Thermal Breakage Prediction

The prediction of glass breakage due to thermal stress is an important analysis for the longevity of a window. Thermal breakage occurs when there is a large temperature differential between the edge and center of glass. The use of heat-treated glass (tempered or heat-strengthened) in conditions where there is a high probability of glass breakage will greatly reduce this risk. This document outlines a methodology for estimating glass breakage probability from thermal stress.

Cardinal recommends the use of FGIA's *TM-1500-14 GUIDELINES TO REDUCE INSTANCE OF THERMAL STRESS* solar absorption limits for determining risk of thermal stress breakage when applicable. Their method is most applicable to dual pane IG units and cannot be used in all situations. Cardinal also recommends considering anything over 55% total solar absorption on the exterior lite high risk (compared to FGIA's recommendation of >60%).

When simple estimates based on absorption are not appropriate to estimate breakage potential, a thermal simulation of the window needs to be conducted using the appropriate glass, coatings, and environmental conditions. For the triple pane IG unit simulations below, Cardinal illustrates two environmental conditions: an extreme winter condition of -20 °F and a more typical condition of 0 °F outdoor temperature. Using the LBNL programs WINDOW and THERM, simulations were conducted for each window and glass type.

For each pane of glass, the edge of glass temperature without solar radiation was compared to the center of glass temperature with solar radiation. This was used to approximate the condition of a fully shaded window frame on a bright sunny cold day (typically the worst condition for thermal stress).

In order to calculate the glass stress, the difference in temperature (°F) was multiplied by the conversion factor of 50 psi/°F. This thermal stress can then be used to calculate breakage probability. Based on field experience, Cardinal used an average breakage stress of 4,500 PSI and a coefficient of variation (COV) of 20% for calculation of the breakage potential.

The environmental conditions of the simulation and the glass strength assumptions are both variables that should be considered by the window manufacturer, as this will have a strong influence on the calculated breakage probability.

The simulations that follow are for illustrative purposes and should be used for comparative purposes only. They are not an exact prediction of expected field breakage. They represent a "worst case" evaluation of the breakage potential. The values shown are based on the analysis by Cardinal IG of its IG products in generic window sash. As can be seen in the charts, the probability of breakage is affected by multiple factors which may include: sash and frame design, glass type, weather conditions, and glass edge quality.

Each window manufacture will experience different amounts of thermal breakage in the field due to the aforementioned factors.

The thermal breakage risk assessment guidelines were attributed to FGIA's TM-1500-14 *Guidelines to Reduce Instances of Thermal Stress* and Cardinal's field history experiences.

Cardinal's Simulations

Double-Pane IG Units

	2.2 mm, 3 mm, 4 mm, and 5 mm Glass Thickness[1]									
	LoĒ™ (#2) / Clear		LoĒ (#2) / LoĒ-i89® (#4)		Clear / LoĒ (#3)		Gray Tint / LoĒ (#3)		Bronze Tint / LoĒ (#3)	
Coating Type	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane
180	Low	Low	Low	Low	Low	Moderate	Low	Low	Low	Low
272	Low	Low	Low	Low	Low	Moderate	Moderate[2]	Low	Low	Low
270	Low	Low	Low	Low	Low	Moderate	Moderate[2]	Low	Low	Low
366	Low	Low	Low	Low	Low	High	Moderate[2]	Low	Low	Low
452	Low	Low	Low	Low	Low	High	Moderate[2]	Low	Low	High
340	Low	Low	Low	Low	Low	High	Moderate[2]	High	Low	High

Notes:

1. 2.2 mm not available in tints.
2. The use of Cardinal's LoĒ^3- 366®, Quad LoĒ- 452+®, and LoĒ^3- 340® are not recommended on the #3 surface of a two pane IG unit with a clear outdoor pane because of concerns for thermal stress breakage.
3. Thermal breakage risk was based on solar absorption and past field history: High: Exterior pane ≥55%, Interior pane ≥15%; Moderate: Exterior pane 50% to 55%, Interior pane 12% to 15%; Low: Exterior pane <50%, Interior pane <12%.

	6 mm Glass Thickness									
	LoĒ (#2) / Clear		LoĒ (#2) / LoĒ-i89® (#4)		Clear / LoĒ (#3)		Gray Tint / LoĒ (#3)		Bronze Tint / LoĒ (#3)	
Coating Type	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane	Outdoor Pane	Indoor Pane
180	Low	Low	Low	Low	Low	Moderate	High	Low	Moderate	Low
272	Low	Low	Low	Low	Low	Moderate	High	Low	High	Low
270	Low	Low	Low	Low	Low	Moderate	High	Low	High	Low
366	Low	Low	Low	Low	Low	High	High	Low	High	Low
452	Low	Low	Low	Low	Low	High	High	Moderate	High	Moderate
340	Low	Low	Low	Low	Low	High	High	High	High	High

Notes:

1. The use of solar control LoĒ™ coatings such as Cardinal LoĒ^3-366®, Quad LoĒ-452+®, and LoĒ^3-340® are not recommended on the #3 surface of a two pane IG unit with a clear outdoor pane because of concerns for thermal stress breakage.
2. Thermal breakage risk was based on solar absorption and past field history.
3. Thermal breakage risk was based on solar absorption and past field history. High: Exterior pane ≥55%, Interior pane ≥15%; Moderate: Exterior pane 50% to 55%, Interior pane 12% to 15%; Low: Exterior pane <50%, Interior pane <12%.

Triple Pane IG Units

The following triple pane insulating glass tables are based on breakage probability per 1,000 lites of glass. The glass breakage probabilities are characterized as follows: Greater than 20/1,000 is "High", 10/1,000 to 19/1,000 is "Moderate", and less than 10/1,000 is "Low". For "High" breakage probability glass, Cardinal recommends heat strengthening the glass.

The tables are intended to be used as a guideline for window producers, with their own judgment, in the decision for the use of heat-treated glass for the prevention of thermal stress breakage. Other than LoĒ-180®, Cardinal LoE coatings should not be used on the center pane lite in a triple pane IG unit.

Triple-Pane	Breakage Prediction Outdoor Temperature -20 °F and 0 °F Extruded Aluminum Clad Wood Windows					
	Outdoor Pane Breakage Probability per 1,000 Outdoor Temperature		Center Pane Breakage Probability per 1,000 Outdoor Temperature		Indoor Pane Breakage Probability per 1,000 Outdoor Temperature	
	-20 °F	0 °F	-20 °F	0 °F	-20 °F	0 °F
Clear/Clear /AL Spacer	0	0	2	1	15	4
180 #2/180 #4	0	0	35	36	9	4
180 #2/180 #5	0	0	8	7	15	6
180 #3/180 #5	0	0	83	83	25	10
180#2/180 #4/ i89 #6	0	0	72	67	55	27
272 #2/180 #4	0	0	3	3	3	1
272 #2/180 #5	0	0	1	1	5	2
272 #2/272 #4	0	0	74	77	7	3
272 #2/272 #5	0	0	4	3	16	6
272 #2/180 #4/i89 #6	0	0	5	4	6	3
272 #2/272 #4/i89 #6	0	0	100	98	17	8
270 #2/180 #4	0	0	2	2	3	1
270 #2/180 #5	0	0	1	1	4	1
270#2/270 #4	0	0	51	54	5	2
270 #2/270 #5	0	0	3	2	14	5
270 #2/180 #4/i89 #6	0	0	3	2	4	2
270 #2/270 #4/i89 #6	0	0	66	65	12	5
366 #2/180 #4	0	0	1	1	2	1
366 #2/180 #5	0	0	1	0	2	1
366 #2/366 #4	0	0	38	42	4	2
366 #2/366 #5	0	0	1	8	12	1
366 #2/180 #4/i89 #6	0	0	1	1	2	1
366 #2/366 #4/i89 #6	0	0	47	48	8	3
452 #2/180 #4	0	0	1	1	2	1
452 #2/180 #5	0	0	1	0	2	1
452 #2/452 #4	0	0	78	83	5	2
452 #2/452 #5	0	0	1	1	15	6
452 #2/180 #4/i89 #6	0	0	1	1	2	1
452 #2/452 #4/i89 #6	0	0	95	95	10	4
340 #2/180 #4	0	0	1	1	2	1
340 #2/180 #5	0	0	1	0	2	1
340 #2/340 #4	0	0	52	54	5	2
340 #2/340 #5	0	0	2	1	15	5
340 #2/180 #4/i89 #6	0	0	1	0	1	0
340 #2/340 #4/i89 #6	0	0	78	61	7	3

Notes:

1. Low Probability, Moderate Probability, High Probability for glass breakage.
2. **Center Glass Temperature Calculations:** The 0 °F conditions: outdoor temperature 0 °F, indoor temperature 70 °F, 12.3 mph windspeed, and full sun (248 BTU/hr-ft²-°F). The -20 °F conditions: outdoor temperature -20 °F, indoor temperature 70 °F, 12.3 mph windspeed, and full sun (248 BTU/hr-ft²-°F).
3. **Edge Temperature Calculations:** Were made using the same conditions as center of glass with the exception of no solar load on the edge. This is a worst case situation with the edge shadowed. Window edge temperatures were determined using the THERM program with a generic aluminum clad wood frame. The simulations were performed by an accredited NFRC simulator. All calculations were made using the Endur IG™ spacer. One exception is the first glazing (which is noted) used an aluminum spacer.
4. **IG Constructions:** Double-pane constructions were based on 3mm glass and a 13.0mm argon filled airspace. Triple-pane constructions were based on 3mm glass and two 13.0mm argon filled airspaces. The wider the airspace in a triple-pane, the higher the center glass temperatures, and therefore, the worst situation for thermal stress.
5. **Edge Damage:** Minor edge damage has been assumed in the glass stress calculations. In the case of shell chips, the same depth of chip will have a greater effect on the strength of 2.2mm glass than on 3mm glass. The same size chip in 2.2mm glass will therefore have a higher probability of breakage than in 3mm glass.
6. **Breakage Probabilities:** Estimated based on a “worst case” condition of shadowed edges with full sun on the center of the glass. The breakage probability in most applications will not be as high as those shown in the table. The breakage probabilities are based on 60 minute load duration with an average breaking stress of 4,500 psi, with a COV of 20%. The breakage probabilities are based on per 1,000 glass panes.

Conclusions

- Breakage potential due to thermal stress will vary greatly by window type and environmental conditions.
- The use of high absorbing or low solar heat gain products on the inboard surfaces (surface #3, #4 or #5) of an IG unit will increase the breakage potential and the need for heat strengthening.
- Heat treatment of the glass reduces the thermal stress breakage probability to less than 1 per 1,000.
- The use of Cardinal's LoĒ coatings on the exterior pane of double-pane and triple-pane insulating glass units reduces the breakage potential of the inboard pane in the IG unit.
- For triple-panes utilizing three coatings, the combination of LoĒ³-366® on the exterior pane, LoĒ-180® on the middle pane, and LoĒ- i89® on the interior pane offers excellent performance with low thermal stress.