Heat Treated Glass for Architectural Glazing

The purpose of this PPG 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 soaking of tempered glass
- Distortion in heat-treated glass

Finally, this document offers PPG'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 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 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 *PPG Technical Document TD-124 Fabrication of Heat Treated Glass* for further information.

Further design information concerning thermal stress can be found by using PPG's on-line thermal stress calculator available at PPG IdeaScapes Website and in *PPG 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 glass is heated to approximately 1200 ◦ F (650 ◦ C) and then force cooled to create surface and/or edge compression in the glass. It is by controlling the rate of cooling that determines if the glass is either heat strengthened or tempered. To produce tempered glass, the cooling is much more rapid, thus creating 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.

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."*

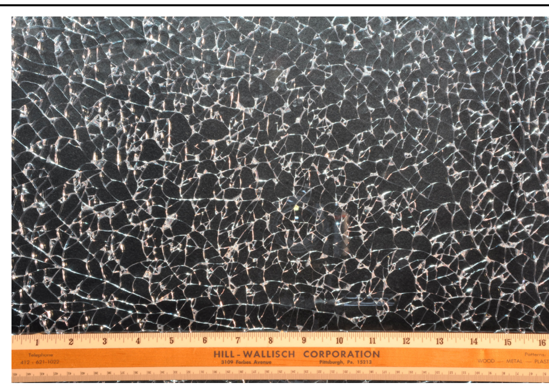
- Heat strengthened glass is defined as having a surface compression of 3,500 to 7,500 psi (24 to 52 Mpa); no requirement for edge compression is specified.
- Tempered glass is defined as having a minimum surface compression of 10,000 psi (69 Mpa), an edge compression of not less than 9,700 psi (67 Mpa), 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 *PPG 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."

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."

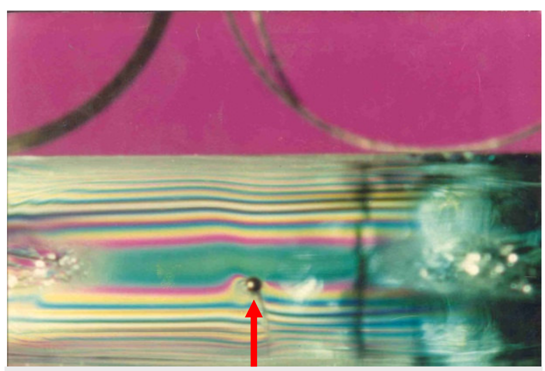
Heat strengthened glass is **not** a safety glazing material. When safety glazing is required, either by code or design, a certified safety glazing material such as tempered or laminated glass must be used.

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. PPG and other North American glassmakers have implemented procedures and controls to greatly reduce the likelihood of nickel sulfide stones. PPG 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, 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 glass with as little residual surface and edge compression as possible. During this annealing phase, any stones have time to undergo the α to β phase change and become stable, without causing glass breakage.

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 cycle required to produce tempered glass arrests the phase change and may trap the stone 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 soaking 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 soaking and the associated extra steps and handling required

What is Heat Soaking and Does It Work?

The concept of heat soaking glass to reduce or eliminate spontaneous breakage due to stone inclusions has been around for decades. Heat soaking 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-soaking proponent. Some believe that lower temperatures for longer times are more appropriate; others believe that higher temperatures for shorter times are appropriate. A typical heat soak process elevates the glass temperature to 550 ◦ F (290 ◦ C) for two hours. Reference BS EN 14179-1 standard.

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. The heat soak test can be conducted on a sampling basis, or on entire lots. Note: If you choose to heat soak coated glass, PPG recommends that all tempered coated glass on the building's façade be heat soaked.

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 soaking process, there is not agreement on the outcome. ***Most agree that heat soaking can eliminate (by destruction) some of the problem lites, but not that heat soaking will guarantee 100% elimination of potential spontaneous breakage due to inclusions.*** In fact, the outcome of heat soaking 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, PPG is not aware of any occurrence of spontaneous breakage in heat strengthened glass; given that heat soaking 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 soaking.

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 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

- 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.

PPG Glass Products Approved for Heat Soaking	
All Uncoated Glass	Solarcool® reflective glass
Solarban® 60VT glass	Vistacool® reflective glass
Solarban® z50VT glass	Sungate® 500 glass
Solarban® z75VT glass	SunClean® glass
Solarban® 70XLVT glass	Sungate® 400VT glass
Solarban® 72VT glass	

When tempered glass is specified, the appropriate decision maker must make an educated decision as to the need and desirability of heat soaking 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 soaking, 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 effects will heat soaking 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 soaking have on the color of the tempered low-e coated glass?

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
- 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.

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 insure 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 mock up, 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 window sill / header.

The appearance of distortion may also occur due to strain patterns in heat-treated glass. Please see *PPG 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 *PPG Technical Document, TD-118 Interference Fringes in Insulating Glass Units.*

PPG Recommendations

- ***PPG reaffirms its longstanding preference 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 PPG Technical Document TD-145, Spandrel Glass - Types and Recommendations, for additional heat treating comments unique to this application.*

- ***PPG continues to believe that heat soaking 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, PPG recommends that all tempered coated glass on the building's façade be heat soaked.**

- **PPG strongly recommends a full size mock-up be viewed under actual jobsite conditions to evaluate the appearance of the heat soaked glass.**

- **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 insure the attributes of the fully tempered glass have not been compromised.**

HISTORY TABLE		
ITEM	DATE	DESCRIPTION
Original Publication	27 May 2004	INSIDE GLASS, Technical Services Recommendations, 92-2, 16 January 1992 *"Use PPG Hestron Heat Strengthened Glass for Architectural Glazing"* is withdrawn and replaced with this document.
New Sections Added	4 Nov 2011	Added comments on heat-soaking PPG MSVD Coated Glass and heat-treated glass distortion