Heat Treated Glass for Architectural Glazing

The purpose of this Vitro Architectural Glass Technical Document is to provide information that may be of assistance in determining which type of heat-treated glass is most appropriate for the intended application. This document includes brief discussions of:

- Heat strengthened and tempered glass
- "Spontaneous" tempered glass breakage and its cause
- Nickel sulfide stone inclusions
- Heat soak testing of tempered glass
- Distortion in heat-treated glass

Finally, this document offers Vitro's recommendations regarding the use of heat-treated glass.

There are many important considerations when designing and using glass in the vision and spandrel areas of architectural glazing applications. When heat treated glass is required to resist wind or snow loads, expected thermal stresses, or to comply with applicable building codes, the responsible design professional must carefully consider the respective performance characteristics of these products before selecting and specifying the glass product type.

In architectural applications, heat-treated glass, sometimes called, "thermally toughened glass", significantly reduces the breakage potential due to thermal stress and stress from uniform loads such as wind and snow loads. In most cases, heat-strengthened glass of the appropriate thickness and quality eliminates opportunities for breakage due to thermal stress and wind load. In cases where safety glazing is required by code or responsible design, then fully tempered glass or laminated heat-strengthened glass should be specified.

Neither heat strengthened nor tempered glass can be safely cut after the heat-treating fabrication process. Please refer to *Vitro Technical Document TD-124 Fabrication of Heat Treated Glass* for further information.

Further design information concerning thermal stress can be found by using Vitro's on-line thermal stress calculator available on the Vitro Glazings Website and in *Vitro Technical Document TD-109 Thermal Stress Update*.

The Difference Between Heat Strengthened and Tempered Glass – Both are Heat Treated

Heat-treated glass products, whether heat strengthened or tempered, are produced in a very similar fashion using the same processing equipment. Briefly, the heating process is identical where the glass is heated to approximately 1200ºF (650ºC) and it is by controlling the rate of cooling that determines if the glass is either heat strengthened or tempered. The rate of forced cooling controls the level of surface and / or edge compression in the glass. To produce tempered glass, the cooling is much more rapid and normally referred to as "quenching" which creates higher surface and/or edge compression in the glass. To produce heat strengthened glass, the cooling is slower and the resultant compression in the glass is lower than fully tempered glass yet still higher than annealed glass.

Heat Treated Glass for Architectural Glazing

The industry standard specification requirements for heat strengthened and tempered glass are set forth in ASTM C1048 "*Standard Specification for Heat Treated Flat Glass – Kind HS, Kind FT Coated and Uncoated Glass."*

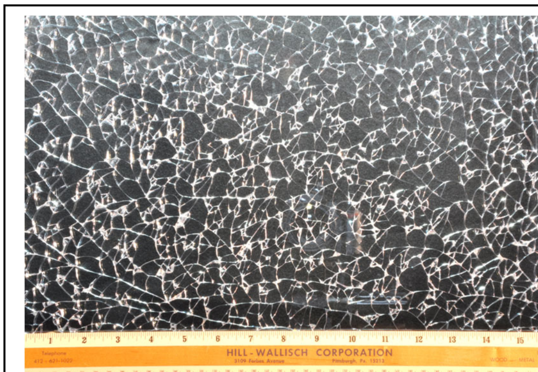
- Heat strengthened glass is defined as having a surface compression of 3,500 to 7,500 psi (24 to 52 Mpa); no requirement for edge compression is specified.
- Tempered glass is defined as having a minimum surface compression of 10,000 psi (69 Mpa), an edge compression of not less than 9,700 psi (67 Mpa) or meet ANSI Standard Z97.1 or CPSC Standard 16CFR1201.

Note that surface compression of heat-strengthened glass must be verified to meet ASTM C1279 "*Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened, and Fully Tempered* Glass" requirements. This is because there is not a strong correlation between the break pattern and surface compression in the range of heat-strengthened glass compression levels.

Because of the compression in the glass, heat strengthened glass is approximately twice as strong as annealed glass of the same thickness. Tempered glass is approximately 4 to 5 times as strong as annealed glass of the same thickness. Except for this increase in mechanical strength, all other properties of the glass remain unchanged including glass deflection. For additional information on glass deflection, please see *Vitro Technical Document TD-113 Why Annealed, Heat Strengthened and Tempered Glass All Deflect the Same Amount*.

The most dramatic and important difference between heat strengthened and tempered glass is in the post breakage characteristics of the two products (i.e., break pattern). If heat strengthened glass should break, the pieces will be relatively large and tend to remain in the glazing system until removed. Tempered glass, on the other hand, is designed to break into innumerable small, roughly cubical pieces. In fact, it is this break pattern that qualifies tempered glass as a safety glazing material. However, because of the break pattern, tempered glass is much more likely to evacuate the glazing system immediately upon breakage. Responsible design professionals must consider the tendency of tempered glass to evacuate the opening upon breakage and the consequences must be acceptable. Responsible parties know that there is always a possibility of glass breakage; therefore, the glass construction must be designed with a low probability of breakage, typically less than 8 lites / 1000 lites, but if the glass does break, the glass design must be done in a manner so that the breakage consequences are acceptable.

Typical Tempered Glass Break Pattern



"Because of the break pattern, tempered glass is much more likely to evacuate the glazing system immediately upon breakage."

Heat Treated Glass for Architectural Glazing

Typical Heat Strengthened Glass Break Pattern

"Because of the break pattern, heat-strengthened glass is much more likely to remain in the glazing system upon breakage until such time it is purposefully removed."

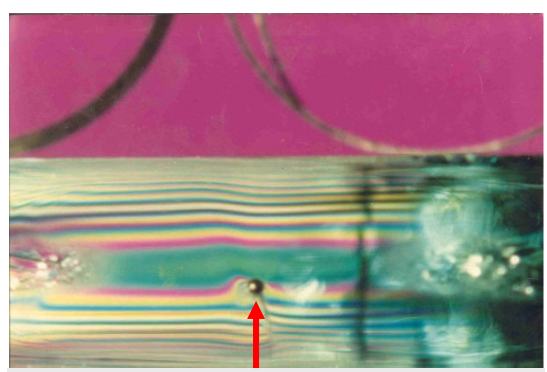
Heat strengthened glass is **not** a safety glazing material. When safety glazing is required, either by code or design, a certified safety glazing material such as tempered or laminated glass must be used.

What is Spontaneous Breakage and What Causes It?

There are instances, after installation, of tempered glass breaking due to no apparent cause. In these cases of "spontaneous breakage", it is most often determined that the glass broke due to existing surface or edge damage that severely compromised the ability of the glass to withstand anticipated wind loads, or normal building movements; or that glass to metal contact combined with movement under wind load initiated the break. In relatively rare instances, the breakage has been traced to the presence of nickel sulfide stones in the center tension zone of the tempered glass.

Although unintended, nickel sulfide stones can form in the production of float glass. Vitro and other North American glassmakers have implemented procedures and controls to greatly reduce the likelihood of nickel sulfide stones. Vitro specifically does not include nickel in any of its primary glass batch formulations, and its float glass plants use magnetic separators and do not use glass batch handling equipment with nickel bearing components.

There is, however, no known technology to totally eliminate the possibility of nickel sulfide stone inclusions in float glass. Such inclusions can occur at random, are often benign, and are almost always very small. Nickel sulfide stones typically range in size between 0.003" and 0.015" (0.076 mm and 0.380 mm) in diameter. This size precludes the use of practical inspection methods common to the production of float glass. ASTM C1036 "*Standard Specification for Flat Glass"*, the basic specification to which float glass is manufactured in the U.S., permits blemishes (including stones) between 0.020" and 0.100" (0.5 mm and 2.5 mm) in float glass, depending on glass size and quality level.



Nickel Sulfide Stone, (0.003" inclusion)

Since nickel sulfide stones can occur in the production of float glass, they may be present in annealed and heat strengthened glass, as well as in tempered glass. However, because of the explanation given below,

Heat Treated Glass for Architectural Glazing

annealed and heat strengthened glass are almost never subject to spontaneous breakage due to nickel sulfide stone inclusions.

Briefly, nickel sulfide stone breakage is due to a phase transformation (so called α to β phase change) that results in an increase in the stone size. The volumetric growth of the stone is small, ranging from approximately 2 to 4%. This volume growth, if the stone is in the center tension zone, can cause stresses potentially resulting in glass breakage.

During the manufacture of float glass, the glass is intentionally cooled at a slow, controlled rate in order to produce annealed float glass with as little residual surface and edge compression as possible. During this annealing phase, any stones have the time to undergo the α to β phase change and become stable.

When glass is re-heated for heat strengthening or tempering, any NiS stones that are present will shrink back to the smaller high-temperature-stable α form. The slower cooling cycle of the heat strengthening process allows the stones to undergo the α to β phase change. However, the rapid cooling / quenching cycle required to produce tempered glass arrests the phase change and may trap the stone in the smaller α phase before it completes its volumetric growth. Then later, due to in-service temperature exposure, the phase change and accompanying volume growth continues and may lead to breakage.

There is general agreement that spontaneous breakage due to stone inclusions is not an issue with annealed or heat strengthened glass. The phenomenon is limited to tempered glass.

Heat Treated Glass Comparison

	PRO'S	CON'S
Heat Strengthened	Increased resistance to wind and snow loads	Does not meet safety glazing requirements unless laminated
	Increased resistance to thermal stresses	
	Typically remains in opening if broken	
	Heat soak testing not required	
	PRO'S	CON'S
Full Tempered	Meets safety glazing requirements	Evacuates opening upon breaking
	Increased resistance to wind and snow loads	Increased probability of breakage due to NiS stones
	Increased resistance to thermal stresses	Increased cost and risk of damaging product due to heat soak testing and the associated extra steps and handling required

What is Heat Soak Testing and Does It Work?

The concept of heat soak testing glass to reduce or eliminate spontaneous breakage due to stone inclusions has been around for decades. Heat soak testing involves exposing the tempered glass to elevated temperatures for some period of time.

The exposure temperature and time is not a constant but varies according to the belief of the heat-soak testing proponent. Some believe that lower temperatures for longer

Heat Treated Glass for Architectural Glazing

times are more appropriate; others believe that higher temperatures for shorter times are appropriate. A typical heat soak process elevates the glass temperature to at least 482°F (250°C) for a minimum of two hours. Reference standard BS EN 14179-1:2016 *Glass in buildings - Heat Soaked thermally toughened soda lime silicate safety glass.*

The obvious objective of the heat soak process is to achieve a “break now, not later” result, based on the assumption that any glass lites with inclusions will break during the heat soak process. It is very important that the protocols of the 2016 or later version of the EN 14179-1 standard be precisely followed. Temperatures or timeframes outside of those cited in the standard can leave α phase nickel sulfide stones in the glass which are then subject to spontaneous breakage at a later time.

It should be pointed out that there is a considerable body of public information on the topic of nickel sulfide stones. There are numerous web sites, and a long history of technical articles from glass industry and material science experts.

While there is general agreement on the concept and intent of the heat soak testing process, there is not agreement on the outcome. ***Most agree that heat soak testing can eliminate (by destruction) many of the problem lites, but not that heat soak testing will guarantee 100% elimination of potential spontaneous breakage due to inclusions.*** In fact, the outcome of heat soak testing can only be expressed statistically, i.e., the predicted probability of breakage due to inclusions may be reduced from x lites/1000 to y lites/1000. This statistically predicted outcome is based on many assumptions, including the incidence of stone occurrence, the complex stoichiometry involved, location of the stone within the body of the glass, and the efficacy of the test procedure. And there is no consensus on the statistical procedures used.

With many decades and millions of square feet of heat strengthened glass production in service, Vitro is not aware of any occurrence of spontaneous breakage in heat strengthened glass; given that heat soak testing cannot guarantee the elimination of spontaneous breakage in tempered glass, it follows that the risk of spontaneous breakage is likely lower in heat strengthened glass than that of heat-soaked tempered glass.

There are also potential unintended consequences associated with heat soak testing.

They include:

- Damage to adjacent test lites should a break occur during the test
- Effect on the tempered glass induced stresses that may alter its break-safe characteristics
- Stable stones that would have not caused field breakage to begin the phase transformation during the heat soak test, but do not break and then the phase change continues later in the field and causes breakage
- Temperatures or timeframes of the heat soak process that intentionally or unintentionally deviate from the protocols defined in the EN 14179-1:2016 standard can result in α phase stones remaining in the glass which are

Heat Treated Glass for Architectural Glazing

then subject to spontaneous breakage at a later time.

- The effects of additional handling and temperature on tempered low-e coated glass including:
  - Scratches or other surface damage resulting in yield loss and extra costs
  - Breakage and/or edge damage that could cause future breakage
  - Potential for a shift in reflected and / or transmitted color of the low-e coating.

Vitro Glass Products Approved for Heat Soak Testing	
All Uncoated Glass	Solarban® 65VT glass
Solarcool® reflective glass	Solarban® 70VT glass
Vistacool® reflective glass	Solarban® 72VT glass
Sungate® 400VT glass	Solarban® 90VT glass
Sungate ThermL™ glass	Solarban® R67VT glass
Solarban® 60VT glass	Solarban® R77VT glass
Solarban® R100VT glass	
Note: Only the above MSVD Low-e Temperable VT coatings are approved for heat soak testing. No annealed version of the MSVD Low-e coating is approved for heat soak testing.	

When tempered glass is specified, the appropriate decision maker must make an educated decision as to the need and desirability of heat soak testing based on, among others, the following considerations:

- The use of heat strengthened glass in lieu of tempered, provided that safety glazing is not required.
- If safety glazing is required by code or by the desire to retain glass in the opening, consideration should be given to laminated heat-strengthened glass.
- Assurances regarding the expected outcome of heat soak testing, i.e., will assurances and guarantees be offered that breakage due to nickel sulfide stones will be eliminated; or, reduced from some predicted level to a lower level?
- What assurances are in place to verify and confirm that the EN 14179-1:2016 heat soak temperatures and timeframes were followed?
- What effects will heat soak testing have on the performance of the tempered glass, i.e., potential reduction of strength and/or deterioration of the break-safe characteristics?
- What effects will heat soak testing have on the color of the tempered low-e coated glass?

Heat Soak Test Oven Parameters and Considerations

There is currently no North American standard for heat soak testing; therefore, companies in North America performing heat soak testing, typically do so in accordance with the European standard: *BS EN 14179-1 Glass in buildings - Heat soaked thermally toughened soda lime silicate safety glass*. This standard includes specific instructions for the heat soak test requirements that need to be followed. Vitro recommends the 2016 version of the standard or newer be utilized for conducting heat soak testing.

The specific parameters called out in the standard include a normal operating glass temperature of 260°C ± 10°C with an

Heat Treated Glass for Architectural Glazing

absolute not to exceed glass temperature of 290°C. It is recommended to **minimize any time the glass might achieve between 270 – 290°C**. Once all the glass in the oven reaches 250°C, the glass shall then be held for a minimum of 2 hours at this temperature. If the heating is not uniform in the heat soak oven, some of the glass will be held longer than 2 hours at the 260°C ± 10°C temperature. Temperatures or timeframes outside of those cited in the 2016 or later version of the standard can leave α phase nickel sulfide stones in the glass which are then subject to spontaneous breakage at a later time.

Vitro has found that MSVD coated glass products that have been heat soak tested with a cycle that deviates from the defined parameters have the potential for more variation in color. Examples of variation may include elevated temperatures, extended heating times, or multiple tests of the same glass.

A best in class approach to verify that each individual heat soak test meets the defined parameters would be to monitor each heat soak test with an array of thermocouples placed throughout the glass layout. These thermocouples would measure the ambient temperature between the glass lites to better understand what temperature the glass surface is being exposed to. Vitro realizes that it may not be practical to monitor each heat soak test with thermocouples due to the time and the cost. However, Vitro does recommend periodically performing and documenting thermocouple monitoring of the heat soak test process to verify the proper time and temperatures are being achieved.

An example of a heat soak oven glass load that has thermocouples placed to monitor the glass temperatures.

If a periodic thermocouple monitoring process would detect irregularities, the heat soak test should be considered questionable if the test parameters set forth in BS EN 14179-1 are deviated by any of the following:

- Any glass temperature exceeds 290°C.
- Any glass temperature above 270°C was held for more than 60 minutes.
- The hold cycle at the 260°C ± 10°C glass temperature exceeded 150 minutes.
- Any other deviation from BS EN 14179-1

If any of the above deviations exist in a heat soak test involving MSVD low-e glass or any MSVD glass was processed more than once through a heat soak test, then Vitro recommends:

- Discard the entire load or
- Check 100% of the lites in the load with a spectrophotometer to verify the color meets the customers internal color requirements or meets the color requirements of ASTM C1376 and is consistent with other glass for the project.

Heat Treated Glass for Architectural Glazing

- Using a GASP meter, the glass should be measured for surface compression or conduct additional particle size testing of the suspect lites to ensure the attributes of the fully tempered glass have not been compromised.

Vito recommends that the heat soak oven be calibrated annually or more frequently, using the calibration procedures called out in BS EN 14179-1:2016 Annex A.

Vitro recommends that if any significant breakage is experienced during a heat soak test, retain examples of the break origin, and notify the Vitro Technical Services department.

Heat-Treated Glass Distortion and Flatness

Optical image distortion may occur in all types of glass for many different reasons such as but not limited to:

- Non-uniform flatness
  - Roller wave
  - Kink
  - Bow
  - Warp
- Laminated constructions
- Thin glass constructions
- Glazing pressure
- Wind load
- Changes in temperature
- Changes in barometric pressure
- Changes in altitude between insulating glass unit fabrication location and installation location.

With heat-treated glass, the heat-treating process itself will modify the original flatness of the annealed glass substrate and result in distortion. This is an inherent condition of all heat treated glass and results in optical distortion due to roller wave, bow, and warp.

Automated surface flatness measuring equipment is readily available from many suppliers and is very helpful with process control and inspection of heat-treated glass flatness. This equipment can also provide surface flatness data for 100% of project lites.

Because different heat-treating processes may produce acceptable optical distortion at different levels of roller wave there is no industry standard to quantify allowed heat-treated glass roller wave. Frequently a roller wave tolerance of 0.005” is specified; however, if available, utilizing a millidiopter specification is more appropriate. Even with a flatness specification there is no guarantee that a specific number will ensure acceptable optics; thus, a full scale mock-up under job-site conditions to evaluate the optical aesthetics of a specific heat-treating process is the best way to minimize job-site surprises. In addition to the full-size mockup, where possible the following additional steps should be taken to minimize the impact of inherent heat-treated glass distortion:

- Produce all heat-treated glass for a given project on the same equipment using the same processing parameters.
- Use thicker glass as it is less prone to all types of distortion.
- Orient the heat-treated glass so that the roller wave is parallel to the windowsill / header.

The appearance of distortion may also occur due to strain patterns in heat-treated glass.

Heat Treated Glass for Architectural Glazing

Please see *Vitro Technical Document, TD-115 Strain Pattern in Heat-Treated Glass* for additional information.

The appearance of distortion may also occur due to interference fringe patterns in insulating glass units with or without heat-treated glass. Please see *Vitro Technical Document, TD-118 Interference Fringes in Insulating Glass Units.*

Vitro Recommendations

- **Vitro reaffirms its longstanding recommendation that heat strengthened glass be specified and used, except where tempered glass is mandated for safety or other purposes by code.** *Note: For spandrel applications, please see Vitro Technical Document TD-145, Spandrel Glass - Types and Recommendations, for additional heat treating comments unique to this application.*
- Utilize heat-treated glass, to improve glass strength and reduce the potential of breakage due to thermal stress and stress from uniform loads such as wind and snow loads.
- **Vitro continues to believe that heat soak testing is not a proven method of eliminating all possibility of glass breakage due to nickel sulfide stone inclusions.**
- **If the decision is made to heat soak coated glass, Vitro recommends that all tempered coated glass on the building's façade be heat soaked.**
- **All MSVD low-e glass that has been heat soaked must be fabricated into sealed IG units within 5 days of tempering.**
- **Fabricators should periodically measure the surface compression or conduct additional particle size testing of heat soaked glass to ensure the attributes of the fully tempered glass have not been compromised.**
- **If any heat soak test on MSVD coated glass exceeds the design parameters of BS EN 14179-1, the load should be discarded or checked 100% using a spectrophotometer to verify it meets the customers internal color requirements or meets the color requirements of ASTM C1376 and is consistent with other glass for the project.**
- **Vito recommends that the heat soak oven be calibrated annually or more frequently, using the calibration procedures called out in BS EN 14179-1 Annex A.**
- **To minimize distortion Vitro recommends the use of thicker glass that is processed so that any roller-wave is parallel to the windowsill.**
- **Vitro strongly recommends a full-size mock-up be viewed under actual jobsite conditions to evaluate the appearance of the heat-treated glass.**

Heat Treated Glass for Architectural Glazing

HISTORY TABLE		
ITEM	DATE	DESCRIPTION
Original Publication	5/27/2004	INSIDE GLASS, Technical Services Recommendations, 92-2, 16 January 1992 *"Use Vitro Hestron Heat Strengthened Glass for Architectural Glazing"* is withdrawn and replaced with this document.
Revision #1	11/4/2011	Added comments on heat soak testing Vitro MSVD Coated Glass and heat-treated glass distortion
Revision #2	7/23/2014	Added SG600 to approved heat soak list
Revision #3	10/04/2016	Updated to Vitro Logo and format
Revision #4	1/25/2019	Updated the Vitro Logo and format
Revision #5	11/17/2020	Added SB90VT to the approved coatings for heat-soak list and removed SG500, SG600 and SunClean discontinued products from the list. General formatting changes.
Revision #6	4/15/2021	Added SBR100VT to the approved coatings for heat-soak list.
Revision #7	7/15/2021	Added SB67VT and SBR77VT to the approved coatings for heat-soak list on page 6. Added the *"Heat Soak Test Oven Parameters and Considerations"* section starting on page 6, added the last two recommendation bullets on page 9.
Revision #8	9/7/2022	Modified heat soak test thermocouple monitoring process verbiage and clarified some other language in the document.
Revision #9	9/11/2024	Deleted SBz50 & SBz75 references and added SB65VT & Sungate ThermL to the approved heat soak testing table on pg 6. Modified disclaimer after history table.