NATIONAL GLASS ASSOCIATION with GANA

Glass Technical Paper FB62-19

Thermal Stress in Heat-Treated Spandrel Glass

Introduction

Spandrel glass is glass that has been rendered near opaque and glazed in wall areas covering structural columns, floors, walls, or other building elements that are intended to be concealed from outside view. Increasing standards of energy efficient initiatives are placing unique and unanticipated demands on spandrel glazing. In the case of insulating glass units (IGUs) installed as spandrel glass, the use of opaque paints and enamels, low-e coatings, thick insulation and other energy efficiency elements are creating, in essence, highly efficient solar collectors. As a result, inner lites of the IGU have been known to reach temperatures of 230 °F or more, resulting in center to edge temperature differences exceeding 130 °F. These gradients create a large thermal stress which, under certain circumstances, may lead to breakage.

Recently, attention has been drawn to several incidents in which spandrel glass has experienced solar-induced thermal stress breakage. Although a relatively rare occurrence, certain design elements are combining to create conditions that allow such breakage to happen. This document discusses the phenomenon of thermal stress build-up, the factors that contribute to it and potential mitigation options.

NOTE: Considerations for other components such as sealants (PIB and/or silicone) and interlayers is not part of the scope of this GTP.

Background

Thermal Gradient Build-Up

Solar Energy generates heat in objects as they absorb sunlight. The intensity of the sunlight is characterized as the Solar Irradiance (SI) and depends upon the latitude, altitude, time of year, time of day, cloud cover, air mass, and other factors. The greater the SI, the greater is the potential for heat build-up under a given set of conditions. As for all objects exposed to sunlight, a glass lite will experience a temperature increase until a balance is reached between the heat gained by absorbing the solar radiation and heat lost through convection, conduction, and re-radiation mechanisms.

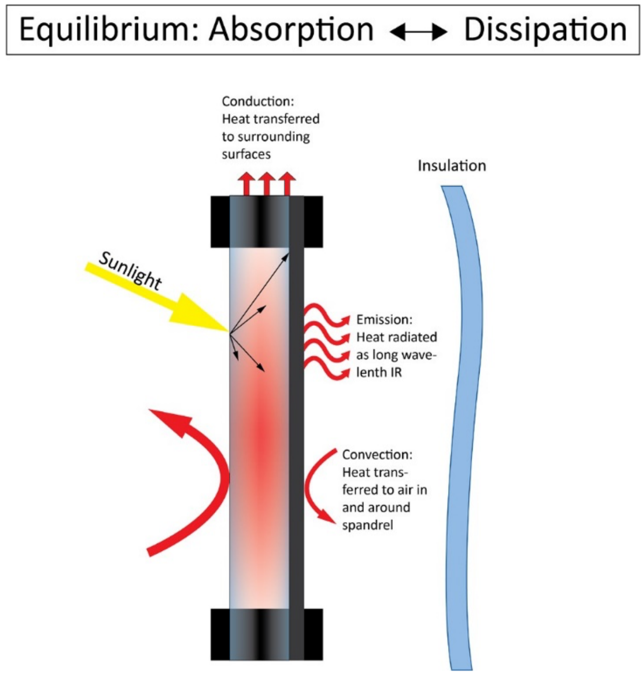

Figure 1

Ultimate heat build-up is based on equilibrium between energy absorption and dissipation

The amount of heat build-up also depends on the design of the glazing and the framing system. Figure 1 shows the competing factors that lead to the thermodynamic equilibrium, or heat balance, for monolithic spandrel glazing. While almost all current thermal analyses are conducted on the basis of heat transfer equilibrium, maximum thermal stress in glass almost always occurs during the transient phase of heating. Clear glass absorbs a small portion of the solar spectrum and converts it to heat, while spandrel glass, which is designed to be opaque, absorbs more solar energy and becomes hotter than vision glass. Darker spandrel colors absorb more solar energy and get hotter than lighter spandrel colors. Moving air (a.k.a. convection) flows past both glass surfaces and removes some of the heat. Convective cooling on the exposed, exterior surface is naturally much greater than for the interior surface, which is typically separated by at least 1 to 2 inches from insulation. Conductive and radiative (IR emission) heat loss also influence the heat balance but are much smaller than the convective heat loss in this case.

The thermal conditions are different for an IGU, which is shown in Figure 2 on the following page. Solar energy transmitted through the outer lite reaches the inner lite, where a significant portion is absorbed and converted to heat. There is very little convection on surface 4 and almost none on surface 3 to dissipate heat build-up. The resulting equilibrium shift causes the inner lite to heat up.

Low-e coatings, designed to save energy by reflecting IR radiation, cause a further shift in the heat balance. As the inner lite heats up, radiative heat emitted from surface 3 crosses the IGU cavity and reaches surface 2. Instead of being transmitted and exiting the IGU, this IR radiation is reflected by the low-e coating back to the inner lite, where it is re-absorbed and converted back to heat. In essence, this situation creates a reasonably efficient solar collector. The limited dissipation of heat from surface 4 will be further reduced if more insulation is used or if the air gap between the insulation and the spandrel IGU is decreased, leading to higher lite temperatures. In highly insulated spandrel IGUs combining low-e coating on surface 2, the temperature gradient of the inner lite can exceed 130 °F.

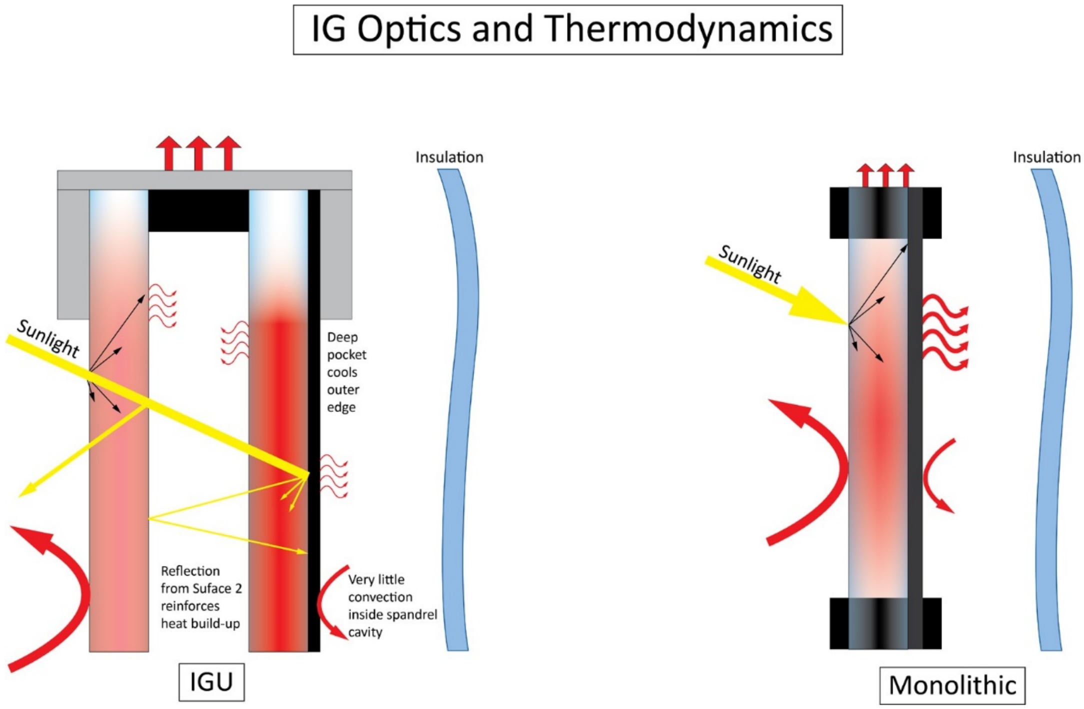

Figure 2

Temperature gradient is heightened when low-e is combined with close insulation and other elements

It is important to note and understand that it is not necessarily excessive heat that causes concern. As long as the lite of glass heats up evenly from center to edges, thermal stress is minimal. However, a thermal gradient results when the heating is not uniform due to shading or masking. This can lead to high levels of thermal stress even at relatively low temperatures and result in glass breakage. A frame can mask the perimeter of the lite, resulting in a cooler area, relative to the exposed section. In the same manner, a temperature gradient can be caused by shadows from a tree, an overhang or mullion, or some neighboring structure. The gradient is most pronounced in the morning after a cold night, as the glass is warmed by the rising sun; which is a good example of conditions necessary to develop thermal stress. On eastern elevations, this warming takes place over the first few hours after sunrise at which point the gradient is at its maximum. Southern or western elevations may also have high stress levels depending on sun path, amount of solar radiation, outside temperature and other factors. Thermal conduction from the center to the edge of the lite works to reduce the gradient, and at the same time, the intensity of sunlight on the lite itself lessens due to the angle of its incidence. The gradient typically lessens from its maximum as the day progresses. (Figure 3) In a recent published case, a typical temperature gradient of 130 °F was measured on a building in the Northeastern U.S. in April for a highly insulated double-glazed unit.

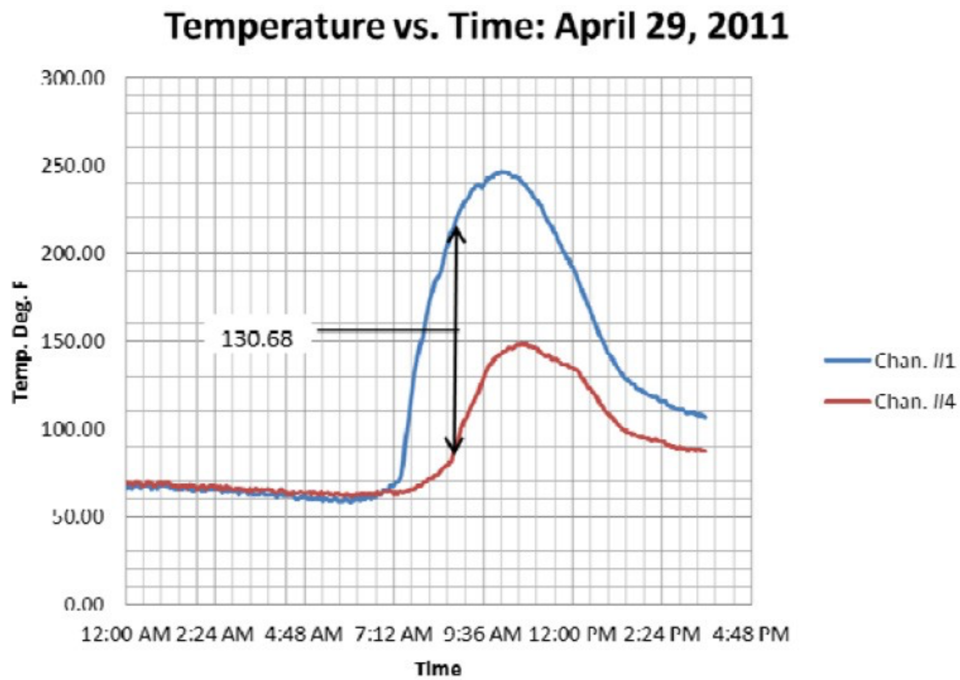

Figure 3

Center and periphery temperature gradient based in a northeastern U.S. state, April morning

Translation into Thermal Stress

Glass, like other materials, undergoes thermal expansion with increasing temperature. The thermal expansion is greatest in the area of the greatest heat build-up. In the example of a captured lite, the expansion is greatest in the center of the lite and least in the cooler perimeter. Because glass is rigid, the result is a net tensile stress at or near the edge of the lite as shown in Figure 4.

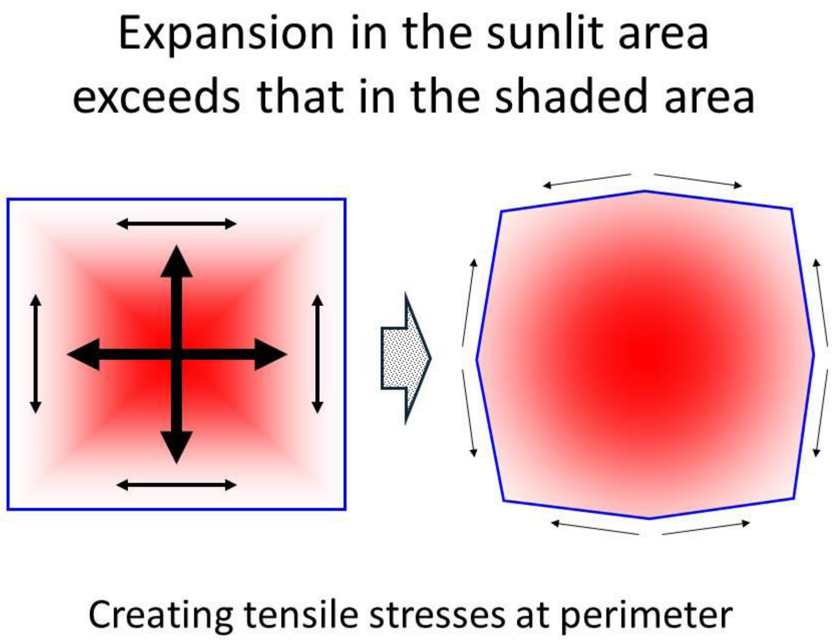

Figure 4

The hotter center expands against the cooler edge, creating tension

The magnitude of the stress depends upon the amount of the temperature gradient and two properties of the glass: the Coefficient of Thermal Expansion, and the Modulus of Elasticity. For float glass (soda lime glass), each one degree Fahrenheit temperature difference from the center to the edge of a lite results in a tensile stress of approximately 50 psi at the edge of the lite. Using this relationship, a temperature gradient of 130 °F would induce a tensile stress of 6500 psi at the edge.

Breakage occurs when the tensile stress exceeds the tensile strength of the glass.

Factors that Influence Thermal Gradients

Environmental Factors

Solar Radiation
The level of solar irradiance depends upon the geographic location, which takes into account various factors, including latitude, altitude and air mass. Solar irradiance is one factor that can influence the temperature gradient on the glass, but alone does not result in a high thermal stress.

Temperature
Typically, a significant temperature gradient will develop in a spandrel glazing unit when the inboard lite is colder and then heats quickly. Low overnight temperatures followed by warm sunny mornings is one scenario that can create such a temperature gradient.

Orientation
In the northern hemisphere, eastern and southeastern elevations will face the sun in the morning and experience the rapid heating that could induce significant thermal stress.

Exterior Shading
Shadows falling on some part of the glazing unit will generate a temperature gradient. This gradient is largest when there is partial and minor coverage of the lite, when the shadow edges are sharp or crisp (not diffuse or fuzzy) and when the shadow is moving slowly and/or it is acutely shaped.

Glazing Design
The glazing design is paramount to either inducing or avoiding thermal stress. Because of the thermodynamics involved, field failures share several of a number of common factors.

Outer Lite
The outer lite is relatively unsusceptible to thermal breakage, since it is typically heat-strengthened and is cooled by convection on the exterior surface. However, it can impact the probability of breakage of the inner lite. Highly transparent outer lites will allow more solar radiation to impact, and be absorbed by, the inner lite. The transparency of the outer lite will impact the heating of the inner lite. Low-e coatings on surface 2 will reflect back the infrared radiation that is reflected from the inner lite. The inner lite will absorb a portion of this energy, contributing to further heat build-up. Less efficient or no low-e coatings allow more of that energy to exit the spandrel assembly. Please see Table 2 for specific examples.

Color
Darker colors absorb more of the visible light than lighter colors. That energy is transformed into heat, increasing heat build-up.

Framing
This is a very important factor to be considered. Anything that tends to keep the perimeter of the glazing unit cool will also tend to increase the temperature gradient. Thermally conductive framing systems, deep concrete pockets, light colored frames, or any system that would function as a heat sink will act to create thermal stress during morning warming.

Building Elevation with an Inside Corner Condition
Where light is reflected from one lite onto another, as can happen with inside corners, the total solar radiation incident on the lite will be increased and so will the potential for heat build-up.

Insulation
Insulation will restrict the ability of the inner lite to dissipate heat, leading to greater heat build-up. The closer the insulation is to the glass, the less convective cooling can occur. It is important to note that this factor has been implicated in field failures and not necessarily because of the design, but sometimes due to improper installation.

Argon-filled IGUs
Because argon gas is less thermally-conductive than air, IGUs that are argon-filled compared to air-filled will have a higher inboard lite temperature, thus increasing the potential for thermal stress in the inboard lite.

Factors that Influence Tensile Strength

Surface Compression
Glass that has been heat-treated will resist greater loads than annealed glass straight from the primary glass manufacturer. For that reason, spandrel glass is typically heat-treated. According to ASTM C1048, heat-strengthened glass is defined as having a surface compression of 3500-7500 psi (24-52 MPa) and is considered to be approximately twice as strong as annealed. According that same standard, glass that has been fully tempered is defined as having a

surface compression of at least 10,000 psi (69 MPa) and is considered to be approximately four times as strong as annealed. This strength relationship has even been included as a factor in ASTM E1300 *Standard Practice for Determining Load Resistance of Glass in Buildings.* Although each kind of heat-treated glass is defined by a range of surface compression, the standard makes no distinction between glass at one end or the other of its respective range. As a result, glass that meets C1048 and has a surface compression of 4000 psi is considered 'heat-strengthened' and no different from glass that is strengthened to 7000 psi.

Surface Flaws

The presence of flaws can greatly reduce the tensile strength of glass. Flaws are introduced in many ways and are often not visible to the naked eye. The likelihood of which they would become fracture origins depends on size, shape, orientation and position on the lite.

Edge Quality

Flaws are introduced at various points during the lifecycle of the glass, from the finishing steps at the float line, through transportation, and at various points in the fabricating process. The quality of the edge finish is an important factor in maintaining the overall tensile strength of glass.

Opacified Coated Glass Strength

Some opacified coatings have been shown to affect the resistance to thermal stress breakage when compared to uncoated glass. The effect is dependent on the coating. The specifier is encouraged to inquire about opacified coated glass strength.

Mitigation Strategies

Reducing Thermal Stress

It is important to estimate to what extent there may be a problem. If all the risk factors are low, then design flexibility is maximized. If several or all of the factors are high, then it is more limited.

Table 1: Environmental risk factors

Environmental factor	High risk*
Solar radiation	> 750 W/m2
Altitude	> 5,000 ft
Winter design temperature	< -13 °F
Orientation	South, Southeast or East

*Anything outside of these parameters does not necessarily imply that the risk has been completely mitigated. When environmental risk factors are high, the building design should address root causes of thermal stress by minimizing thermal gradients to the extent possible within the overall design goal.

Table 2: Design considerations

Design considerations	Lower thermal stress	More thermal stress
Framing	Structurally glazed or non-thermally broken dark colored framing	Captured with thermally broken framing
Building Elevation with an Inside Corner Condition	Not present or only on northern elevation	Present on elevations where reflection falls on otherwise sunlit units
Exterior shading	No shadows or large, straight shadows	Small shadows with angles
Color of inner lite	Light	Dark
Low-e coating	Low solar transmittance	High solar transmittance
Outer lite	Tinted	Highly transparent
Insulation	Multi-inch space between insulation and innermost lite	Little or no space between insulation and innermost lite
Ventilation	Yes	No
Other design factors	<10" vertical mullions, <2" over- hangs, >75% of glass shaded	>20" mullions, >3" overhangs, 'V' or 'L'15-35% shaded

Increasing Tensile Strength

It is recommended that all spandrel glass be heat-treated according to ASTM C1048, either heat-strengthened (HS) or fully tempered (FT). Various factors would determine if the lite should be fully tempered. If the risk factors are numerous and high, and the root cause(s) cannot be sufficiently addressed through design, then additional measures can be taken to increase the tensile strength of the spandrel glass, for example using fully tempered inner lite(s). This doubles the strength over HS glass and provides a comfortable safety factor for most situations.

One should also consider that the tensile strength of FT and HS glass lites can be reduced by any number of conditions arising when the lite is produced and then fabricated into its final configuration. The presence and nature of surface flaws, edge quality variation, and the opacifying coating have been mentioned as factors that influence tensile strength.

Opacifying Coating Options

Some opacifying coatings have been demonstrated to not lower the tensile strength of heat-strengthened or fully tempered glass. Thus, heat-treated glass opacified with these types of coatings can be expected to have the strength that would be expected of newly fabricated glass. Therefore, when considering factors to mitigate the occurrence of breakage due to thermally induced tensile stress, the effect of opacifying coatings on glass should be considered.

Conclusion

With the current emphasis on energy efficiency, a number of design elements are combining to create severe thermal stresses in spandrel glass, which in rare cases has led to breakage. When spandrel glazing was primarily monolithic, convection across the exterior surface of the spandrel lite prevented the extreme temperature gradients that generate a large thermal stress. Today's insulating glass constructions increase the potential

for thermal stress on the inner lite due to high visible transmittance and more efficient low-emissivity coatings (double and triple silver) on the inside of the outer lite. Dark opacifier coatings on the interior lite result in even greater heat build-up. Highly insulated spandrel cavities, especially when the insulation is close to or touching the glass unit, allow for little dissipation of this built-up heat. In certain environmental locations, these factors can combine to create temperature gradients of 130 °F or more from center to edge. This temperature gradient can contribute 6500+ psi thermal stress at the edge of the lite. Breakage can result if this thermal stress exceeds the actual tensile strength of the lite, which is influenced by heat-treatment, and the presence and nature of surface flaws, edge quality variations, and the opacifying coating.

The combination of environmental, design and tensile strength factors determine the overall risk of thermal breakage. Mitigation strategies that consider these factors can be used to either prevent large thermal gradients from developing on the inner lite, or to increase or maintain the tensile strength of the inner lite. Engineers should understand these phenomena, assess the risk that is associated with a project, and choose a mitigation strategy to help prevent thermally induced breakage of spandrel glass.

References

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