# POST-GLASS BREAKAGE PERFORMANCE OF LAMINATED SAFETY GLASS

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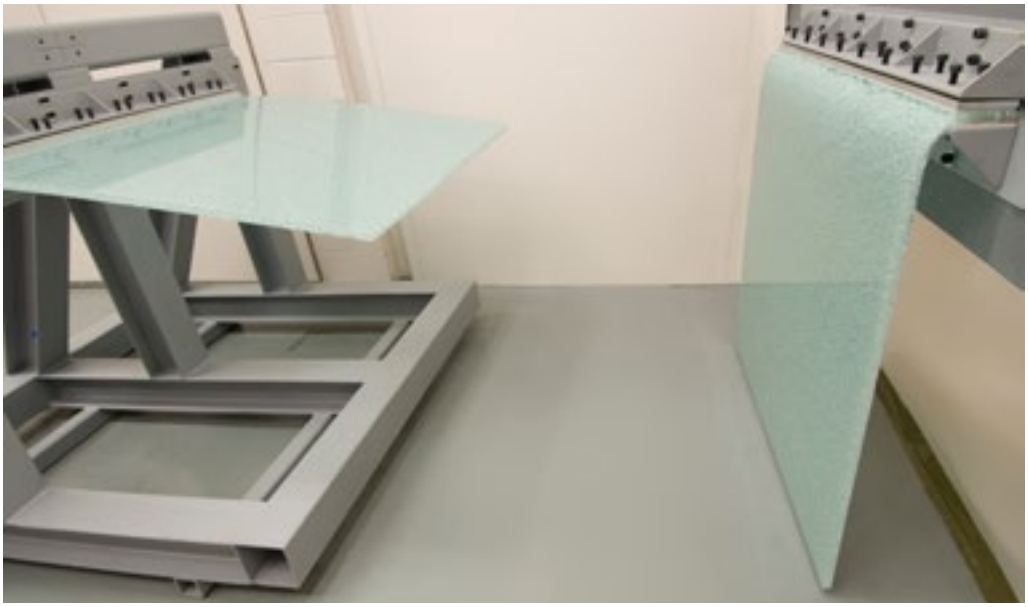
## INTRODUCTION



SentryGlas® vs PVB – post-glass breakage

Laminated safety glass for architectural applications is the only safety glazing that provides optical quality that remains intact after breakage. Following a strong enough impact, the glass will break, but the potentially hazardous fragments of glass will remain adhered to the interlayer. As a result, the risk of injury to passers-by is significantly reduced, while some of the protective advantages of the glazing against wind and rain are retained.

This bulletin therefore outlines the various tests that are used to analyze the impact resistance and post-glass breakage performance of laminated glass.

## WHAT IS IMPACT RESISTANCE?

When subjected to an increasing load over time, laminated safety glass will deflect (bend) until it breaks at a certain load. At what load it breaks depends on the strength and impact resistance of the laminate.

### HOW IS IMPACT RESISTANCE MEASURED?

Pendulum impact tests according to EN 12600 & ANSI can also be conducted on laminated safety glass in order to measure the effects of dynamic loads and to analyze the post-breakage performance of the glass once it has broken.

Pendulum impact tests employ soft body impactors such as traditional shot bags or twin tyre impactors to evaluate the safe breakage characteristics of safety glass with the intention of reducing cutting and piercing injuries to persons through accidental impact.

## OTHER IMPACT TEST METHODS

There are many other methods of testing the impact resistance of laminated safety glass. These include ball-drop tests, where a steel ball is dropped from a specific height onto the safety glass in order to determine the impact resistance of the laminate. The drop test is repeated a set number of times and with different size (weight) steel balls.

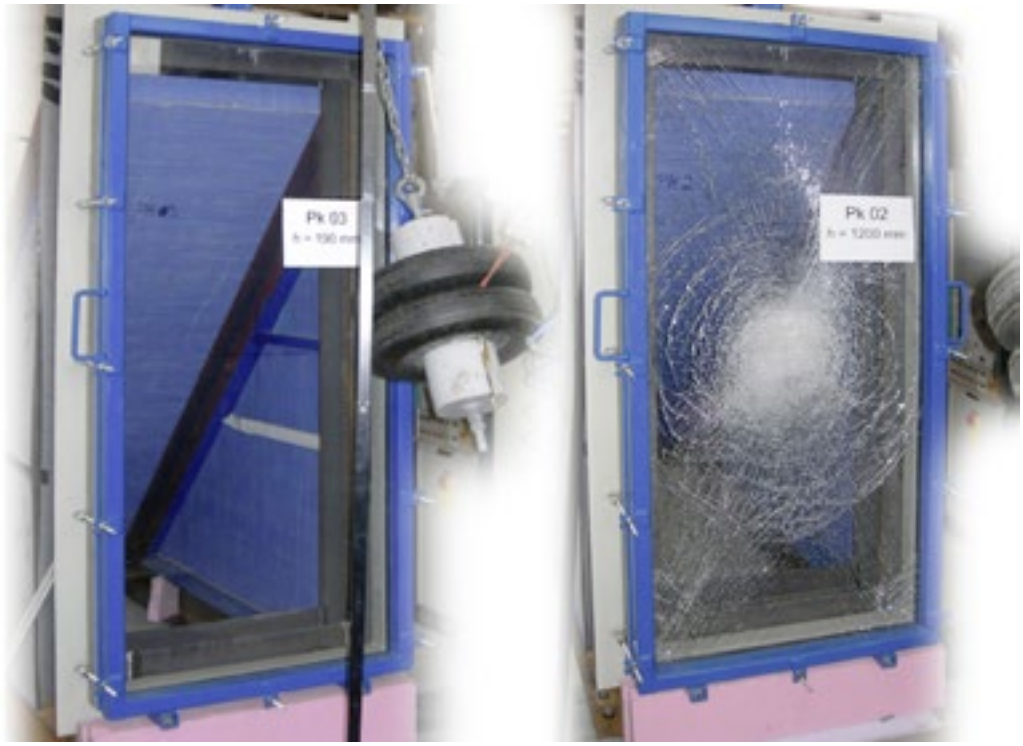
For hurricane-resistant glazing applications, missile impact tests are conducted using timber missiles, which are projected at various speeds to impact the safety glass (to simulate damage from windborne debris).

This impact is normally then followed by pressure cycling to simulate hurricane wind conditions.

Other impact tests are used for specific glazing applications such as anti-intrusion (anti-theft, anti-vandalism) tests, bomb-blast, and ballistic (BRG) tests. Test methods and classifications are established by local building codes.

In terms of impact resistance, the benefits of SentryGlas® ionoplast interlayer compared to PVB are shown in the figure below.

## IMPACT TEST



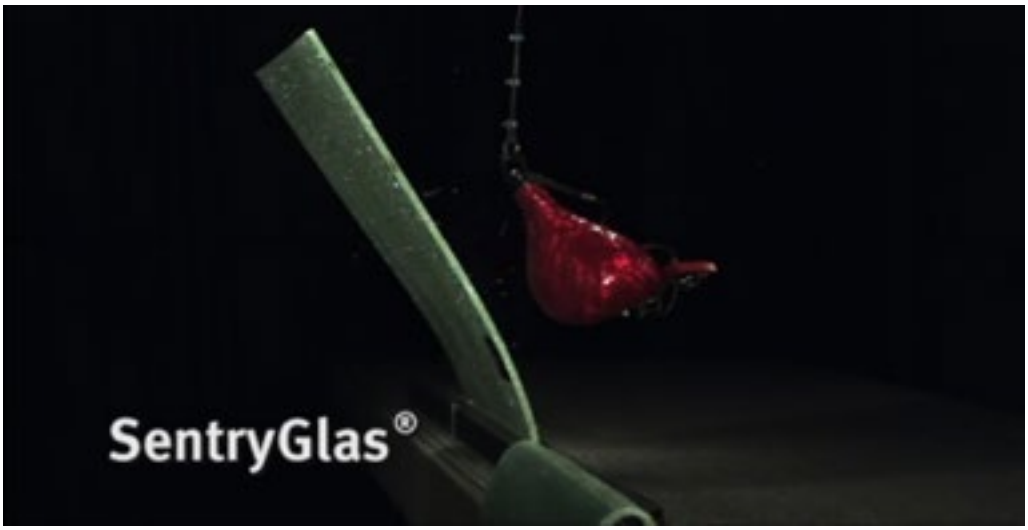

Impact test EN 12600 by University of Applied Science, Munich, Germany, 2009.

## WHAT IS POST-GLASS BREAKAGE?

The post-glass breakage behavior of laminated glass is defined as the state when one or more glass sheets are cracked and the broken pieces of glass remain bonded to the interlayer. Predicting what happens to the glass after it has been broken is an important design consideration. How large will the glass fragments be on break up and will these pose a safety risk to passers-by or to employees working underneath a glass canopy or skylight?

Factors affecting post-glass breakage stiffness of laminated glass include the polymer modulus of the interlayer. This property varies considerably, particularly when comparing polymer types (e.g. PVB vs SentryGlas® ionoplast interlayer). Load duration and temperature are also important factors that need to be considered.

In addition, the glass fragmentation scale (i.e. the size of glass fragments after breakage) and glass pattern are important factors. These are affected by the glass type (e.g. annealed, heat strengthened, tempered), as well as the nature of loading, support and the breakage event itself. Loading rate and glass thickness also need to be considered here. The adhesion properties of the lami-



nated glass and interlayer will also affect post-glass breakage stiffness. While polymer / glass debonding is essential for laminate toughness, this also affects compliance after glass breakage.

Post-glass breakage is a complex topic that is actively being researched and developed.

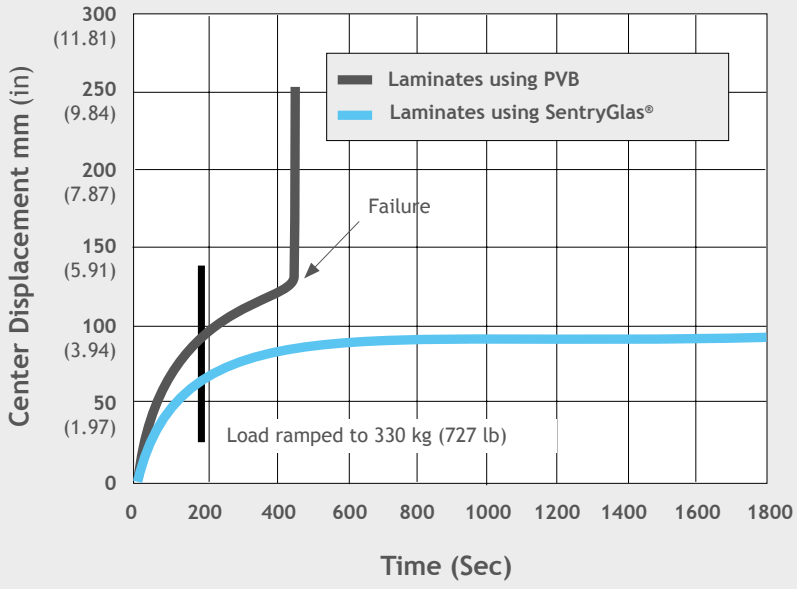
Although post-glass breakage performance tests carried out on laminated glass are less quantitative than pre-glass breakage methods, these tests still provide valuable information about the post-breakage strength and stiffness of different laminate interlayers and glass types. Indeed, as yet there are no standards provided on this important topic.

## GLASS LAMINATES USING PVB OR SENTRYGLAS®

Results from comparative tests conducted by Kuraray and independent research institutes demonstrate that the post-breakage performance of laminates with SentryGlas® ionoplast interlayer are superior to those with PVB. This is due to the unique properties (modulus and adhesion) of the SentryGlas® polymer interlayer.

During creep load tests, both laminates were loaded with 330 kg (727 lb) sandbags. The glass was then fractured with the load remaining constant. The deformation (center displacement) was then recorded over time.

## POST-GLASS BREAKAGE PERFORMANCE




From the table above, it can be seen that deformation of the PVB laminate was much greater than the laminates using SentryGlas®.

Furthermore, the PVB laminate tore after approximately 7 minutes, whereas the laminate with SentryGlas® remained intact.

## COMPARATIVE TESTS ON BALUSTRADES WITH PVB AND LAMINATES WITH SENTRYGLAS®

In further tests at Kuraray, cantilevered glass balustrades / railings were tested for their post-glass breakage performance. These impact tests simulate potential human loading. The tests involved multiple high strength glass types (all were fully tempered with open, polished edges). This included laminates with PVB interlayer, SentryGlas® interlayers, monolithic fully tempered glass, and applied PET film.

### TEST SETUP

The tests involved the use of cantilevered glass balustrades manufactured by R.B. Wagner Industries, which were impact tested using a 45 kg (100 lb) shot bag dropped from various heights.

The glass panels that were tested were chosen because they represented a range of typical balustrade applications:

- 12.7 mm (½ in) fully tempered (FT) monolithic glass
- 12.7 mm (½ in) FT monolithic glass with applied PET film 0.2 mm (8 mil)
- 6 mm (¼ in) FT | 1.52 mm (60 mil) PVB | 6 mm (¼ in) FT
- 6 mm (¼ in) FT | 0.89 mm (35 mil) SentryGlas® | 6 mm (¼ in) FT
- 5 mm (3/16 in) FT | 1.52 mm (60 mil) SentryGlas® | 5 mm (3/16 in) FT

The multiple glass panels were all mounted into a channel using a dry-glazed mounting system. The shot bag was dropped from 1.524 m (5 ft) (500 ft.lbs of energy).

## TEST RESULTS AND CONCLUSIONS

- The test results showed that the laminates with SentryGlas® interlayer provided significant increased post-breakage strength compared to the laminate with PVB interlayer.
- Fully tempered monolithic glass provides no residual barrier on impact breakage.
- Applied PET film does not retain the glass in place on breakage.
- PVB laminates remain attached to the system on impact breakage. However, PVB laminates display no residual barrier after glass breakage.
- Laminates with SentryGlas® do display a residual barrier after glass breakage. The 0.89 mm (35 mil) SentryGlas® demonstrates considerable post-glass breakage integrity. The 1.52 mm (60 mil) SentryGlas® allows a reduction in glass thickness, with good barrier performance.

# COMPARATIVE TESTS ON CANOPIES WITH KURARAY BUTACITE® PVB AND LAMINATES WITH SENTRYGLAS®

Kuraray recently conducted tests on the mechanical behavior of laminated glass in point-supported horizontal (canopy) applications. These tests were set up in order to evaluate the impact and post-glass breakage performance of four different types of laminated safety glass: SentryGlas® ionoplast interlayer, Butacite® PVB (standard architectural PVB), stiff PVB and architectural EVA interlayer, as well as tempered glass.

The laminate thickness make up used in the tests was 6 mm (¼ in) FT | 0.89 (35 mil)or 1.52 mm (60 mil) Interlayer | 6 mm (¼ in) FT. Panel sizes were 1 500 x 1 194 mm (59.06 x 47 in), supported in the four corners by C.R. Lawrence rotules.

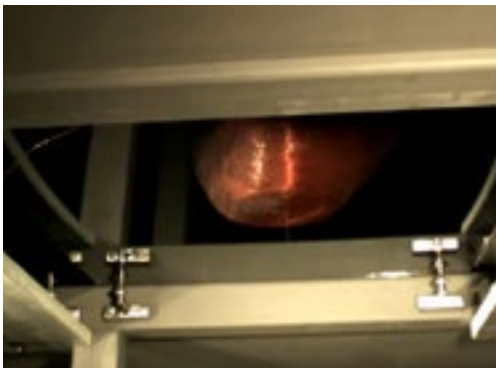
50 kg (110 lb) or 100 kg (220 lb) shot bags were dropped from various drop heights and left in place for 15 minutes. This was to simulate potential loading from installation and / or maintenance workers in distress.

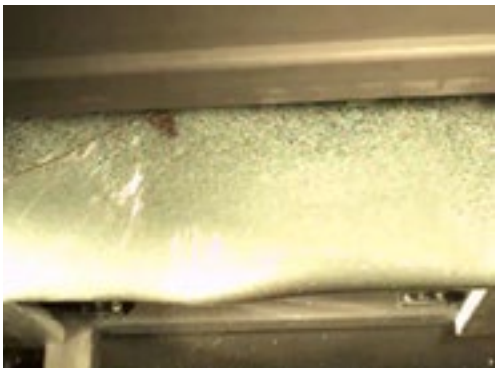
Two tests were conducted, one at room temperature (23 °C [73.4 °F]) and one at elevated temperature (50 °C [122 °F]). The elevated temperature test was carried out in accordance with ASTM E1300 (although this test is not described in ASTM E1300, the test was conducted in accordance with ASTM E1300 conditions, but at 50 °C [122°F]). This test simulates a scenario in which a person may need access to a glass roof or canopy for maintenance purposes. In this scenario, a person may accidentally slip and fall down onto the glass. The impact of this body (or a sharp tool) could break the glass, which must then be capable of withstanding this load for a certain period of time to allow the worker to be rescued from the roof or canopy. If this incident occurs during summer time at elevated temperatures (i.e. up to 50°C [122 °F]), the designer must be confident that the glass can withstand the load at this temperature.

## TEST TEMPERED GLASS

canopy test / tempered glass / 50 kg (110 lb)

## TEST SENTRYGLAS® 0.89 MM (35 MIL)





canopy test / SentryGlas® 0.89 mm (35 mil) / 100 kg (220 lb)

## TEST RESULTS

- From these tests, it was concluded that tempered glass provides no barrier to fall-through after the glass is broken at room temperature and elevated temperatures.
- In the 23 °C (73.4 °F) test, standard PVB laminates survives the initial impact, but fails after 15 seconds, providing no barrier to fall-through after the glass is broken.
- At 50 °C (122 °F), standard PVB laminates, stiff PVB laminates and EVA laminates all failed immediately on impact, providing no barrier to fall-through after breakage.
- At both 23 °C (73.4 °F) and 50 °C (122 °F), laminates with SentryGlas® provides impact resistance and remains in place after glass breakage for the test conditions used (and therefore provides a barrier to fall-through).

# TEMPERATURE CONSIDERATIONS

The post-glass breakage performance (integrity, adhesion and toughness) of laminated glass is greatly affected by the ambient temperature.

Laminates with SentryGlas® offer excellent performance over a broad range of temperatures, from -50 °C (-58 °F) to +82 °C (180°F). This performance has been thoroughly tested by Kuraray and through real life architectural projects, where SentryGlas® laminates have withstood these temperature extremes for several years without showing any signs of delamination or other temperature-related problems. These applications include laminated glass for roofs, windows and doors, with butt glazed open edges and point-fixed supports.

The laminates' ability to perform well at different temperatures depends on a number of factors, including integrity, glass retention / adhesion, and toughness.

## HIGH TEMPERATURE PERFORMANCE OF SENTRYGLAS®

Properly laminated glass made with SentryGlas® interlayer has demonstrated capability of withstanding an environment of 100 ºC (212 ºF) for at least 16 hours, without bubble formation in the major viewing area. For more prolonged periods of time, of greater than 16 hours, a temperature limit of 82 ºC (180 ºF) or lower is recommended.

This information is based on the visual inspection of a glass laminate after a high temperature bake test. In this test, a test specimen of laminated glass is heated to a temperature of 100 ºC (212 ºF). Bubble formation within the major viewing area of the laminate (typically excluding 12 mm or ~1/2 in from the laminate edge) constitutes a failure of this test. Based on this limited data, properly laminated specimens with SentryGlas® interlayer appear capable of meeting these test conditions.

As with any application, specific glass constructions and designs may vary and prototype testing of systems is advisable.

## GLASS RETENTION / ADHESION TESTS

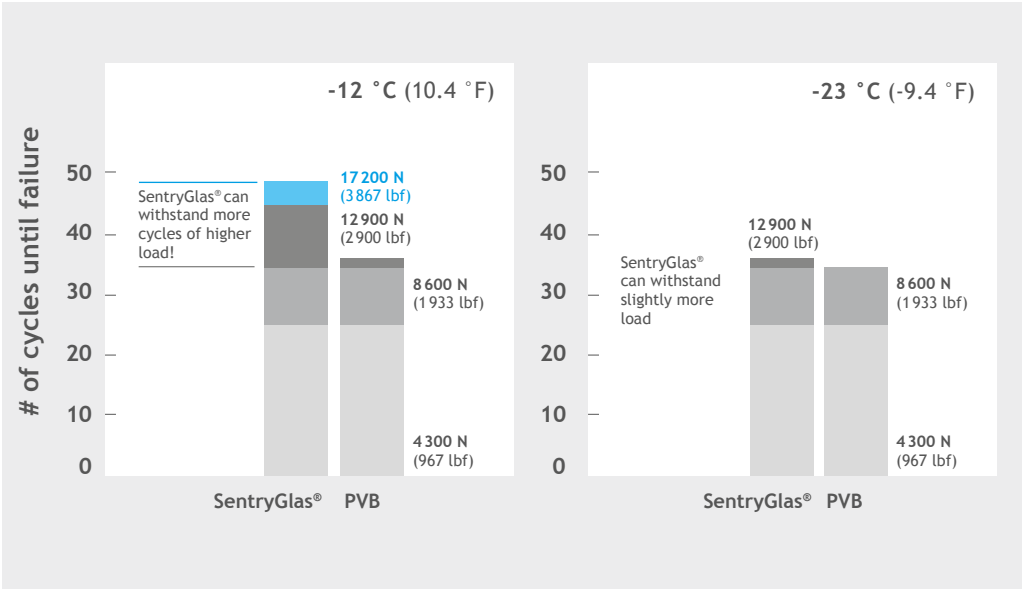
In glass retention / adhesion tests at Kuraray, SentryGlas® also performed well at low temperatures (-12 °C [10.4 °F]). The laminates were subjected to 5 load cycles of 4.4 kN and negligible glass loss was observed. After glass breakage, glass loss was concentrated only in the area of impact and there were no widespread adhesion problems.
See test graphics below.

## TOUGHNESS TESTS

In toughness tests, laminates with SentryGlas® were compared with PVB laminates.Laminates with SentryGlas® showed excellent performance over a broad temperature range.

Both types of laminates were tested by applying an increasing load until the glass broke. How many load sequences it took until glass breakage were recorded.
See test graphics below.

## TOUGHNESS PERFORMANCE EVALUATION




The results demonstrate the good toughness of SentryGlas® interlayer even at low temperatures. At -12 °C (10.4 °F), compared to PVB, SentryGlas® interlayer withstood more cycles of higher load. At -23 °C (-9.4 °F), SentryGlas® withstood slightly higher load.

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