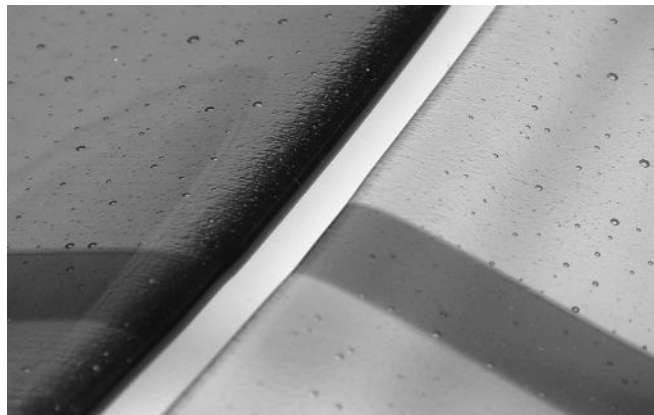


Volume & Bubble Control

TECHNOTES 5 | Understanding Distortion & Trapped Air When Firing Bullseye Glass

Two common problems encountered when fusing glass are distortions of shape and unanticipated bubbles. To avoid these effects—or to engineer them into your work—you need to learn how to control volume and trapped air during firing.



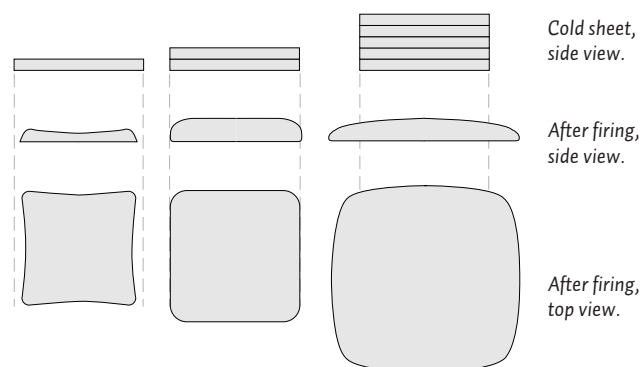
Understanding Volume

When held at its full fusing temperature for an adequate amount of time, Bullseye glass will follow the Six Millimeter Rule and assume a thickness of 6 mm (0.25”) unless contained by dams, molds, or other restraints. This equates to two standard layers of Bullseye 3 mm (0.125”) sheet glass.

With less than two standard layers, the glass will pull in at a full fuse to assume a 6 mm thickness. As a result, the project “footprint” or surface area will be smaller after firing.

With more than two standard layers, the glass will flow out at process temperature to assume a thickness of 6 mm resulting in a larger project footprint.

These general principles may be modified slightly by the viscosity of the glass.



11/2” (4 cm) squares of standard-thickness glass in 1, 2, and 5 layers.

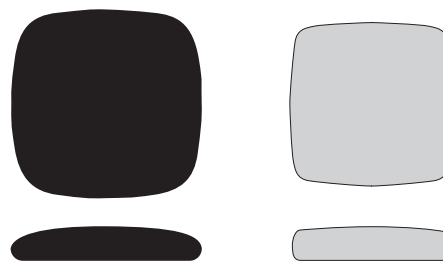
Viscosity

Viscosity is the resistance of a liquid to flow. For example, molasses is a highly viscous material, while water has very low viscosity.

Heated to sufficiently high temperatures, glass behaves like a liquid. But different glass styles have different viscosities, depending on their composition. A glass with low viscosity is sometimes said to be “soft.” A glass with high viscosity is considered to be “hard” or “stiff.”

While all Bullseye glasses will flow in accordance with the general principles discussed above, the viscosities of the individual glasses may modify flow slightly.

Black (000100) is a soft glass. The surface area it will cover when multiple layers are fired to full fuse temperature will be slightly larger than that covered by the same amount of a stiffer glass, such as French Vanilla (000137), fired under the same conditions.



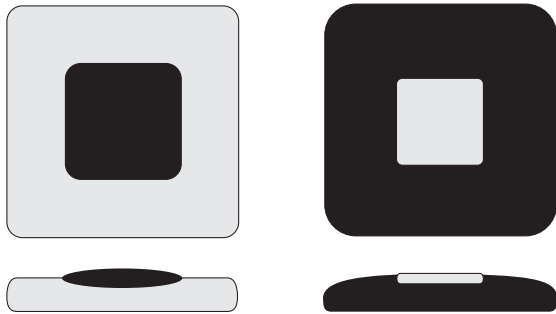
After firing, 5 layers of Black (left) vs. 5 layers of French Vanilla (right).

The Softening Temperature

Just as various types of glass differ in viscosity, they also differ in the rates at which they soften. Some glasses will begin to flow at lower temperatures than others. This fact can affect the design of a fused project.

For example, Black softens before White (000113). When Black is placed on top of the stiffer White, the Black softens and flows out over the surface of the White before sinking into the base.

By contrast, if the stiffer White is set on top of the Black, the White will sink into the base rather than softening and spreading over the surface.



Top views and cross sections of Black and White squares laid on each other.

Note that the footprint of the Black square will be slightly larger after firing than the White square. Note also that the corners of the Black square will be slightly more rounded.

Once you become aware of viscosity and its impact on the fusing process, you'll be able to take advantage of it in designing your work.

Effect of Volume on Design

As noted above, compositions thinner than 6 mm will contract, while those thicker than 6 mm will flow out. These effects will be most noticeable around the perimeter of a fused project. If unrestrained pieces of glass are stacked thickly at the edge of your work, they will flow out beyond the perimeter of the original footprint, creating an irregular edge. If areas close to the edge are less than 6 mm thick, they will tend to shrink in toward the mass of the work and result in an irregular perimeter.

If you are designing a project with areas of varying thickness, keep the variations away from the edge to minimize distortion of the shape or footprint.

Controlling Bubbles

Fusing art glass almost always results in the formation of some air bubbles. Controlling the size, shape, and number of bubbles is mostly a matter of paying attention to how air can become trapped between glass layers and between glass and the kiln shelf.

HOW AIR GETS TRAPPED BETWEEN LAYERS

Many air bubbles are generated as a direct result of the firing cycle. If glass is heated too rapidly, the edges of larger pieces can soften and fuse before their interiors do. This earlier fusing of edges may trap air between layers, resulting in bubbles. You can reduce unwanted air bubbles by adding a pre-rapid heat soak to the firing cycle. For a typical 6 mm project, hold the kiln at a temperature from 1150–1250°F (621–677°C) for 15–45 minutes. At this temperature, the glass will soften enough to begin moving, but not enough to fuse. Thus, the top layer can settle onto the bottom layer, squeezing out the air laterally from between the layers. Likewise, using a slower rate of heat in the rapid heat segment of your firing—for example, 400°F (222°C) per hour instead of AFAP (as fast as possible)—may reduce the number and size of bubbles.

If the edges of your project are too close to the kiln elements, or if the kiln has only side elements, the direct heat can cause your layers of glass to seal up at the edges before air can escape. Ceramic fiber paper or kiln dams can be placed on the edges of the shelf to baffle, or shield, the heat from the edges of your glass, thus allowing air to escape from between layers.

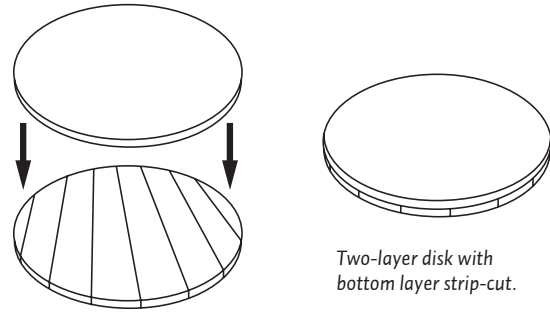
Another variable that can contribute to bubble formation is the flatness or waviness of the glass sheets being used in a project. For example, single-rolled (-0000) glasses are less flat than double-rolled (-0030) glasses and tend to trap more air between stacked layers.

Other bubbles may result from the design of a piece of work. For example, bubbles can form between layers from air pockets created when stacking component pieces of a design, or when cut pieces do not fit together well.

Also, consider the weight of the materials you add to the top layer of a piece. If you take two unfused layers of sheet glass and put a “frame” of sheet glass, frit, or powder around the top perimeter of those sheets, the extra weight along the edges of the piece can prevent air from escaping laterally from between the bottom two layers. Air will be trapped, causing bubbles. To prevent such bubbles, consider pre-firing the bottom two layers and then adding the frame element in the second firing, or else start the project using 6 mm glass.

Placing accessory glasses such as frit, powder, or stringers between layers is an almost certain recipe for bubbles. Instead, place accessory materials on the top layer of your project, or pre-fuse them in separate firings to the point where they are smooth and so less likely to trap air when stacked for a subsequent firing.

Tip: To fire two identical disks together, cut the lower disk into strips no more than 4 cm (1.5") wide, reassemble the pieces, and cap with the uncut disk. If the strips are tightly fitted together, they will be barely noticeable after fusing, and the piece will be relatively bubble free. This technique also allows air trapped between the glass and the kiln shelf to escape.



HOW AIR GETS TRAPPED BETWEEN GLASS AND THE KILN SHELF

Hot air rises. If it can't escape from underneath a piece laterally, it will force the softened glass upward. The resulting distortion, while not technically a bubble, will generally be undesirable. Fired to a high enough temperature, the trapped air will push completely through the softened glass, forming a crater or hole in the fused work.

Very large areas of glass, especially if constructed of layers with a total depth of less than 6 mm, will tend to trap air. Other conditions can aggravate this effect.

Moisture in a kiln shelf will turn to steam upon heating, and steam will create bubbles faster than hot air will. Make sure that your kiln shelf is thoroughly dry before firing by heating it to 500°F (260°C) and holding it at that temperature for 20 minutes. Using ceramic fiber paper instead of kiln wash will ensure that any moisture trapped below the glass can escape. The porosity of the ceramic fiber paper will also ensure an escape route for any trapped air.

A shelf that is not flat can also cause bubbles to form. A shelf containing a dip of 1.5 mm (0.0625") can create a significant bubble problem for typical fused projects that are 6 mm thick. To avoid the problem, check your shelves for flatness by using a straightedge. Shelves that are distorted enough to cause bubbles or other problems may still work if fiber paper is used between the glass and the shelf.

Otherwise, distorted shelves should be discarded, cut up for other uses, or used as "foundation" shelves for something like a sand bed.

Excessively rapid heating during the firing cycle can result in some areas of a glass project changing in thickness faster than others. This is especially likely to happen around the perimeter of pieces less than 6 mm thick, causing the "escape channels" for air between the glass and the shelf to be impeded. To avoid this, consider using a more conservative heating cycle or firing on a breathable shelf separator, such as ceramic fiber paper, to allow air that would otherwise be trapped to escape.

Bubbles can form between glass and a mold during slumping. This happens for a variety of reasons.

- If a mold is not porous and contains no holes through which air can escape as the glass slumps into the form.
- If holes become blocked before the glass has finished slumping.
- If the glass is in contact with the mold for too long or at temperatures that are too high.
- To prevent these problems, review your program and visually confirm the slump. Best results in slumping are usually obtained by holding the glass at lower temperatures for a longer period of time, rather than at higher temperatures for a shorter period of time.

TO PREVENT THE FORMATION OF BUBBLES BETWEEN LAYERS

1. Incorporate a pre-rapid heat hold in the firing cycle.
2. Increase the amount of time spent in the rapid-heating stage.
3. Baffle the edges of the piece with fiber paper, kiln dams, or pieces of sawn-up kiln shelf.
4. Eliminate air pockets from the design.
5. Pre-fire layers when necessary or work with 6 mm (0.25") glass.
6. Consider cutting the bottom layer of a piece to allow air to escape. (See tip above.)

TO PREVENT THE FORMATION OF BUBBLES OR DISTORTIONS BETWEEN YOUR GLASS AND KILN SHELF

1. Use layers of glass with a thickness of at least 6 mm (0.25")—for example, two layers of standard 3 mm (0.125") sheet glass.
2. Make sure that your shelf is thoroughly dry.
3. Use fiber paper between the shelf and the glass.
4. Increase the firing time up to full fuse in the rapid-heat stage.
5. Make sure that your shelf is flat.
6. Be certain that holes in slumping molds are properly positioned.
7. Confirm slumping visually.
8. Use smaller component pieces in laying up the work. (See tip above.)

Tip: Flip-Firing

This technique prevents bubbles from disfiguring a glass surface. The work is first fired with its face side down. During this “flipped” firing, the bubbles rise toward the top surface. When the piece is turned over for the second firing, the former top surface (toward which bubbles have risen) becomes the underside of the piece. The new top surface (the face) will be free of the bumpy texture resulting from bubbles. It can be fire polished on a second firing, though it may need to be sandblasted or overlazed.

Flip-firing was developed by Ray Ahlgren, owner of Fireart Glass in Portland, Oregon, during the fabrication of Silvia Levenson’s *Un Mondo Migliore* at the Bullseye factory in 1996.

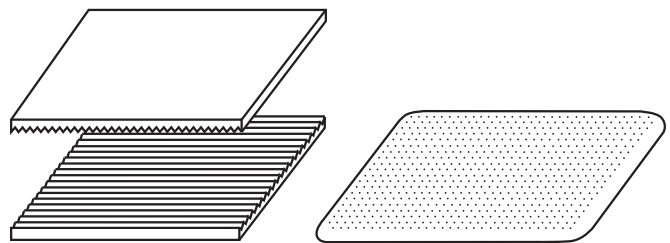
What If You Want Bubbles?

Just as you can prevent bubbles in your work by controlling your glass and firings, you can also purposely design bubbles into your work.

CREATING BUBBLES WITH TEXTURED GLASS

Textured glasses can be manipulated to create bubbles. Bullseye reeded glass (-0043 and -0053) has a tight linear pattern of ridges and grooves. Placing textured surfaces together with the ridges running at right angles to each other will create a grid-like pattern of air pockets, regularly spaced between layers. Fire to full fuse to create tiny, evenly spaced bubbles within the glass.

Bullseye accordion glass (-0045 and -0055) has a linear pattern of regularly increasing and decreasing spaces between its ridges. Use it with itself or combined with reeded glass to form another variety of bubble pattern.



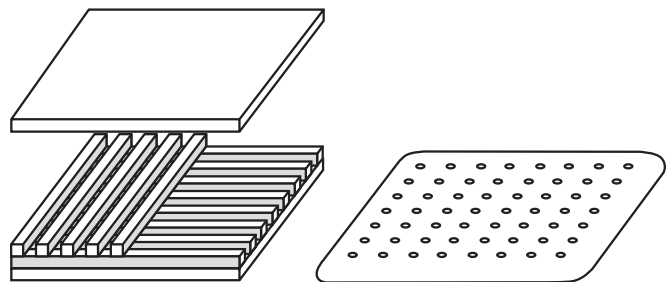
Reeded glass laid up at right angles and resulting bubble pattern.

CREATING BUBBLES WITH GLASS STRIPS

Crosshatching strips of glass and sandwiching them between two full layers of glass can yield bubbles that are large, defined, and dramatic.

STRINGER-PATTERNED BUBBLES

Crosshatching 1 mm or 2 mm glass stringers between layers of sheet glass will create an effect similar to that achieved by the glass-strip method, but with smaller bubbles.



Glass strips laid up at right angles and resulting bubble pattern.

There are other ways to trap air in a controlled fashion within a kilnformed piece, including combinations of the techniques listed above.

Conclusion

The basic concepts of volume and bubble control provided here are just starting points. Investigating these ideas through your own tests and experiments will strengthen your skills and craftsmanship in kilnformed glass.