A Review and Study of Thermal Stress Conditions in Heat-Strengthened Spandrel Glass

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A Review and Study of Thermal Stress Conditions in Heat-Strengthened Spandrel Glass

Items to Cover

- Definition and Description of Thermal Stress
- Conditions Causing Thermal Stress
    - **Altitude**
    - **Building Design**
    - **Design Winter and Summer Temperatures**
    - **Orientation**
    - **Glass Edge Conditions**
    - **Coatings and Applied Films**
    - **Framing Considerations**
    - **Glass Kind**
    - **Glass Type**
    - **Heat Traps From Indoor Conditions**
    - **Insulation**
    - **Solar Absorption**
    - **Solar Radiation**
    - **Spandrel Condition**
    - **Storage Methods**

A Review and Study of Thermal Stress Conditions in Heat-Strengthened Spandrel Glass

Definition and Description of Thermal Stress

1. Thermal stress induced by differential heating in glass has long been recognized as a major mechanism that can result in the failure of window glass.
2. The vast majority of thermal stress failures initiate along a single edge of the glass due to tensile stresses induced by differential heating.
3. The differential heating is caused when the edges of window glass, installed in frames is shielded from the direct effects of solar radiation or heat sources, while the central areas of the glass are exposed to the direct effects of the solar radiation.
4. The window glass thus supported is subjected to solar radiation causing the temperatures of the central areas of the glass to be increased while the temperatures along the edges of the glass remain relatively constant.
5. This differential heating induces significant tensile stresses acting parallel to the glass edges. Depending upon the character of the flaws distributed along the edge and the edge area, thermally induced fractures have resulted.

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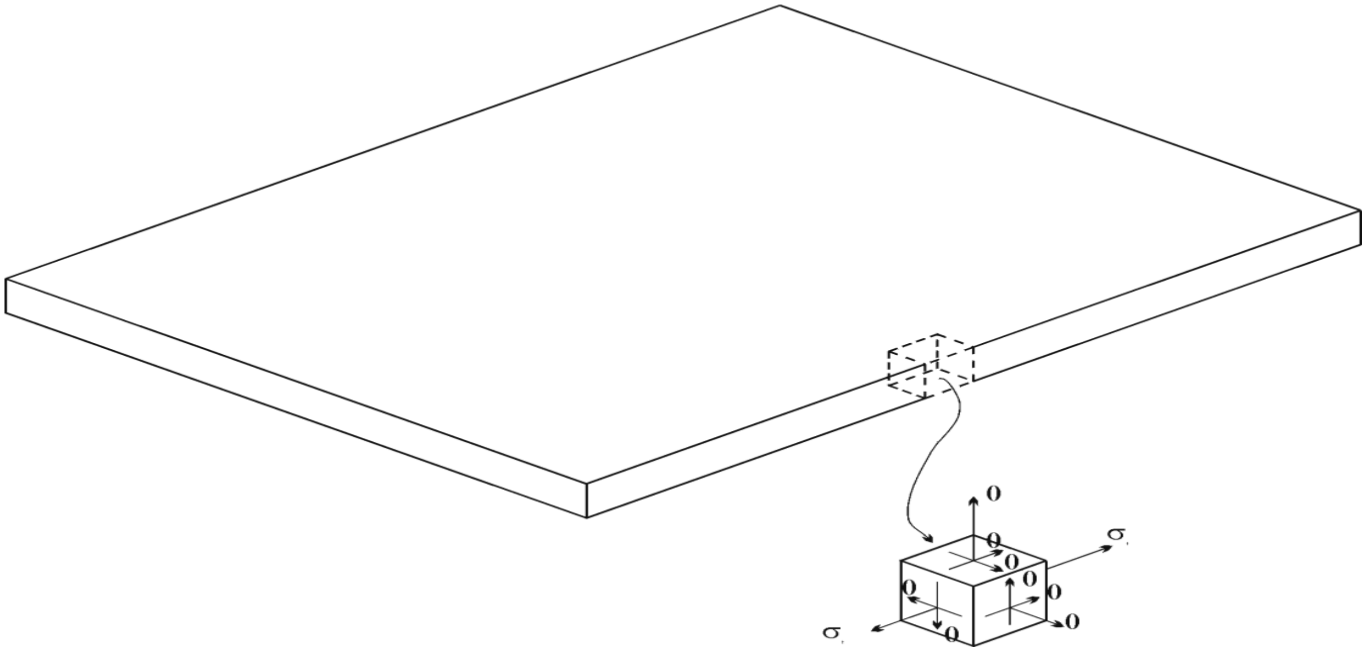
Definition and Description of Thermal Stress



Thermally induced stresses are membrane stresses, both the top and bottom surfaces of the glass are exposed to the same stress

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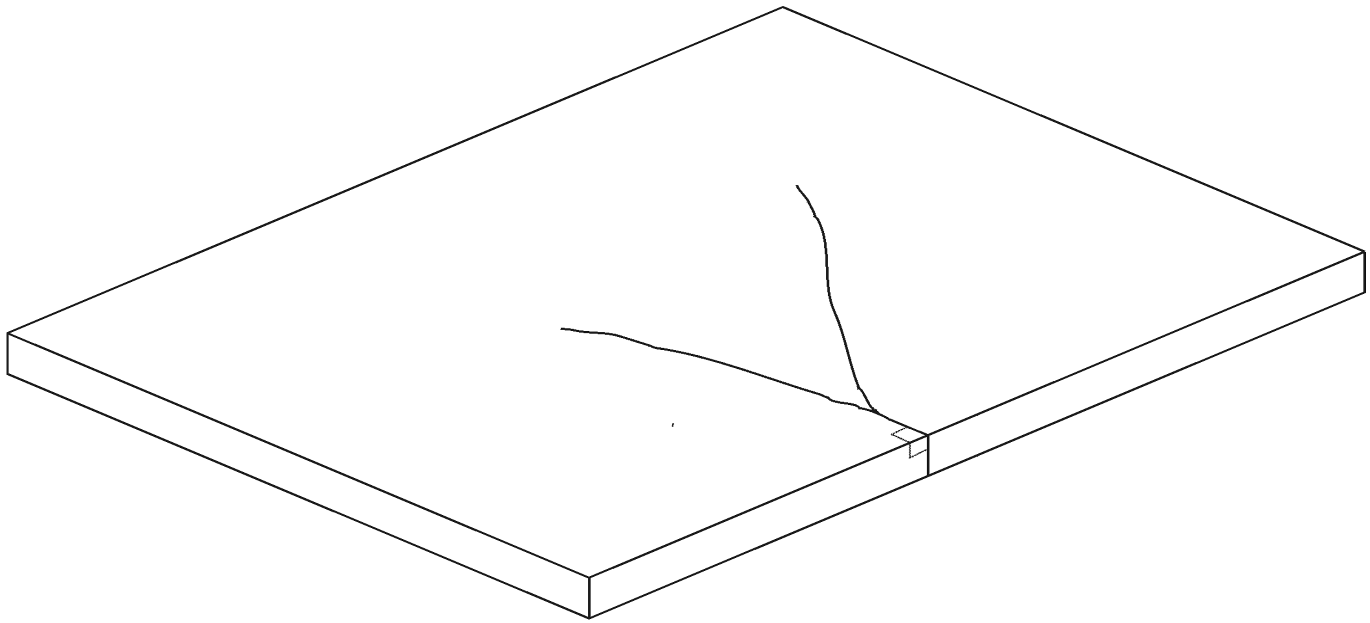
Definition and Description of Thermal Stress



Breakage at the edge of a thermally loaded glass plate usually results in a crack normal to both vertical and horizontal projections of the edge as shown in the figure with the crack propagating inward.

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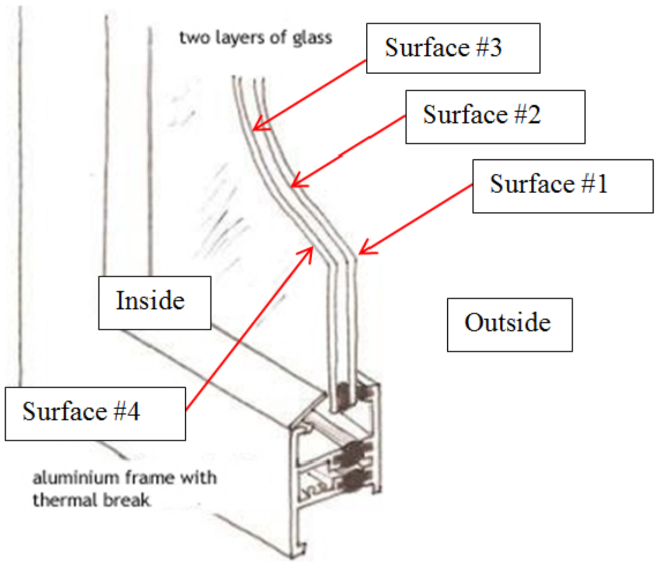

Figure 1: Typical IG Unit

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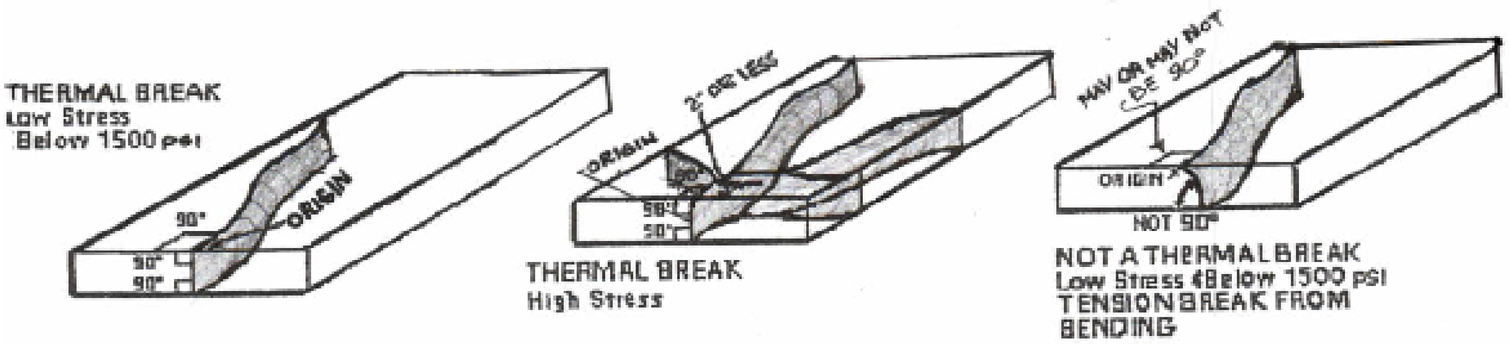
Definition and Description of Thermal Stress



Examples of thermal stress fractures. The stress distribution in the plate becomes more complicated as the crack may branch in different directions depending on the transient state of stress within the glass as it fractures. The examples shown above illustrate a low thermal stress fracture along with a higher thermal stress break and a mechanical stress break.

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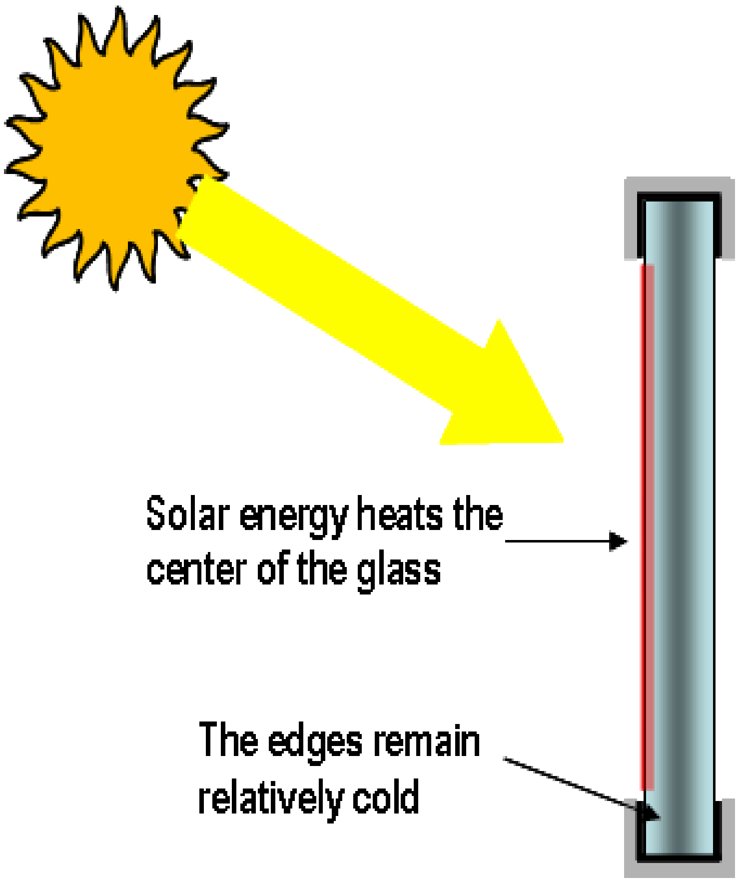
In a thermal breakage situation, the edges of the glass are subjected to higher tensile stresses than the surface of the glass away from the edges. The thermally induced edge stress will be of a tensile condition, which occurs when the center of the glass is heated substantially and the outer edges of the glass, protected by the glazing system, remain much cooler and create tension as the center portion expands.



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Conditions Causing Thermal Stress

Building Design

Shadows from vertical mullions and horizontal frame overhangs cause temperature differences in glass. Vertical mullions greater than 20" deep develop "static" shadows, which leads to high glass thermal stress.

Overhangs greater than 3" deep develop static shadows. Mobile shadows typically develop 11% more stress than the "no shadow" situation.

Static shadows develop about 35% more stress than the "no shadow" condition.

Unusual shadow patterns e.g. "V" or "L" shaped shadows cause higher

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Conditions Causing Thermal Stress

Building Design

Unusual shadow patterns e.g. “V” “L” or “angular” shaped shadows cause higher cause higher thermal stresses than the simple cold edge case previously discussed.

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Conditions Causing Thermal Stress

Glass Edge Condition

Very Low risk - Laser Cut edges, with no damage

Low risk

a. Polished edges with no damage

b. Ground edges with or without any exposed shiners, and with no damage

c. Clean-cut edges with no damage.

d. Clean-cut edges with a uniform seam using a 120 grit or finer belt or grinding wheel, and no damage. The seam is where the cut edge is ground off to an angle of approximately 45 degrees. The width of the seam is approximately 0.8mm (0.030”).

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Conditions Causing Thermal Stress

Glass Edge Condition

Medium risk:

a. Seamed edges using a belt or grinding wheel with a grit less than 120

b. Ground edges with offset grind that is caused by improper grinding wheel set-up. One of the original cut edges is exposed above the grind.

c. Any clean cut or seamed edge with borderline cut edges.

d. Borderline cut edges – shark teeth up to ½ the glass thickness, serration hackle, and/ or chips

Note 1. Shark Teeth: **Dagger-like imperfections which start from the score surface. The edge strength and resulting potential for glass breakage increases as the depth, roughness and number of shark teeth increases.**

Note 2. Serration Hackle: **Edge imperfections, usually perpendicular to glass surface, which occur at surface opposite the score. The edge strength and resulting potential for glass breakage increases as the density and depth increases.**

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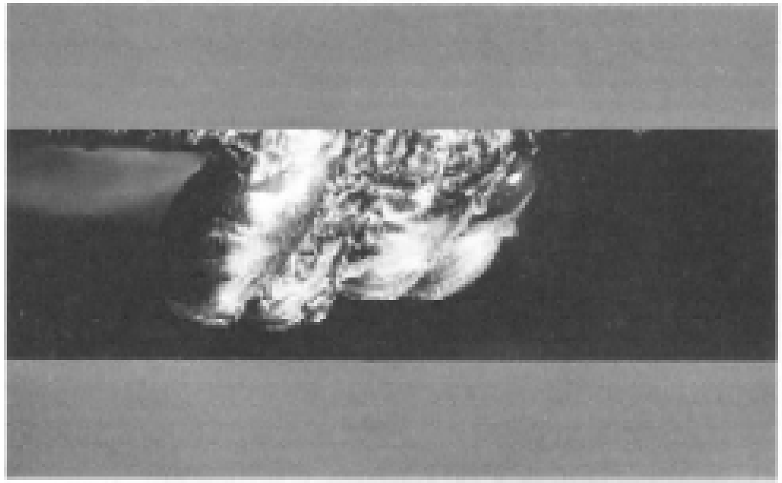
Conditions Causing Thermal Stress

Glass Edge Condition

High risk

a. Cut Edges with deep serration hackle
b. Cut Edges with deep shark teeth (> ½ thickness)
c. Cut edges with serration hackle and spalls
d. Impact damage to any type of edge condition



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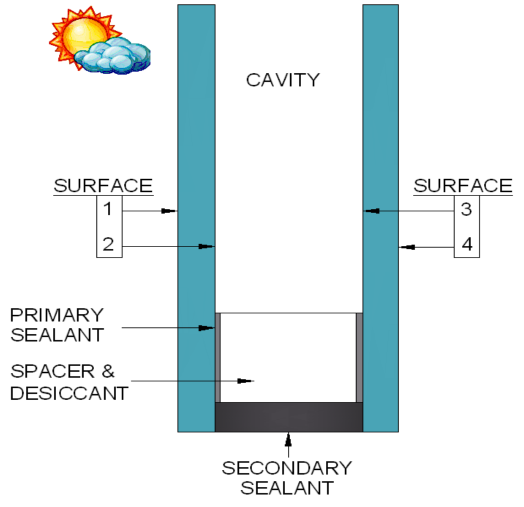
Conditions Causing Thermal Stress

Applied Films (post installation)

Retrofit films are films applied to glass and insulating glass units after installation either to reduce glare and the amount of solar energy entering a building or home (tinted or reflective films) and/or to hold the glass in place should the glass fracture (clear films). Normally the film is placed on the indoor lite (surface #4 - see Figure) as this is the surface that is least exposed to harsh weather conditions and is the most accessible surface to the installer.



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Conditions Causing Thermal Stress

Applied Films (post installation)

Reflective and tinted films, when placed on surface #4, tend to absorb solar energy and reflect the energy back into the glazing cavity. This elevates the temperature of the indoor lite of glass and the glazing cavity to a higher temperature than it normally would be without the film.

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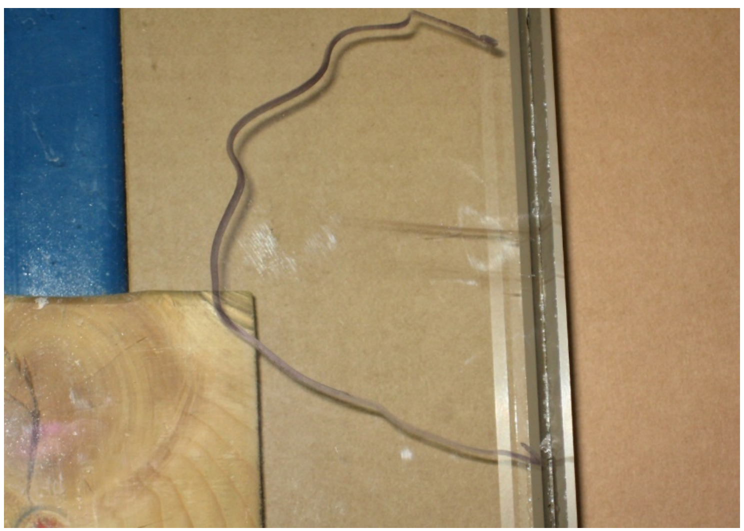
Conditions Causing Thermal Stress

Framing System Considerations

Excessive Cover/Shadow



Inside Corner

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Conditions Causing Thermal Stress

Spandrel Glass Conditions

Risk depends on what is behind the spandrel (insulation). Heat treated glass has been recommended for spandrel conditions. For some extreme conditions heat-strengthened glass may not be sufficient and fully tempered glass may be required.

Low risk: fully-tempered glass

Medium risk: heat-strengthened glass.

High risk: annealed glass

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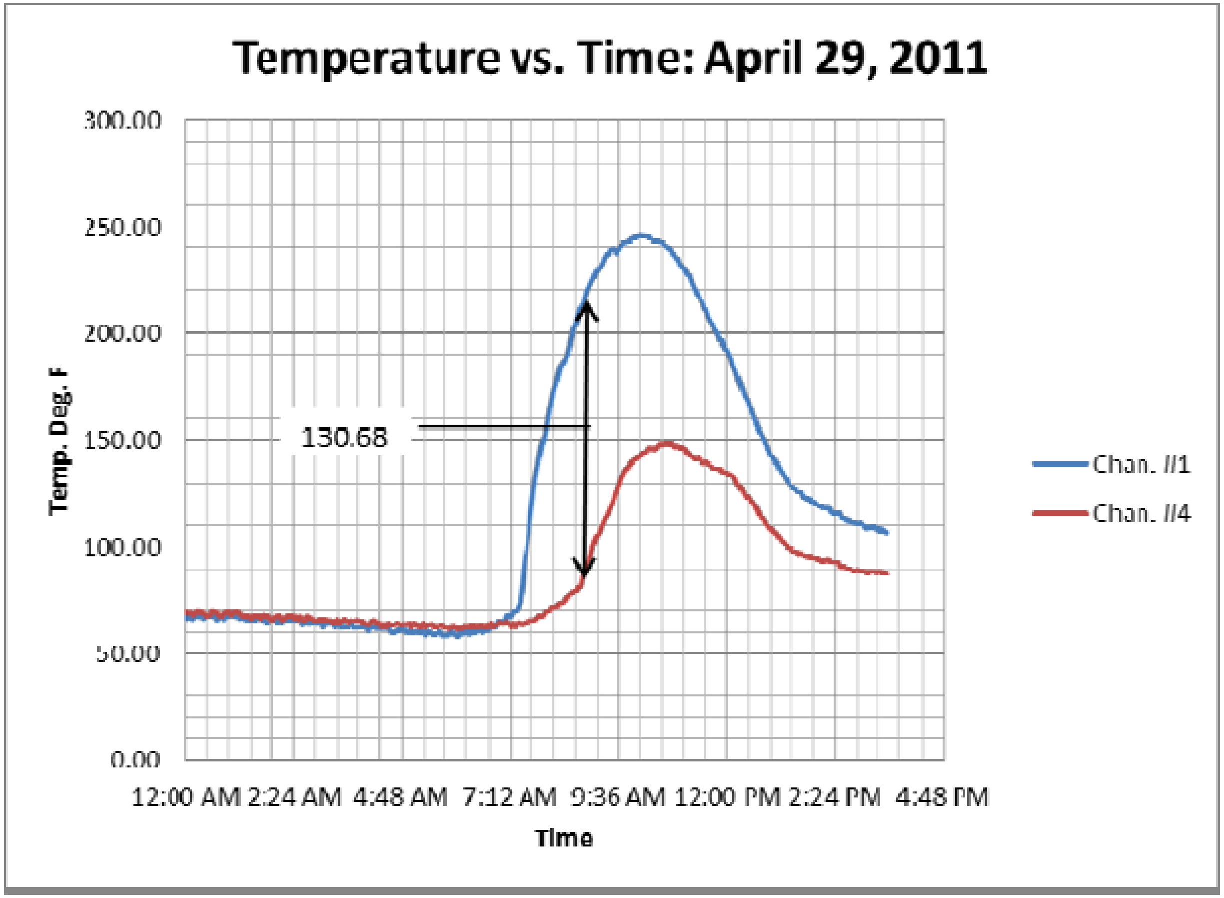

WJE report with insulation against #4 surface of spandrel unit- temperature recordings near edge and at center of glass

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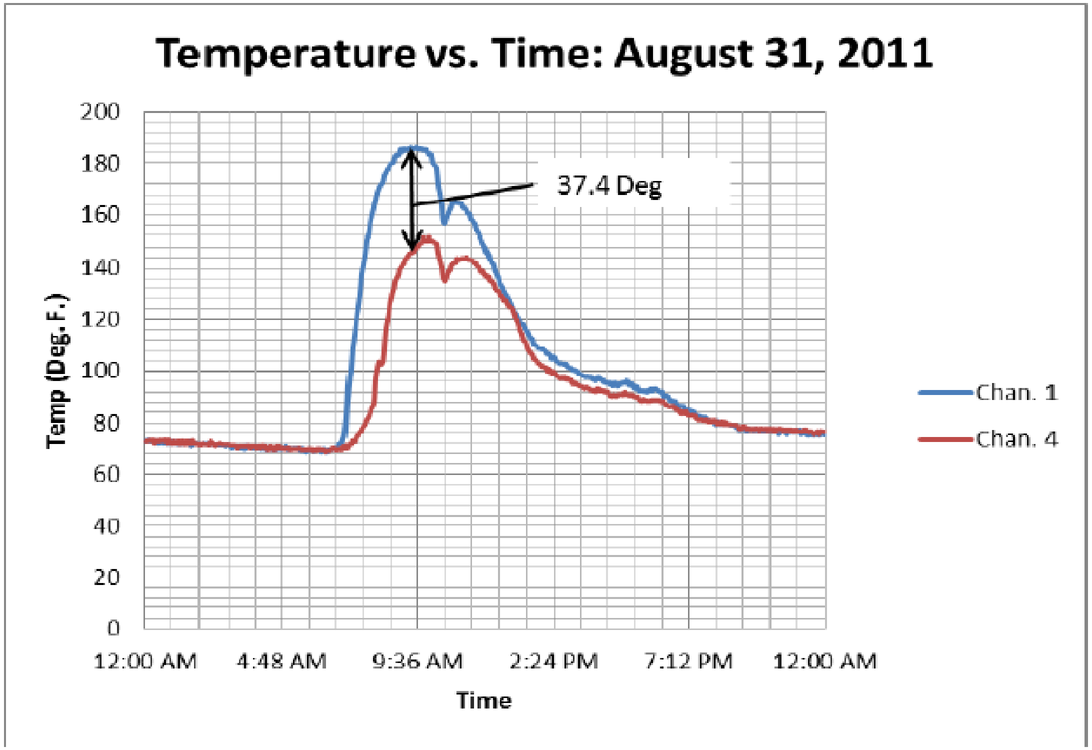

WJE report with insulation 8.5”away from the #4 surface of spandrel unit-temperature recordings near edge and at center of glass

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Conditions Causing Thermal Stress

Spandrel Glass Conditions

The thermal stress ($\sigma_{thermal}$) in glass can be estimated by taking the modulus of elasticity (E) times the coefficient of thermal expansion (ε) times the change in temperature (ΔT). Written in a formula this becomes:

$$\sigma_{thermal} = E\,\varepsilon\,\Delta T$$

Where $E = 10.4 \times 10^6$ psi for float glass

$\varepsilon = 49 \times 10^{-7}$ in/in/°F

ΔT = change in temperature in °F

Conditions Causing Thermal Stress

Solar Absorption

Solar absorptance is the amount of total solar radiation absorbed by the glass (expressed as a percent) and is one of the highest ranking items relating to thermal stress evaluation in annealed glass.

Low risk: <50% exterior lite and / or <12% room side lite

Medium risk: 50 to 60% exterior lite and / or 12%-15% room side lite

High risk: Over 60% exterior lite and / or >15% room side lite

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Conditions Causing Thermal Stress

Solar Radiation

The solar irradiance is important to the evaluation of thermal stress as this is the basic load that will heat the glass having a solar exposure along with the indoor-outdoor temperature difference. The solar irradiance (SI) will vary based on the latitude, time of year, time of day and elevation.

Low risk: SI < 300 W/m^2 , 95 BTU/(hr ft^2)

Medium risk: SI 300 – 749 W/m^2 , 95 – 237 BTU/(hr ft^2)

High risk: SI > 750 W/m^2 , 238 BTU/(hr ft^2)

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Fracture Origin Example-HS Glass with Ceramic Enamel

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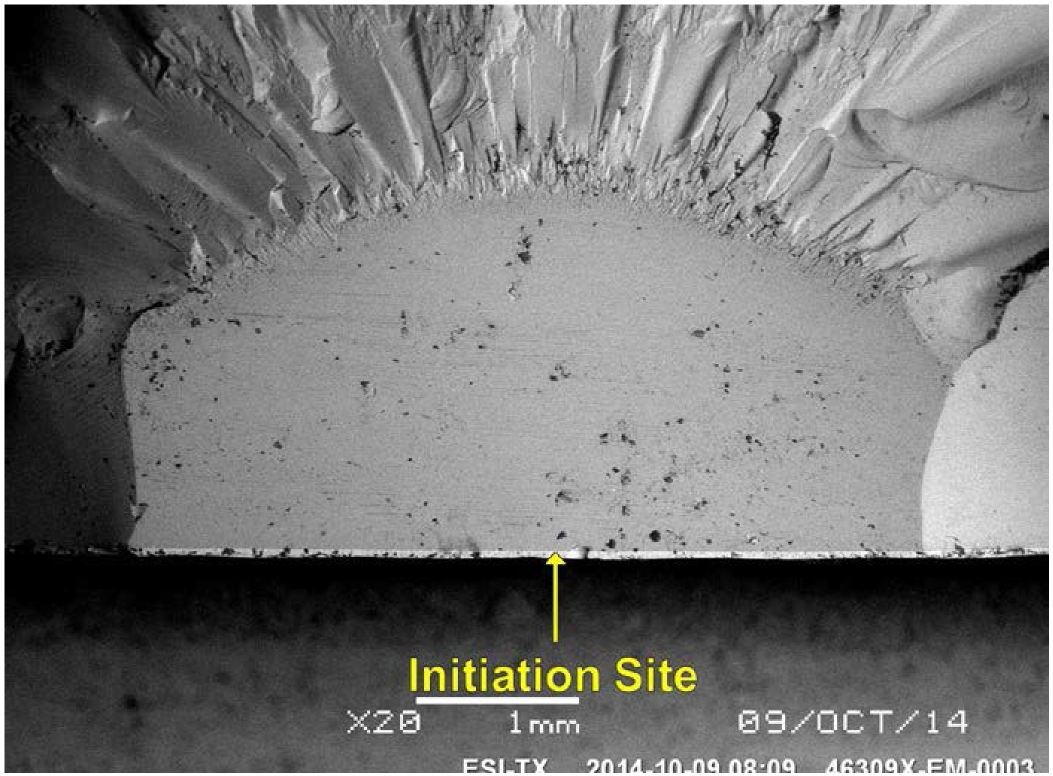

Heat-Strengthened Glass Fracture in Spandrel

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Break patterns of three samples of spandrel glass fracture

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Spandrel area with insulation tight up against #4 surface of insulating glass

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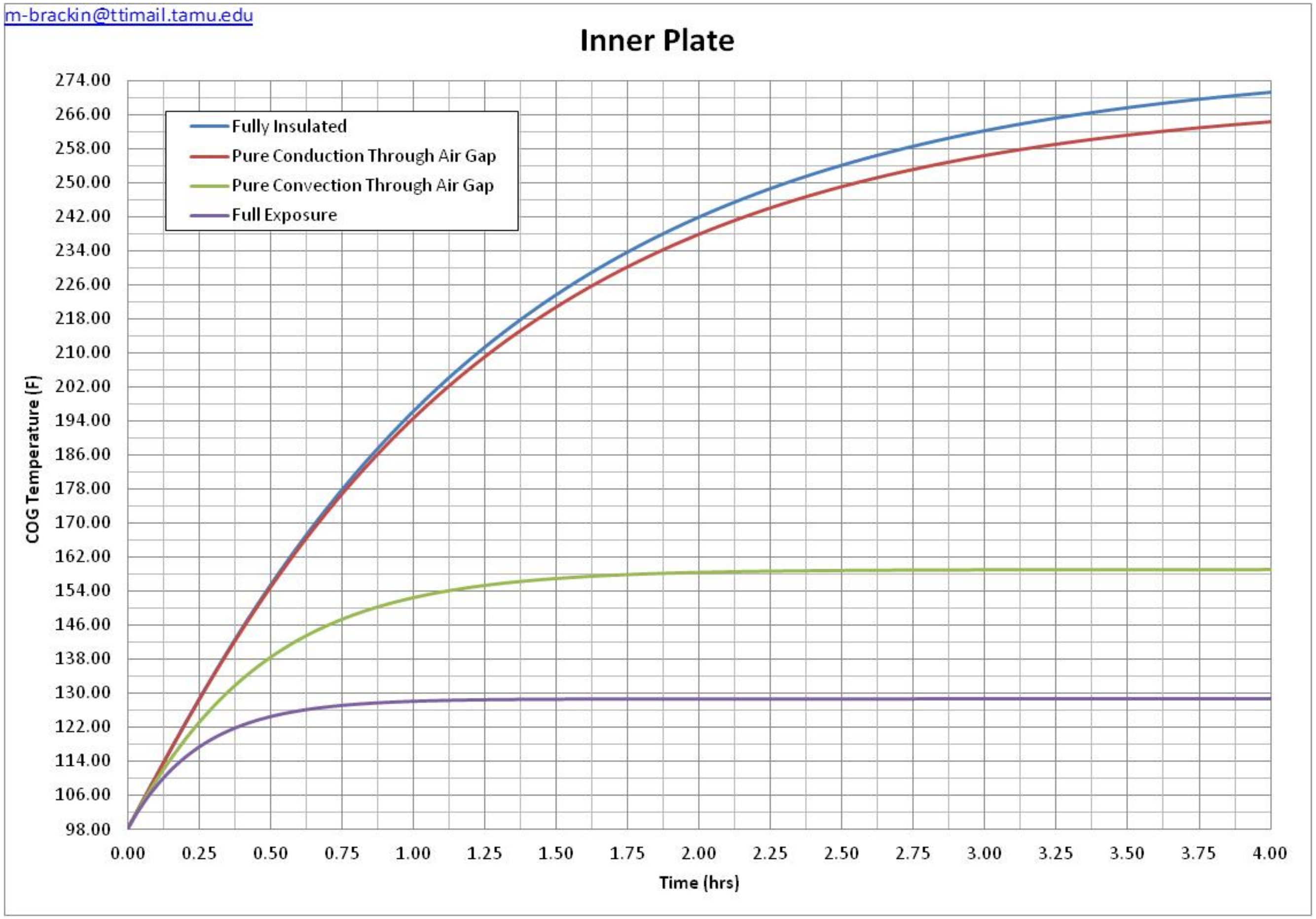

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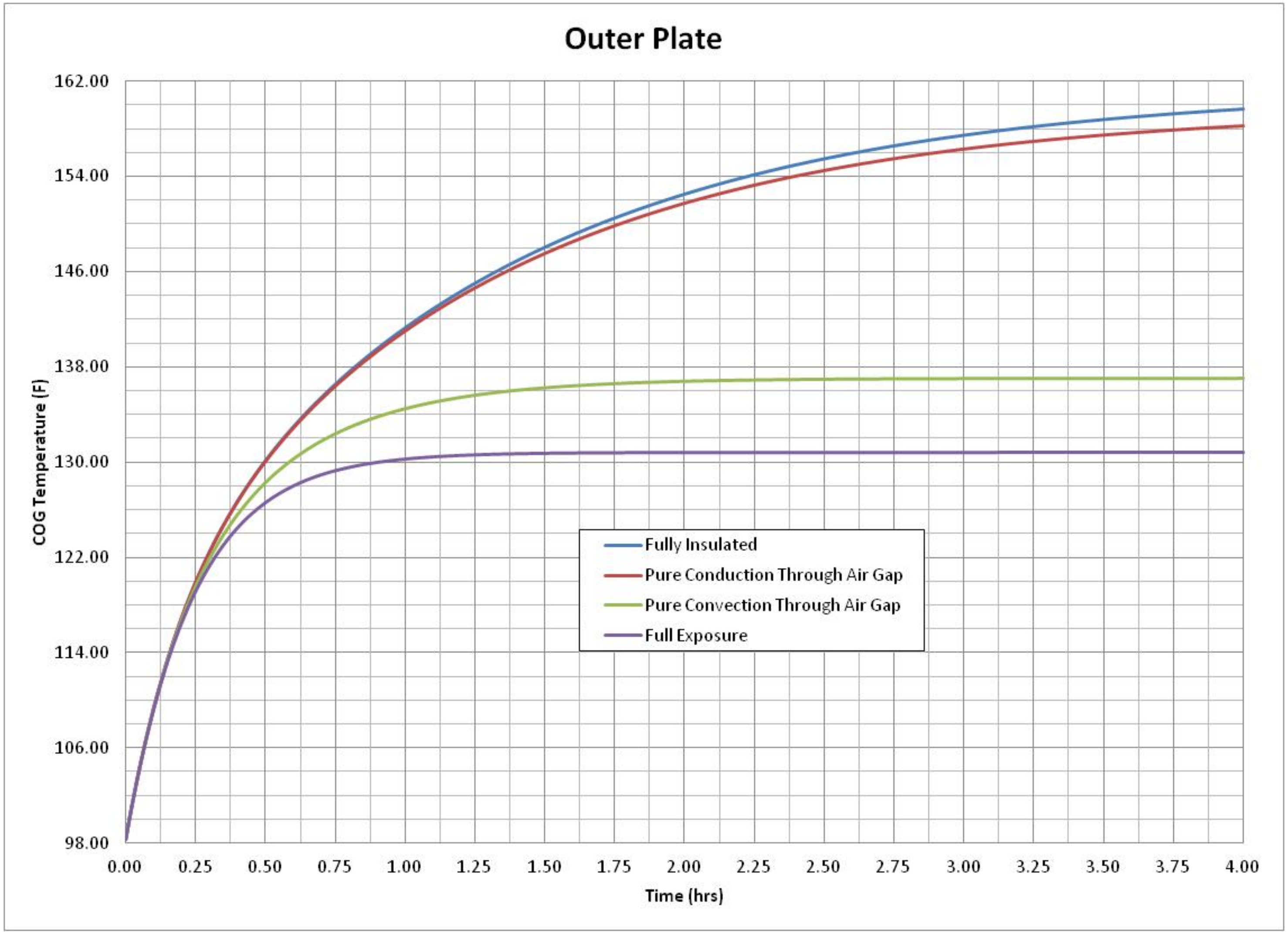

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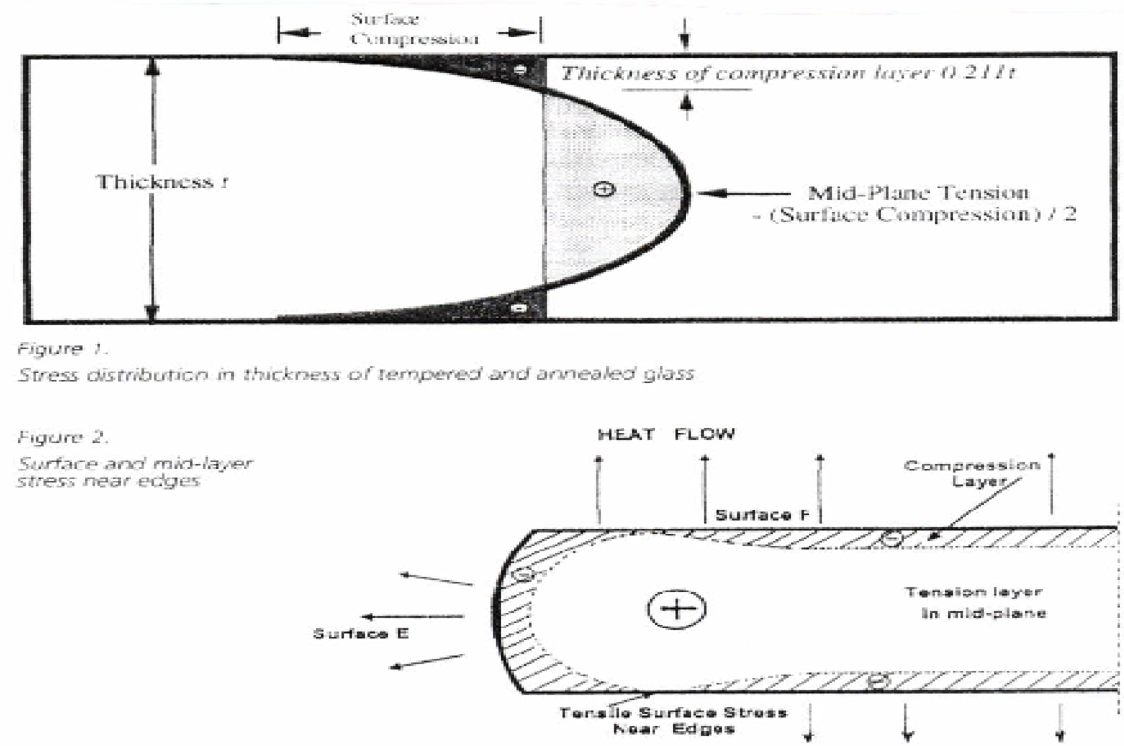

Surface compression and mid-layer tension stress illustration near edges Alex Redner, Strainoptics

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EN 1863-1:2000

9 Mechanical strength

The value of mechanical strength can only be given as a statistical value associated with a particular probability of breakage and with a particular type of loading.

The mechanical strength values apply to quasi-static loading over a short time, e.g. wind loading, and relate to a 5 % probability of breakage at the lower limit of the 95 % confidence interval. The values for different types of glass are listed in table 5.

Table 5: Values for the mechanical strength of heat strengthened soda lime silicate glass

Type of glass	Minimum values N/mm^2	psi
Float: clear tinted coated	70	10,150
Enamelled float (based on the enamelled surface in tension)	45	6525
Patterned glass and drawn sheet	55	7975

At least 10 specimens of heat strengthened soda lime silicate glass shall be tested according to prEN 1288-3. The 5 % breakage probability, statistically evaluated at the lower limit of the 95 % confidence interval, shall be not less than the value in table 5.

$MPa = N/mm^2 \times 145 = psi$

EN Standard-Mechanical Strength of Heat-Strengthened Glass

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Items for investigation

Structural issues within the ceramic enamel-porosity and fineness of grinding process

Coefficient of thermal expansion of enamel and glass concerns

Application techniques and enamel thickness

Temperature variations during the heat-treating and cooling process

Absorption properties of colors

Quality assurance programs at supplier and fabricator

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OVERVIEW

- Spandrel Breakage
  - Background
  - Incidences of breakage on different buildings
  - Various climate zones
  - Ceramic enamel/organic
  - Grey and black
  - Outboard lite - low-e and non low-e
  - IGU and monolithic
- Standards, Papers and Testing
  - EN
  - ASTM E1300 discussions
  - Compliance with C1048-subtest (C978)
  - WJE paper Thermal Breakage of Spandrel Glass: A Case Study, Forensic Engineering 2012 ASCE
  - *The Strength of Enameled Glass* - P. Krampe - Krampe – Beratende Ingenieure – Berlin / Dresden, German
  - Testing and evaluation of testing-small samples and full size panels
- Mitigation
  - Insulation depth and position
  - Ventilation/non-ventilation
  - Design criteria
  - Different formulas for ceramic enamels and other materials
  - Application methods

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