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.

In order to estimate breakage potential, a thermal simulation of the window needs to be conducted using the appropriate glass, coatings and environmental conditions. For the 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 of a no solar condition was compared to the center of glass temperature of a full solar condition. 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 (in °F) was multiplied by the conversion factor of 50psi/°F. This thermal stress can then be used to calculate breakage probability. Based on field experience, Cardinal used an average breakage stress of 4500 PSI and a coefficient of variation (COV) of 20% for calculation of the breakage potential.

The environmental conditions of the simulation as well as the glass strength assumptions are both variables that should be considered by the window manufacturer, as both 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 including: sash and frame design, glass type, weather conditions and glass edge quality.

The thermal breakage risk tables at the end of this TSB are a conservative interpretation of the results. Each window manufacture will experience different amounts of thermal breakage in the field due to the aforementioned factors.

Cardinal's Simulations

Double-Pane	Breakage Prediction Outdoor Temperature -20° F and 0° F			
	Vinyl or Wood Windows Roomside Pane Breakage Probability per 1000 Outdoor Temperature		**Extruded Aluminum Clad Wood Windows** Roomside Pane Breakage Probability per 1000 Outdoor Temperature	
	-20° F	0° F	-20° F	0° F
178 #3/AL Spacer[1]	31	10	91	28
180 #2	2	1	6	2
180 #3	6	4	15	8
180 #2/i89 #4	5	5	12	8
272 #2	1	1	4	1
272 #3	16	9	35	17
272 #2/i89 #4	1	1	3	1
270 #2	1	1	4	1
270 #3	17	9	38	18
270 #2/i89 #4	1	1	2	1
366 #2	1	1	4	1
366 #3	28	28	58	29
366 #2/i89 #4	1	1	2	1
340 #2	2	1	5	1
340 #3	217	149	330	29
340 #2/i89 #4	2	1	2	1

Color Coding: low thermal breakage probability, moderate thermal breakage probability, high thermal breakage probability.

1. Double-Pane LoE-178 #3/AL spacer is no longer available. Past field history showed a breakage probability on the roomside pane approaching 10 per 1000 (1%) with wood windows.

Triple-Pane	Breakage Prediction Outdoor Temperature -20° F and 0° F Vinyl or Wood Windows					
	Center Pane Breakage Probability per 1000 Outdoor Temperature		Roomside Pane Breakage Probability per 1000 Outdoor Temperature		Total IG Breakage Probability per 1000 Outdoor Temperature	
	-20°F	0° F	-20° F	0° F	-20° F	0° F
Clear/Clear/AL Spacer	<1	<1	3	1	4	2
180 #2/180 #4	12	14	3	1	15	15
180 #2/180 #5	2	2	4	2	6	4
180 #3/180 #5	35	35	8	3	43	41
180#2/180 #4/i89 #6	31	31	22	11	53	45
272 #2/180 #4	1	1	1	<1	2	2
272 #2/180 #5	4	<1	1	<1	5	2
272 #2/272 #4	33	33	2	1	32	32
272 #2/272 #5	1	1	5	2	6	3
272 #2/180 #4/i89 #6	1	2	2	1	3	3
272 #2/272 #4/i89 #6	46	46	6	3	52	52
270 #2/180 #4	<1	<1	<1	<1	2	2
270 #2/180 #5	<1	<1	1	<1	2	2
270 #2/270 #4	19	19	1	<1	20	20
270 #2/270 #5	1	1	4	1	5	2
270 #2/180 #4/i89 #6	1	1	1	1	2	2
270 #2/270 #4/i89 #6	28	28	4	2	32	32
366 #2/180 #4	<1	<1	<1	<1	2	2
366 #2/180 #5	<1	<1	1	<1	2	2
366 #2/366 #4	14	16	1	<1	15	15
366 #2/366 #5	<1	<1	4	1	5	2
366 #2/180 #4/i89 #6	<1	<1	<1	<1	2	2
366 #2/366 #4/i89 #6	19	19	2	1	21	21
340 #2/180 #4	1	1	1	<1	1	1
340 #2/180 #5	<1	<1	1	<1	1	1
340 #2/340 #4	27	31	2	1	29	31
340 #2/340 #5	1	1	5	2	6	3
340 #2/180 #4/i89 #6	1	1	1	1	1	1
340 #2/340 #4/i89 #6	34	42	2	1	36	43

Color Coding: low thermal breakage probability, moderate thermal breakage probability, high thermal breakage probability.

Triple-Pane	Breakage Prediction Outdoor Temperature -20° F and 0° F Extruded Aluminum Clad Wood Windows					
	Center Pane Breakage Probability per 1000 Outdoor Temperature		Roomside Pane Breakage Probability per 1000 Outdoor Temperature		IG Breakage Probability per 1000 Outdoor Temperature	
	-20° F	0° F	-20° F	0° F	-20° F	0° F
Clear/Clear /AL Spacer	2	1	15	4	17	5
180 #2/180 #4	35	35	9	4	44	40
180 #2/180 #5	8	7	15	6	23	13
180 #3/180 #5	83	83	25	10	108	93
180#2/180 #4/ i89 #6	72	67	55	27	127	94
272 #2/180 #4	3	3	3	1	6	4
272 #2/180 #5	1	1	5	2	6	3
272 #2/272 #4	74	74	7	3	81	80
272 #2/272 #5	4	3	16	6	20	9
272 #2/180 #4/i89 #6	5	4	6	3	11	10
272 #2/272 #4/i89 #6	100	98	56	8	156	106
270 #2/180 #4	2	2	3	1	5	3
270 #2/180 #5	1	1	4	1	5	2
270#2/270 #4	51	51	5	2	56	56
270 #2/270 #5	3	2	14	5	17	7
270 #2/180 #4/i89 #6	3	2	4	2	7	4
270 #2/270 #4/i89 #6	66	65	12	5	78	70
366 #2/180 #4	1	1	2	1	3	2
366 #2/180 #5	1	<1	2	1	3	2
366 #2/366 #4	38	38	4	2	42	44
366 #2/366 #5	1	1	12	5	13	6
366 #2/180 #4/i89 #6	1	1	2	1	3	2
366 #2/366 #4/i89 #6	47	47	8	3	55	51
340 #2/180 #4	1	1	2	1	3	2
340 #2/180 #5	1	1	2	1	3	2
340 #2/340 #4	73	73	6	2	79	75
340 #2/340 #5	2	2	17	6	19	8
340 #2/180 #4/i89 #6	1	1	1	1	2	2
340 #2/340 #4/i89 #6	78	80	8	4	86	84

Color Coding: low thermal breakage probability, moderate thermal breakage probability, high thermal breakage probability.

1. **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).
2. **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 vinyl or 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.
3. **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.
4. **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.
5. **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 average breaking stress of 4500 psi, with a COV of 20%.
   The breakage probability on the exterior pane on the shown triple-pane IG units is estimated to be less than 1/1000. The breakage probabilities shown are for each pane of the IG unit. For triple-panes the IG Breakage Probability is the sum of the breakage probabilities of the center pane and the roomside pane.

Summary

Based on the generic simulations above and previous Cardinal field experience, Cardinal has developed a summary table of expected thermal breakage risk.

It is 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.

This summary was based on the -20° F temperature condition and an extruded aluminum clad window. Risks are based on an average glass breakage stress of 4500 psi and 20% COV.

The use of solar control coatings on surfaces 3 and 5 of a triple-pane (compared to surface 2 and 4 or 2 and 5) will increase the breakage probability and is not suggested. The use of heat-treated glass is typically suggested in constructions with high levels of expected thermal breakage.

Double-Pane IG Units

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

Note:

1. 2.2mm not available in tints.
2. For thickness of 5mm and above, gray tint on the outdoor pane with LoĒ -366® or LoĒ -340™ room side on surface #3 has a high risk of thermal breakage.
3. The use of solar control LoE® coatings such as Cardinal LoĒ® 272, 270, 366, and 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.
4. For units containing tinted glass substrates thermal breakage risk was based on solar absorption and past field history.

Coating Type	6 mm Glass Thickness									
	LoĒ® #2 Outdoor Pane	Room Side Pane	LoĒ® #2 Outdoor Pane	LoĒ®i89™ Room Side Pane	Clear Outdoor Pane	LoĒ® #3 Room Side Pane	Gray Tint Outdoor Pane	LoĒ® #3 Room Side Pane	Bronze Tint Outdoor Pane	LoĒ® #3 Room Side Pane
180	Low	Low	Low	Moderate	Low	Moderate	High	Low	Moderate	Low
272	Low	Low	Low	Low	Low	High	High	Low	High	Low
270	Low	Low	Low	Low	Low	High	High	Low	High	Low
366	Low	Low	Low	Low	Low	High	High	Low	High	Low
340	Low	Low	Low	Low	Low	High	High	High	High	High

Note:

1. The use of solar control LoE® coatings such as Cardinal LoĒ® 272, 270, 366, and 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. For units containing tinted glass substrates thermal breakage risk was based on solar absorption and past field history.

Triple-Panes with Two LoĒ® Coatings

Glazing Description	Outdoor Pane	Center Pane	Room Side Pane
180 #2/180 #4	Low	High	Low
180 #2/180 #5	Low	Low	Moderate
180 #3/180 #5	Low	High	High
272 #2/180 #4	Low	Low	Low
272 #2/180 #5	Low	Low	Low
272 #2/272 #4	Low	High	Low
272 #2/272 #5	Low	Low	Moderate
270 #2/180 #4	Low	Low	Low
270 #2/180 #5	Low	Low	Low
270 #2/270 #4	Low	High	Low
270 #2/270 #5	Low	Low	Moderate
366 #2/180 #4	Low	Low	Low
366 #2/180 #5	Low	Low	Low
366 #2/366 #4	Low	High	Low
366 #2/366 #5	Low	Low	Moderate
340 #2/180 #4	Low	Low	Low
340 #2/180 #5	Low	Low	Low
340 #2/340 #4	Low	High	Low
340 #2/340 #5	Low	Low	Moderate

Triple-Panes with Three LoĒ® Coatings

Glazing Description	Outdoor Pane	Center Pane	Room Side Pane
180 #2/180 #4/i89 #6	Low	High	High
272 #2/180 #4/i89 #6 (Preferred)	Low	Low	Low
272 #2/272 #4/i89 #6	Low	High	High
270 #2/180 #4/i89 #6 (Preferred)	Low	Low	Low
270 #2/270 #4/i89 #6	Low	High	Moderate
366 #2/180 #4/i89 #6 (Preferred)	Low	Low	Low
366 #2/366 #4/i89 #6	Low	High	Low
340 #2/180 #4/i89 #6 (Preferred)	Low	Low	Low
340 #2/340 #4/i89 #6	Low	High	Low

Note:

1. The use of LoĒ® solar control coatings such as Cardinal LoĒ® 272, 270, 366, and 340 are not recommended on the center pane of a triple pane IG unit due to concerns with thermal stress and heat buildup in the airspace.
2. Heat Treating (H/T) recommendation based on cold winter climate, with full sun, shadowed edges, metal clad wood frame, with estimated maximum allowable thermal stress of 2600 psi (breakage probability of 17 per 1000 based on 4500 psi average breaking stress and coefficient of variation of 20%).

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 1000.
- The use of Cardinal LoĒ³-366® on the exterior pane of double-panes and triple-panes 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.

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