Northstar® Borocolour®

Annealing Chart

July 2004

Borosilicate Annealing

Anneal Time: 1 hour for every 0.25 inches of piece thickness

Soak Time @ A/T – 125 deg: 50% of the Anneal Time for pieces 0.25 inches thick or less. 100% of the anneal time for pieces greater the 0.25 inches thick

Soak Time @ A/T – 200 deg: 25% of the Anneal Time

Soak Time @ A/T – 350 deg: 25% of the Anneal Time

Soak Time @ A/T – 550 deg: 25% of the Anneal Time

All temperatures are in degrees F and for 33 expansion borosilicate glass.

A/T = Annealing Temperature. Effective 01/03

Critical temperatures for clear:

- Working temperature: 2228 degrees F
- Softening temperature: 1508 degrees F
- Annealing temperature: 1050 degrees F
- Strain temperature: 960 degrees F

For closed forms, assume the wall thickness to be doubled (i.e. 0.125 wall = 0.5 wall for annealing, 0.5 wall = 1.0 wall, etc.).

A piece may also be brought to temperatures 100 to 150 degrees above the A/T for a few minutes to improve the vibrancy of certain colors. This does not improve the annealing process.

As the wall thickness increases, the first soak stage (the soak time at the first temperature drop equal to the A/T minus 125 degrees), becomes more critical in the overall annealing process. This temperature is just below the strain point and allows the thicker, more complex pieces to cool slowly and come to a steady state before continuing with the ramp down in temperature. Additional soak points allow the piece to cool in a controlled fashion and to stabilize before continuing the cooling process.

The times listed for each of the soak periods includes the ramp down time as well as the time at the new temperature. For example, for a one inch thick piece, the time at the A/T is approximately 4 hrs. After 4 hrs, reduce the temperature by 125 degrees and allow the piece to soak for another 4 hrs. Then reduce the temperature again for a 1 hour soak, etc.

The schedule is based on clear and may need to be adjusted for the different colors being used. Specifically, metallic based colors may need a slightly higher A/T (maybe 25 degrees). The magnitude of the temperature decrease may need to be adjusted as well. The soak times can also be a variable that can be adjusted by color in conjunction or separately with the ramp down temperatures.

For non-metallic colors, the soak duration may be able to be reduced and the last one to two ramps eliminated altogether. For pieces that are to be re-worked, it may be necessary to ramp up the temperature of the piece in reverse order to avoid cracking. The thought being that a piece that can crack during the annealing and cooling process, might also crack during re-heating.

While having compatible COE's between the different colors and the clear tubing and rod is of primary importance, similar annealing characteristics of the different glass components is also something that needs to be considered. If the annealing temperatures are different enough, and the cycle is set for a component with a lower annealing temperature, the higher end component(s) may not be fully annealed and therefore there may be enough residual stress to cause the piece to check either during cooling or at some later date.

Colors like Forest Green, Blackberry, Moss, and Blue Spruce all have anneal and strain temperatures approximately 100 degree lower than either the clear or the other standard colors. This is by design and is accomplished in the formulation process. The softening point of these colors is still the same (approximately 1508) so there will not be any piece deformity even though annealing is occurring 100 degrees above the A/T. These colors were prone to cracking before the re-formulations about 18 months ago and one of the objectives was to make them more "annealing friendly".

In general, the assumption built into the schedule is that even if the COE's of the clear and different colors are compatible, the annealing temperatures may not be. If this is the case, care must be taken to minimize/eliminate the possibility of cracking by increasing the different soak times and decreasing the temperature drops between each soak. An additional soak period may also be necessary with some colors.

Other factors that can increase or require changes to the annealing cycle include:

- The piece complexity and amount of sharp angles (design induced stresses)
- Thickness variation within the piece
- Thermal gradients in the annealing kiln itself (more pronounced in larger kilns)
- The absorption characteristics of the colors used (variation in the absorption of light in the different spectrums and how this affects radiant cooling/heating rates)
- The amount of re-work and extended heating and cooling