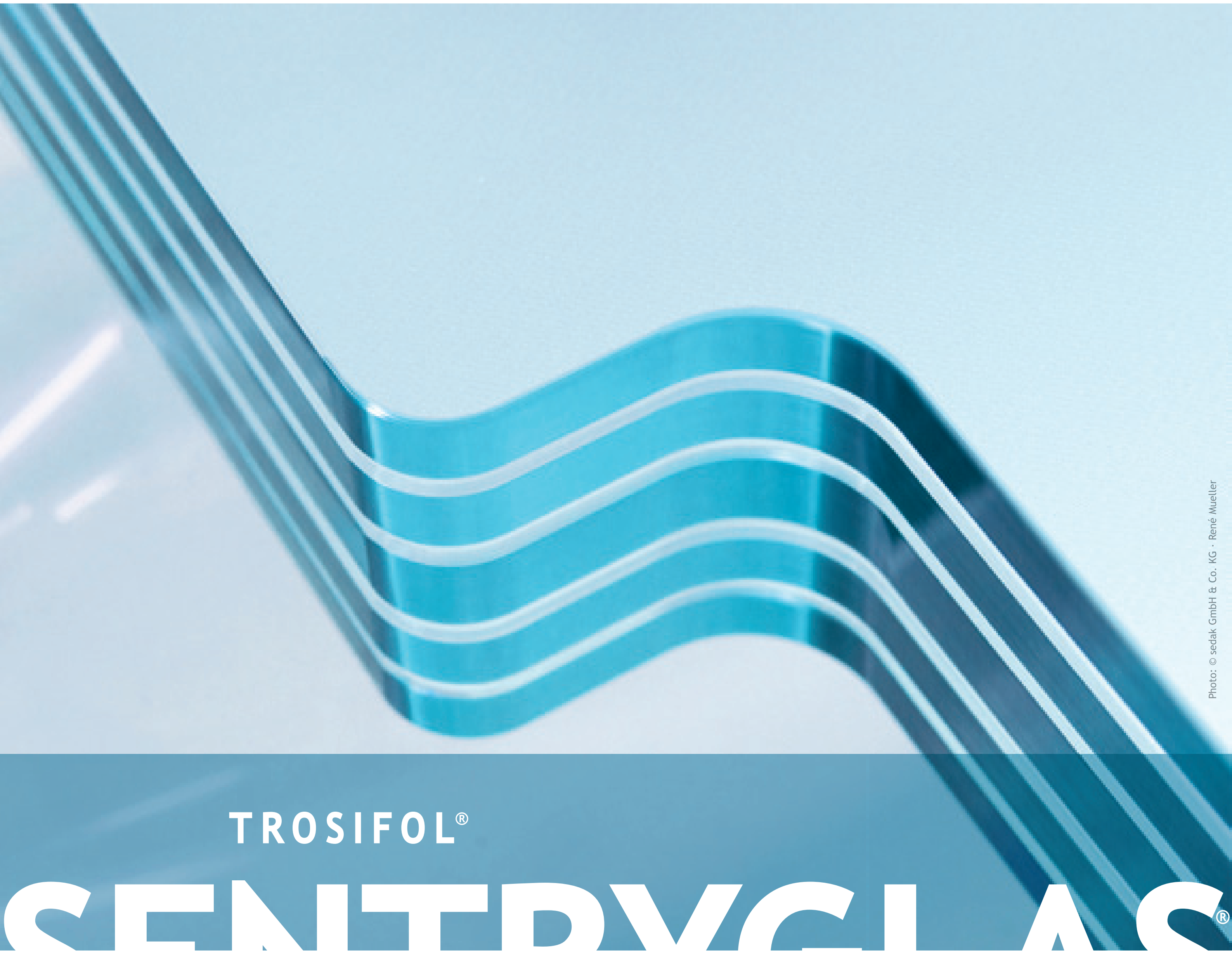
kuraray

trosifol™
world of interlayers



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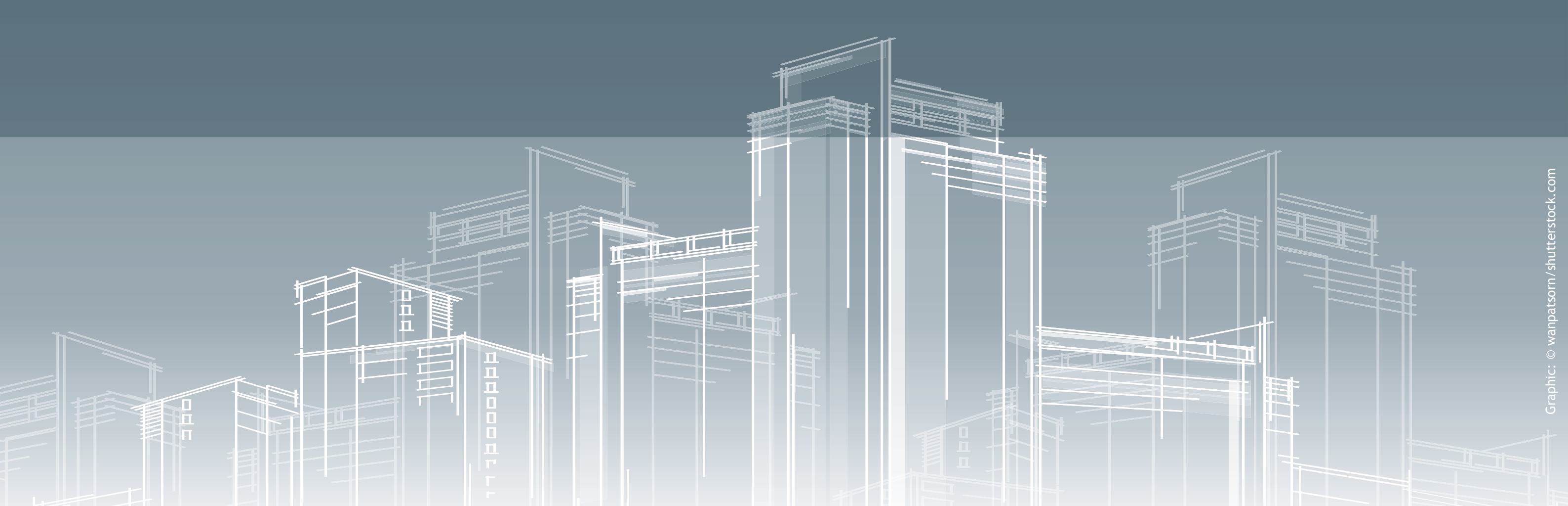
TROSIFOL®

SENTRYGLAS®



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English

PRODUCT PORTFOLIO

TROSIFOL™ - WORLD OF INTERLAYERS

Kuraray's Trosifol™ business is a leading global specialist in the development, manufacture and supply of PVB and ionoplast interlayers for laminated safety glass applications in the architectural, automotive and photovoltaic industries.

The evolution of the Trosifol™ & Glass Laminating Solutions (GLS) merger has resulted in consolidation of the Trosifol®, SentryGlas® and Butacite® product brands into a single brand: the new Trosifol™.

Trosifol™ offers the world's broadest portfolio of innovative glass-laminating solutions, including structural and functional interlayers for safety and security applications, sound insulation and UV protection. For decorative applications, it supplies colored interlayers, digitally printable films and other innovative products for interior design projects. Trosifol® UltraClear films exhibit the lowest Yellowness Index (YID) in the industry.

Trosifol® products give applications an expression of strength, clarity and their own character, delivering advanced capabilities that enable engineers, designers and architects to save energy, increase safety and build with greater design freedom. Applications range from automotive and other transportation glazing, to architectural and structural glazing - located overhead, underfoot, and all around some of the world's most interesting spaces.

TROSIFOL™ - YOUR GLOBAL PARTNER FOR LAMINATED SAFETY GLASS

Following the acquisition of DuPont's Glass Laminating Solutions by Kuraray in 2014, Trosifol®, Sentryglas® and Butacite® product brands are being consolidated into a single brand: the new Trosifol™.

The SentryGlas® interlayer from the Trosifol® Structural product familiy is five times stronger and up to 100 times stiffer than conventional laminating materials. With this kind of strength the glass can be a more active structural element in the building envelope, opening up design possibilities that didn't exist before. Besides its strength, SentryGlas® ionoplast interlayer retains its clarity – even after years of service. Unlike other interlayers, SentryGlas® ionoplast interlayer is much less vulnerable to moisture exposure or yellowing over time.

Initially developed for the high building envelope protection required for hurricane glazing in the United States, the use of SentryGlas® ionoplast interlayer has now expanded considerably as structural engineers have recognized that the performance benefits developed for hurricane applications could also be beneficial for many other aspects of a building, including façades, overhead glazing, balustrades, doors and partitions.

PRODUCT OFFERING AND TECHNICAL DATA

Structural & Security Interlayers* – Physical properties

Type	Adhesion	Film thickness [mm]	Color	Light transmittance*1 [%]	UV transmittance*1 [%]	Solar absorption*1 [%]
Trosifol® Extra Stiff	high	0.76	Clear	88	< 1	20
SentryGlas®	high	0.76	Clear	88	< 1	19
SentryGlas®	high	0.89	Clear	88	< 1	19
SentryGlas®	high	1.52	Clear	88	< 1	20
SentryGlas®	high	2.28	Clear	88	< 1	21
SentryGlas® Translucent White	high	0.80	Translucent White	81	57	20
SentryGlas® Natural UV*1	high	0.89	UltraClear	89	40	
SentryGlas® Natural UV*1	high	1.52	UltraClear	88	50	

* LSG with 2 x 4 mm Floatglass according EN 410 / ISO 9050
*1 Values calculated using Lawrence Berkeley National Laboratory Optic 6 and Windows 7.4 software.

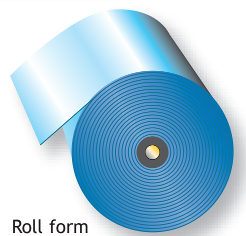
Structural & Security Interlayers* – Dimensions for Products on rolls

Product	Thickness [mm]	Thickness [mil]	Color	Roll Widths [mm]	Roll Widths [in]	Roll Lengths [m]	Roll Lengths [ft]
Trosifol® Extra Stiff	0.76	30	Clear	1000/1300/1600/2000/2250/2600/3210	40/51/63/78/88/102/126	250	820
SentryGlas®	0.76	30	Clear	1050/1150/1300/1600/2250/2400/2600/2700	41/45/51/63/88/94/102/106	250	820
SentryGlas®	0.76	30	Clear	1220/1530/1830	48/60/72	200	656
SentryGlas®	0.76	30	Clear	1530	48	50	164
SentryGlas®	0.76	30	Clear	1050/1600/2250/2400/2600/2700	41/63/88/94/102/106	60	197
SentryGlas®	0.89	35	Clear	1220/1530/1830/2250/2400/2500/2700	48/60/72/88/84/102/106	200	656
SentryGlas®	0.89	35	Clear	1530/2250/2400/2500/2700	60/88/94/102/106	50	164
SentryGlas® Translucent White	0.80	31	Transl. White	1220/1830 1530	48/72 60	200 200/50	656 656/164
SentryGlas® Natural UV	0.89	35	Ultra Clear	1220/1530/1830	48/60/72	50/200	

Structural & Security Interlayers* – Dimensions for Sheet Products

Product	Thickness [mm]	Thickness [mil]	Sheet Widths [mm]	Sheet Widths [in]	Sheet Lengths [m]	Sheet Lengths [ft]
SentryGlas®	0.89	35	610-2160**	24-85	6	19
SentryGlas®	1.52	60	610-2160**	24-85	6	19
SentryGlas®	2.28	90	610-2160**	24-85	6	19
SentryGlas®	2.53	100	610-1830	24-72	6	19
SentryGlas®	3.04	120	610-1830	24-73	6	19
SentryGlas® Natural UV	1.52	60	610-2160	24-85	6	19


Sheet form


Roll form

* The table shows the global product program. Not all products are available in all regions.
** Oversize shipment possible up to 2500 mm/98 inches

PHYSICAL PROPERTIES

STIFFNESS AND ELASTIC PROPERTIES OF SENTRYGLAS® IONOPLAST INTERLAYER AND TROSIFOL® CLEAR

Originally developed for glazing in hurricane zones, SentryGlas® ionoplast interlayers are significantly stiffer than standard PVBs such as Trosifol® Clear.

STIFFNESS AND ELASTIC PROPERTIES

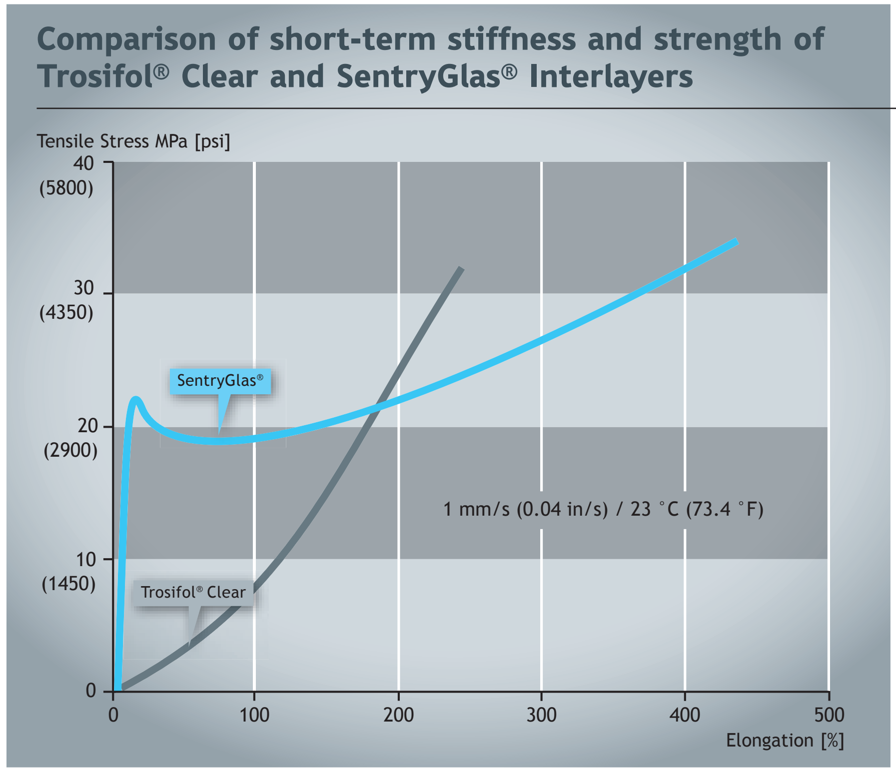
If two sheets of glass, lying on top of one another, are placed under load, they will start to bend (distort) independently. Displacement occurs between the two inner surfaces, which are in direct contact with each other. This is because one of the two surfaces is being stretched while the other is being compressed. If both sheets are laminated with an adhesive polymer interlayer, this must be able to internally compensate for the distortional differences (i.e. absorb shear forces).

Photo: © Museo Jumex, Mexico

HOW ARE STIFFNESS AND ELASTICITY MEASURED?

Most laminated safety glass interlayers are viscoelastic. Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing de- formation. Viscous materials resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and quickly return to their original state once the stress is removed. Viscoelastic materials therefore have elements of both of these properties and as such exhibit time-dependent strain.

Important material design values for the calculation of stresses and deformations are represented by the elastic constants, i.e. the modulus of elasticity (Young's Modulus) and Poisson's ratio. The modulus of elasticity, which by definition can be used as a direct comparison parameter for material stiffness, shows a dependence on the material and temperature.



Shear modulus or modulus of rigidity is defined as the ratio of shear stress to the shear strain. Shear modulus' derived SI unit is the pascal (Pa), although it is normally expressed in Megapascals (MPa), or in thousands of pounds per square inch (ksi).

The shear modulus is always positive. Young's Modulus describes the material's response to linear strain. The shear modulus describes the material's response to shearing strains.

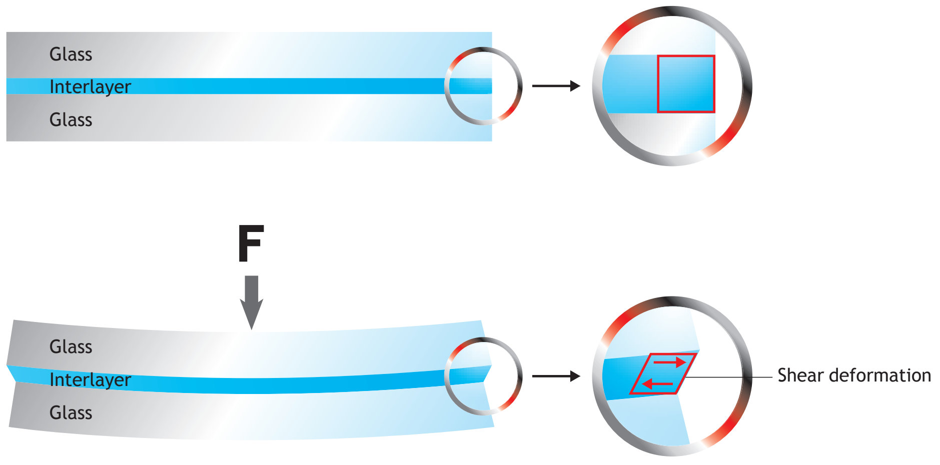
Stiffness (Young's Modulus and shear modulus) and Poisson ratio vary as a function of temperature and load duration (creep).

For designers of architectural glazing, it is therefore important to assess the likelihood of achieving full design load at the design temperature and load duration. How can structural designers ensure that the specified laminated safety glass interlayer is capable of meeting the design specification and building codes? The appropriate elastic property values need to be selected for the design case and assigned to an effective elastic interlayer. Kuraray Trosifol™ Solutions can provide technical support and guidance here.

COMPARISON TESTS: SENTRYGLAS® VS TROSIFOL® CLEAR PVB INTERLAYERS

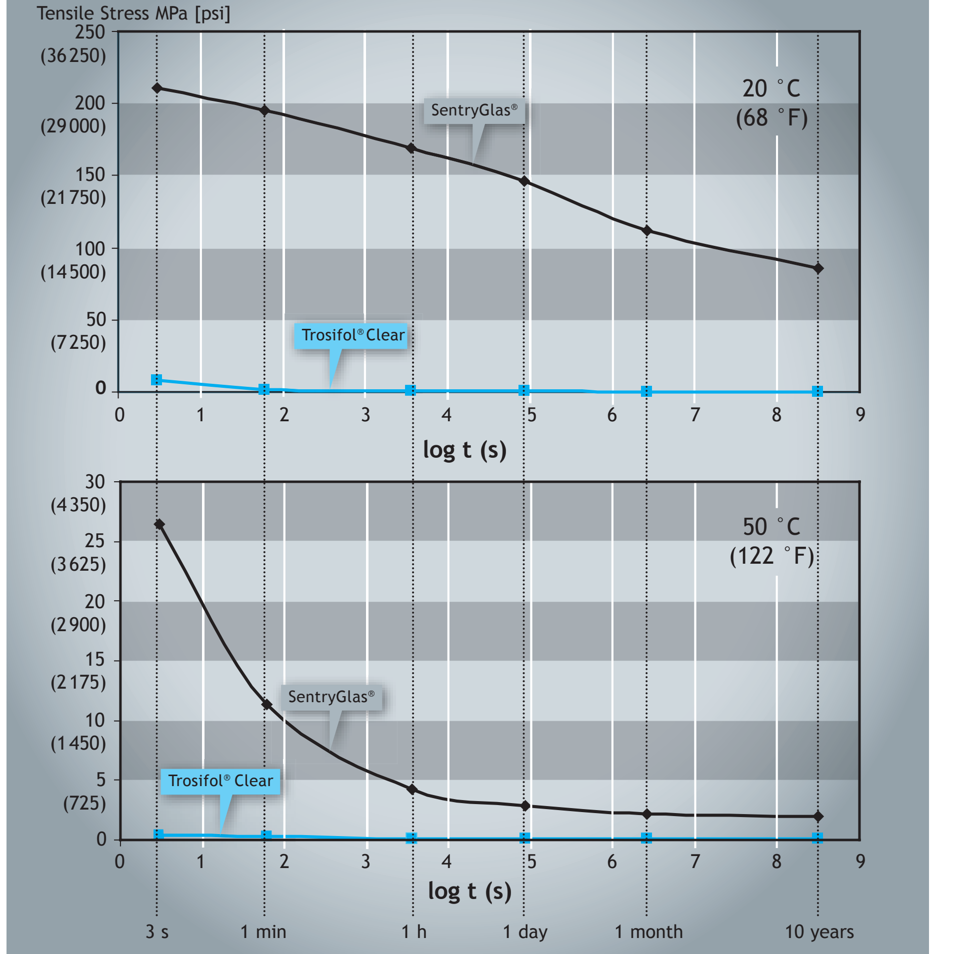
When exposed to sudden, short temporary loads, PVB interlayers such as Trosifol® Clear are able to internally compensate for the distortional differences (i.e. absorb shear forces) due to the glass sheets. Therefore, laminated safety glass produced with PVB interlayer provides excellent protection against, for example, the effects of vandalism, hurricanes or explosions. However, standard PVB is a soft polymer that starts to creep under long-term loads. As a result, two glass sheets laminated together using PVB – and exposed to a long-term flexural load and / or high temperatures - worst case behave in exactly the same way as two sheets that have not been joined together. Therefore, static calculations to date only consider the properties of the glass components and not of the overall laminate coupling effect of laminated safety glass.

Effect under bending load



Laminated safety glass with SentryGlas® interlayers react quite differently to PVB interlayers. In tensile tests, the strength of SentryGlas® is considerably higher than PVB. In addition, the stiffness of SentryGlas® is up to 100 times greater than PVB.

Stiffness (shear modulus) of Trosifol® Clear PVB and SentryGlas® Interlayers at room and elevated temperatures



The stiffness behavior of SentryGlas® at increased temperatures also shows improvements compared to PVB.

When designing static-loaded laminated glass panels, structural engineers must consider the changes in the mechanical properties and behavior of the interlayer, in particular, the constraints when using PVB rather than SentryGlas® ionoplast. In order to evaluate the elastic properties of laminated safety glass interlayers over a range of specific test temperatures and load duration (time), Kuraray Trosifol™ Solutions has conducted a series of tests on SentryGlas® (SG5000) interlayers, using dynamic mechanical analysis and creep tests (according to ASTM D 4065). In these tests, the interlayer was subjected to a specific load at different temperatures from 10 °C (50 °F) up to 80 °C (176 °F) for a duration of time ranging from 1 second up to 10 years.

→ see APPENDIX in this chapter

As well as internal tests by Kuraray Trosifol™ Solutions, external independent tests have also been conducted, including comparison tests of SentryGlas®, PVB and monolithic / tempered glass.

RESULTS

The results of all two sets of tests consistently showed that the rate of deflection of laminated safety glass with SentryGlas® was less than half of that with the PVB interlayer, and that this rate of deflection is similar to – or even less than – that recorded with the monolithic sheet. Mechanical tension accumulated in the glass was correspondingly lower.

CONCLUSIONS

The test results above (and subsequent tests) show that the stiffness of SentryGlas® interlayer is so high that there is an almost perfect transfer of load between the glass sheets. This applies to a wide temperature range and also under long-term conditions. This means it is possible to produce high load-bearing laminates from SentryGlas® with exceptional performance / weight ratio.

Significant Benefits:
Compared to PVB laminates, laminates with SentryGlas® provide significant opportunities for designers in the following areas:

- Reduction of glass thickness (often in the region of one to two standard glass thicknesses)
- Installation of larger glass panels at determined loads
- Or, a reduction in the number of fixing points for frameless glazing
- Significant increase in post-glass breakage performance

For users, this enables both a reduction in costs and a reduction in the overall weight of the glazing.

APPENDIX

ELASTIC PROPERTIES OF SENTRYGLAS® SG5000 FOR STRUCTURAL CALCULATIONS

Data has been evaluated according to ASTM.

Youngs Modulus E(t) / MPa

Temperature	Load duration										
	1 sec	3 sec	5 sec	10 sec	30 sec	1 min	5 min	10 min	30 min	1 hour	6 hours
-20°C (-4°F)	838	835	835	832	832	829	821	818	815	809	806
0°C (32°F)	749	743	740	737	732	726	717	714	708	703	680
10°C (50°F)	693	661	678	664	661	651	638	618	629	597	574
20°C (68°F)	629	612	606	594	602	567	549	525	511	493	458
25°C (77°F)	511	485	474	456	433	413	340	334	308	294	263
30°C (86°F)	443	413	405	381	349	342	243	220	194	178	162
35°C (95°F)	338	302	287	266	230	209	158	141	112	103	78.2
40°C (104°F)	229	187	167	143	109	92.0	57	46.9	34	27.8	17.1
50°C (122°F)	108.6	78	66.3	166.5	40	33.8	21.7	18.57	14.6	12.6	9.72
60°C (140°F)	35.4	24.5	20.67	51.84	12.8	10.9	7.6	6.75	5.5	5.1	4.26
70°C (158°F)	11.31	8.8	8.13	22.05	6.3	5.64	4.2	3.45	2.9	2.5	1.95
80°C (176°F)	4.65	4.0	3.66	9.99	2.9	2.5	1.7	1.35	1.1	1.0	0.9

Temperature	Load duration									
	12 hours	1 day	2 days	5 days	1 week	3 weeks	1 month	1 year	10 years	50 years
-20°C (-4°F)	804	801	798	795	795	792	786	772	749	720
0°C (32°F)	668	665	654	648	645	639	636	605	579	559
10°C (50°F)	560	553	543	516	519	498	499	467	448	421
20°C (68°F)	438	428	406	380	368	336	330	282	256	223
25°C (77°F)	250	234	206	177	160	131	123	93.3	70.6	52.6
30°C (86°F)	153	146	105	72	66.0	38	35	20.3	15	11.9
35°C (95°F)	68.4	60.1	48.9	36.7	33.8	24.6	22.1	14.7	12.2	9.03
40°C (104°F)	15.0	13.5	12.3	11	10.9	10	9.9	9.3	8.84	6.86
50°C (122°F)	8.94	8.4	8.01	7.2	7.26	6.5	6.5	6.3	6.0	5.46
60°C (140°F)	4.05	3.8	3.78	3.6	3.54	3.3	3.3	3.0	2.9	2.22
70°C (158°F)	1.89	1.8	1.74	1.6	1.62	1.5	1.5	1.4	1.3	1.05
80°C (176°F)	0.9	0.8	0.87	0.7	0.75	0.6	0.8	0.6	0.5	0.48

E(t) was calculated according $E(t) = 2 \times G(t) \times (1+v)$ for isotropic materials with: $v = 0.47$ (Trosifol® Extra Stiff), $v = 0.49$ (Trosifol® Clear, Trosifol® SC Monolayer); the Poisson ratio v was measured in accordance to EN ISO 527 (23°C, 30% r. H.). No E(t) data for Trosifol® SC Multilayer due to anisotropic material behavior.

Shear Modulus G(t) / MPa

Temperature	Load duration									
	1 sec	3 sec	5 sec	10 sec	30 sec	1 min	5 min	10 min	30 min	1 hour	6 hours
-20°C (-4°F)	291	290	290	289	289	288	285	284	283	281	280
0°C (32°F)	260	258	257	256	254	252	249	248	246	244	236
10°C (50°F)	240	236	235	230	228	225	216	214	217	206	199
20°C (68°F)	217	211	209	205	206	192	185	181	175	169	158
25°C (77°F)	176	167	163	157	149	142	117	115	106	101	90.6
30°C (86°F)	151	141	138	130	119	110	85.5	75.2	66	60	55.3
35°C (95°F)	114	102	96.9	89.9	77.7	70.5	53.4	47.7	37.9	34.7	26.4
40°C (104°F)	77	63	56.4	48.1	37	31	19.7	15.8	11.4	9.3	5.76
50°C (122°F)	36.2	26.4	22.1	18.5	13.5	11.3	7.38	6.19	4.9	4.2	3.24
60°C (140°F)	11.8	8.2	6.89	5.76	4.3	3.6	2.56	2.25	1.9	1.7	1.42
70°C (158°F)	3.77	2.9	2.71	2.45	2	1.9	1.34	1.15	1.0	0.8	0.65
80°C (176°F)	1.55	1.3	1.22	1.11	1.0	0.8	0.53	0.45	0.4	0.3	0.3

Temperature	Load duration									
	12 hours	1 day	2 days	5 days	1 week	3 weeks	1 month	1 year	10 years	50 years
-20°C (-4°F)	279	278	277	276	276	275	273	268	260	250
0°C (32°F)	232	231	227	225	224	222	221	210	201	194
10°C (50°F)	194	190	188	178	180	172	171	161	153	146
20°C (68°F)	151	146	140	130	127	115	112	96.5	86.6	77.1
25°C (77°F)	86.2	80.5	70.8	60.8	55.1	45.1	42.4	32.1	24.3	18.1
30°C (86°F)	52.3	50	35.9	24.7	22.5	12.9	11.6	6.8	5.31	4.05
35°C (95°F)	23.1	20.3	16.5	12.4	11.4	8.31	7.45	4.95	4.11	3.05
40°C (104°F)	5.06	4.5	4.16	3.6	3.66	3.4	3.3	3.1	2.9	2.31
50°C (122°F)	2.98	2.8	2.67	2.4	2.42	2.2	2.2	2	2	1.82
60°C (140°F)	1.35	1.3	1.26	1.2	1.18	1.1	1.1	1.0	0.97	0.74
70°C (158°F)	0.63	0.6	0.58	0.5	0.54	0.5	0.5	0.5	0.45	0.35
80°C (176°F)	0.3	0.3	0.29	0.2	0.25	0.2	0.2	0.2	0.2	0.16

G(t) data were determined by Dynamic-Mechanical-Analysis in accordance to EN ISO 6721 within the linear range of deformation. All samples were stored at 23°C for 4 weeks before measurement. G(t) data were experimentally verified by 4-Point-Bend-Tests on laminated glass following prEN 16613 at third party labs for selected time-load combinations.

Poisson Ratio

Temperature	Load duration						
	1 sec	3 sec	1 min	1 hour	1 day	1 month	10 years
10°C (50°F)	0.442	0.443	0.446	0.450	0.454	0.458	0.463
20°C (68°F)	0.448	0.449	0.446	0.459	0.464	0.473	0.479
24°C (75°F)	0.452	0.453	0.458	0.465	0.473	0.482	0.489
30°C (86°F)	0.463	0.466	0.473	0.485	0.488	0.497	0.499
40°C (104°F)	0.481	0.484	0.492	0.498	0.499	0.499	0.499
50°C (122°F)	0.491	0.493	0.497	0.499	0.499	0.500	0.500
60°C (140°F)	0.497	0.498	0.499	0.500	0.500	0.500	0.500
70°C (158°F)	0.499	0.499	0.500	0.500	0.500	0.500	0.500
80°C (176°F)	0.500	0.500	0.500	0.500	0.500	0.500	0.500

Conversion table MPa to kpsi

MPa	kpsi	MPa	kpsi	MPa	kpsi
10	1.450	50	7.251	400	58.015
15	2.175	60	8.702	500	72.519
20	2.900	70	10.513	600	87.023
25	3.625	80	11.603	700	101.526
30	4.351	90	13.053	800	116.030
35	5.076	100	14.503	900	130.534
40	5.801	200	29.007	1000	145.037
45	6.526	300	43.511	1100	159.542

SENTRYGLAS® ELASTIC PROPERTIES (SG5000)

SPECIFYING AND TECHNICAL DATA

The following information is presented to help you evaluate or order SentryGlas® ionoplast interlayers. SentryGlas® interlayer is available on roll or as sheet and has a Yellowness-Index (YID) of < 2.0.

Sheet dimensions

Caliper [mm]	[mil]	Width* [cm]	[in]	Length [cm]	[in]
0.89	35	61-216	24-85	up to 600	up to 236
1.52	60	61-216	24-85	up to 600	up to 236
2.28	90	61-216	24-85	up to 600	up to 236
2.53	100	61-183	24-72	up to 600	up to 236
3.04	120	61-183	24-72	up to 600	up to 236

* Ordered, -0 +7 mm (-0 +¼ in)

Roll dimensions

Caliper [mm]	[mil]	Width* [cm]	[in]	Length [cm]	[feet]
0.89	35	122	48	200	656
		153	60		
		183	72		
0.89	35	153	60	50	164

* Ordered, -0 +7 mm (-0 +¼ in)

In addition to the standard stock sizes above, SentryGlas® can be ordered as 'cut-to-size', 'cut-to-fit' or 'cut-to-form' sheet, which means that none of the material is wasted. In all cases, sheet thickness is 0.89 mm (35 mil), 1.52 mm (60 mil) or 2.28 mm (90 mil). As these custom sizes require special handling/cutting, lead times are longer. For details about the 'cut-to-size', 'cut-to-fit' or 'cut-to-form' sheet offering feel free to contact us.

ELASTIC PROPERTIES

Laminate properties

Property	Units Metric (English)	Units Metric (English)	Test
Haze	%	< 2	ASTM D1003
Impact test 227 g (0.5 lb)	m (ft)	> 9.14 (> 30)	ANSI Z26.1
Boil test 2 hr	-	No defects	ANSI Z26.1
Bake test 2 hr/100 °C	-	No defects	ANSI Z26.1

Interlayer typical properties

Property	Units Metric (English)	Value	ASTM Test
Young's Modulus	Mpa (kpsi)	300 (43.5)	D5026
Tear Strength	MJ/m^3 ($ft\ lb/in^3$)	50 (604)	D638
Tensile Strength	Mpa (kpsi)	34.5 (5.0)	D638
Elongation	%	400 (400)	D638
Density	g/cm^3 (lb/in^3)	0.95 (0.0343)	D792
Flex Modulus 23 °C (73 °F)	Mpa (kpsi)	345 (50)	D790
Heat Deflection Temperature (HDT) @ 0.46 MPa	°C (°F)	43 (110)	D648
Melting Point	°C (°F)	94 (201)	(DSC)
Coeff. of Thermal Expansion (-20 °C to 32 °C)	10^{-5} cm/m °C (mils/in °C)	10 - 15 (0.10 - 0.15)	D696
Thermal Conductivity	W/M-K (BTU-in/hr-ft2 °F)	0.246 (1.71)	

POLYMER INTERLAYER BEHAVIOR

All interlayers are viscoelastic

- Stiffness (modulus) and Poisson ratio vary as a function of temperature and load duration (creep)
- Evaluate properties over a range of test temperature and time using dynamic mechanical analysis and creep tests (ASTM D 4065)
- 'Small' strain values (< 20 % engineering strain)

Young's Modulus, E, shear modulus, G & Poisson ratio, v

- Extract E, G and v for specified temperature and load duration
- Choose appropriate elastic property values for design case and assign to an effective elastic interlayer
- Important to asses the likelihood of achieving full design load at the design temperature and load duration

STRUCTURAL PROPERTIES OF LAMINATED SAFETY GLASS

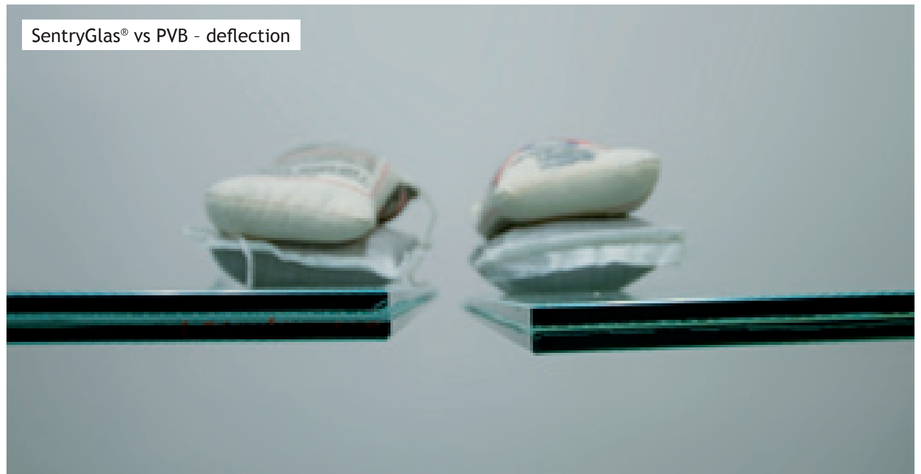
The structural behavior of laminated glass is a complex topic. Many factors influence the response of a laminated plate or beam to an imposed load. Despite this complexity, much progress has been made in understanding laminated glass in the last 15 years.

INTRODUCTION

The structural behavior of laminated glass is a complex topic. Many factors influence the response of a laminated plate or beam to an imposed load. Despite this complexity, much progress has been made in understanding laminated glass in the last 15 years. This progress is primarily attributable to advances in mechanics and associated computational tools (e.g. FEA software) and the development of appropriate interlayer property information that accurately captures the effects of load duration and temperature on the polymer properties.

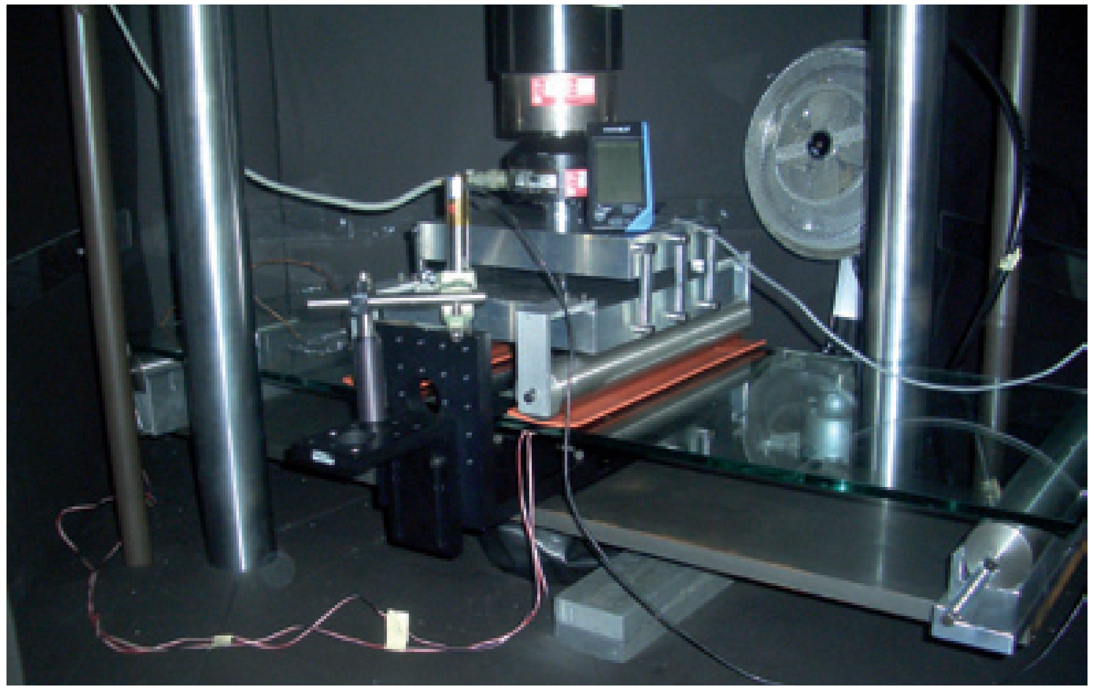
The result of this body of work is the capability to now model accurately the structural behavior of laminated glass using modern finite element analysis (FEA) methods. However, the glass design industry often takes the approach of using simplified calculation methods for engineering laminated glass due to the slow adoption of FEA technology. These simplified design approaches are often inaccurate, although usually conservatively so. Such conservative approaches tend to result in an abundance of over-designed laminated glass systems, which in turn leads to unnecessary extra cost. Accordingly, there is a need to develop calculation methods that capture accurately the mechanical response of laminated glass while being relatively straightforward to implement in standards and existing calculation methodologies.

This chapter outlines the properties and structural advantages of laminated safety glass and how common interlayer types (i.e. PVB and SentryGlas® ionoplast interlayer) perform under various test conditions. This includes tests that enable comparisons to be made between the structural performance of PVB laminates, laminates with SentryGlas® ionoplast interlayer and monolithic / tempered glass. These tests include bending / deflection tests (four-point bending), as well as tests that enable the effective thickness of laminated glass to be determined accurately.


SentryGlas® vs PVB - deflection

→ Post-glass breakage performance of Laminated Safety Glass

This chapter also describes the various methods currently available for comparing and calculating the strength of laminated safety glass.



BENDING TESTS

In the glazing industry, the Four-Point Bending Test is the industry-standard test for determining the strength and stress properties of laminated glass and monolithic tempered glass. These tests are defined in EN ISO 1288- 3 standards and ASTM C158.

EN ISO 1288-3 is a useful test for studying laminated glass, including load-bearing capacity (i.e. applied load-glass stress behavior and laminate deflection behavior). The effective thickness of laminate can be extracted directly from these tests. Temperature and load duration effects can also be analyzed.

The Four-Point Bending test involves measuring the glass stress (using strain gauges) and sample deflection. These are normally short duration tests that also involve simulating sudden gusts of wind. During these tests, the temperature is normally varied from room temperature up to around 70 °C (158 °F).

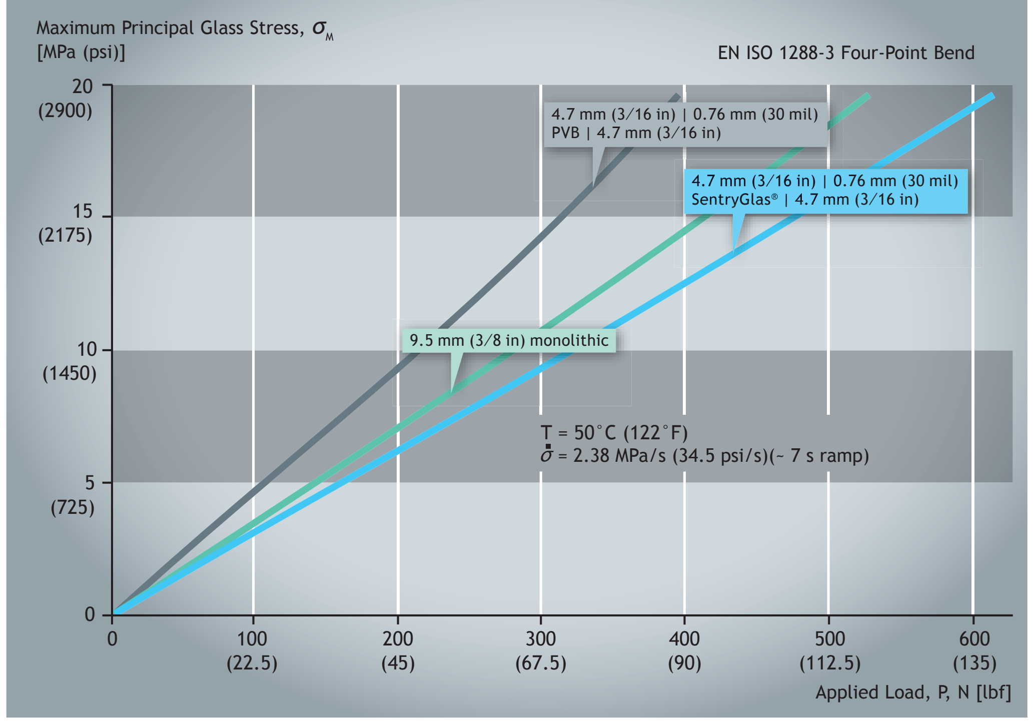
COMPARISON OF SENTRYGLAS® VS TROSIFOL® CLEAR PVB INTERLAYERS

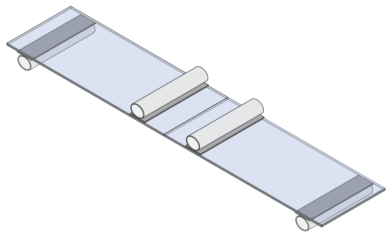
Kuraray Trosifol™ Solutions has collaborated with various material research institutes to investigate and compare the performance of laminated safety glass interlayers made from SentryGlas® and PVB, as well as monolithic glass.

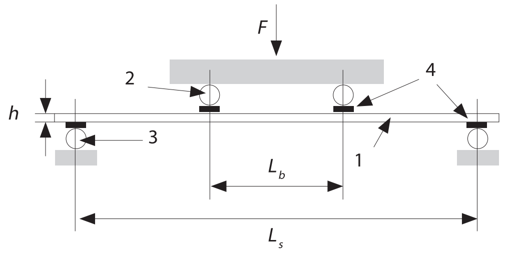
In tests at Trosifol® Clear, the materials compared in the tests were:

- Monolithic glass: nominal 10 mm (3⁄8 in) annealed
- Trosifol® Clear PVB laminated glass: nominal 5 mm (3⁄16 in) | 0.76 mm (30 mil) | nominal 5 mm (3⁄16 in)
- SentryGlas®: nominal 5 mm (3⁄16 in) | 0.76 mm (30 mil) | nominal 5 mm (3⁄16 in)

Glass Stress Development

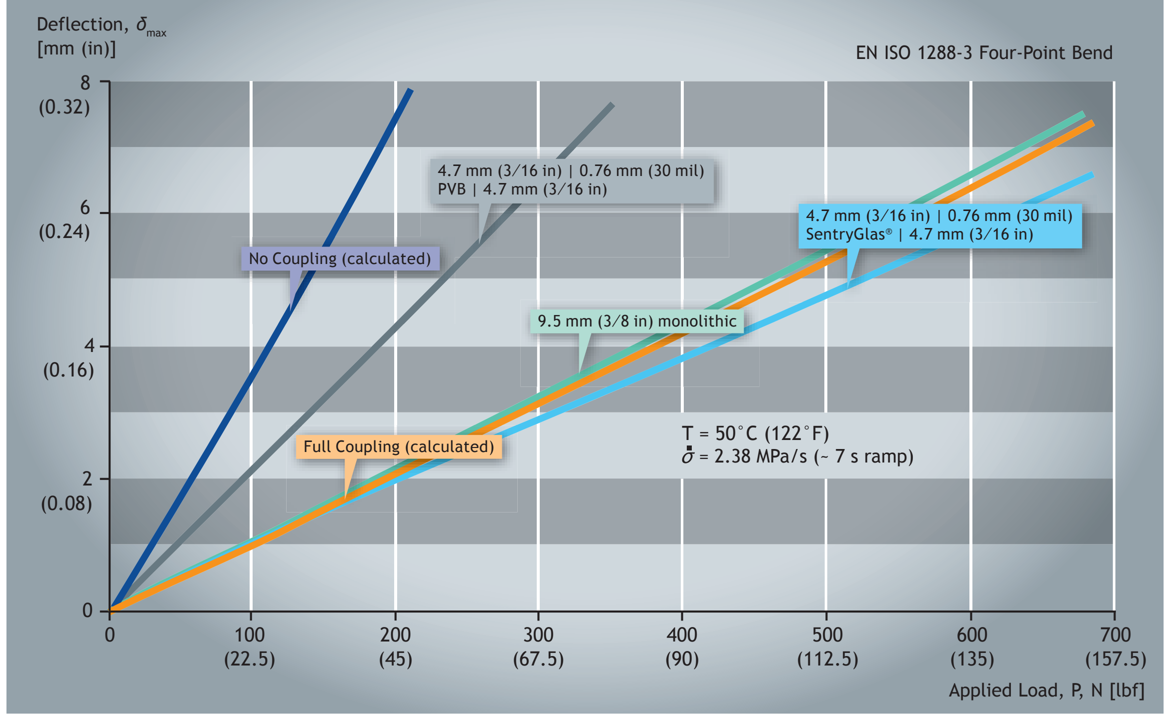


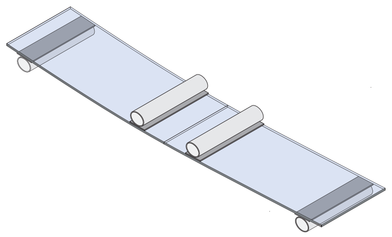




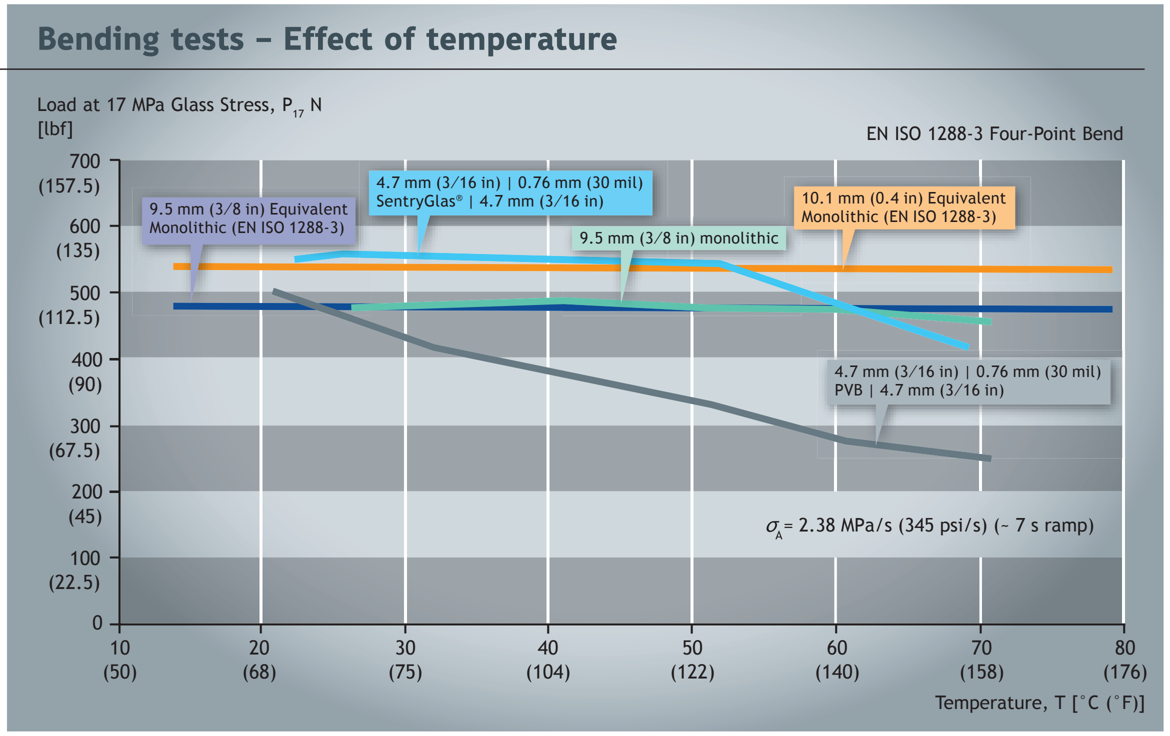
From the test results it can be seen that laminates with SentryGlas® develop the least glass stress at a specified applied load.

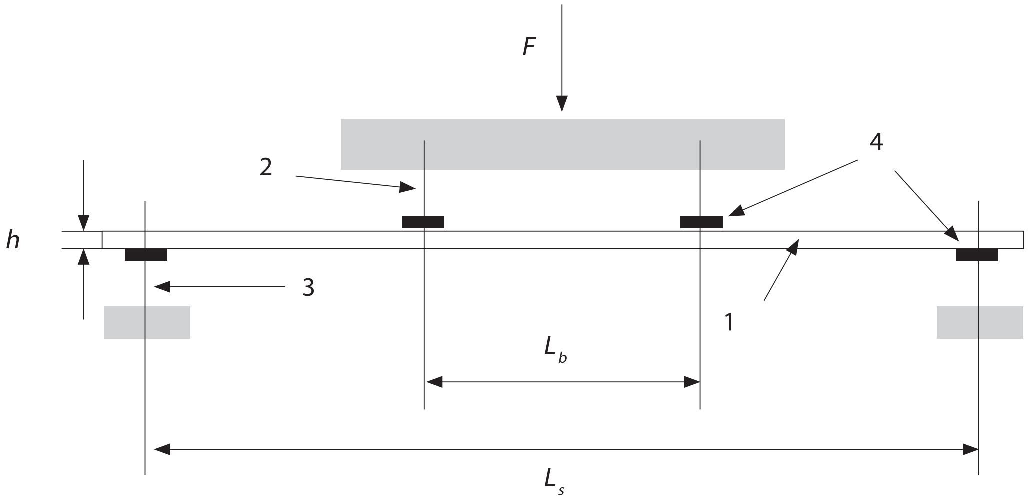
Deflection Data





The test results show that laminates with SentryGlas® develop the least deflection at a specified load.





When the samples were heated in a temperature-controlled chamber, the test results show that laminates with SentryGlas® were insensitive up to around 50 °C (122 °F). However, the structural performance of PVB laminate is temperature-sensitive. For short duration loads, PVB laminates show reduced strength (compared to the equivalent monolithic glass) above 20 °C (68 °F).

BENDING TESTS ON BALUSTRADES

Kuraray Trosifol™ Solutions has also collaborated with an independent research institute in the UK to compare the structural performance of glass balustrades made from PVB laminates, SentryGlas® and monolithic glass.

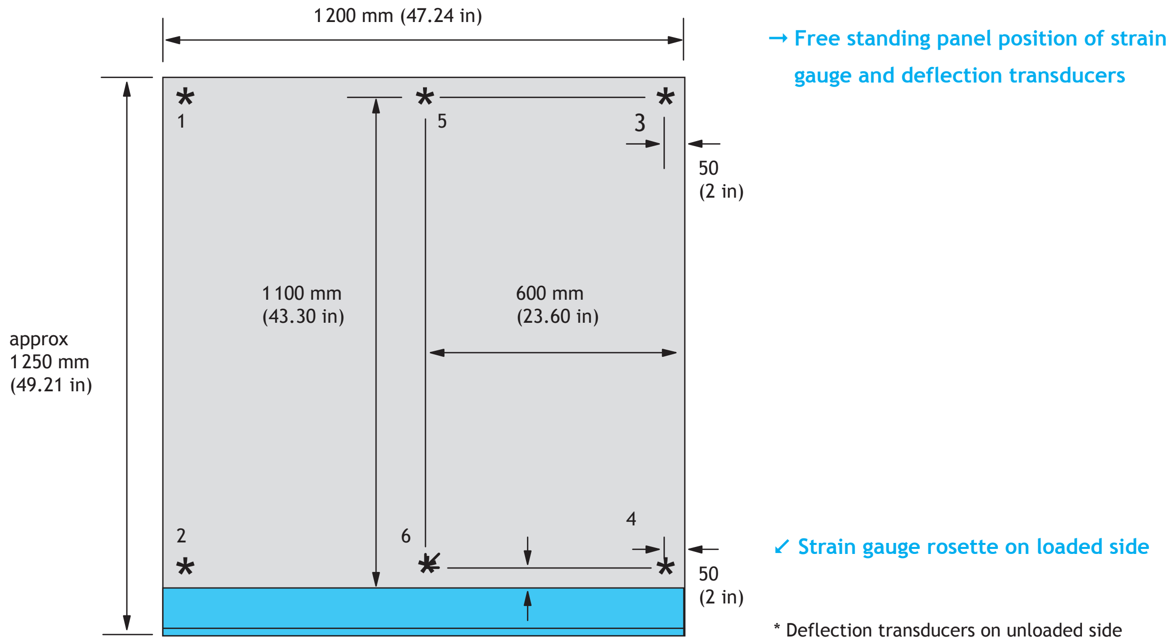
The Balustrade Test Program, which was developed by UK consultant John Colvin, compared the pre-glass breakage strength and deflection properties of the glass panels, which were manufactured by UK company Kite Glass.

The panels measured as follows:

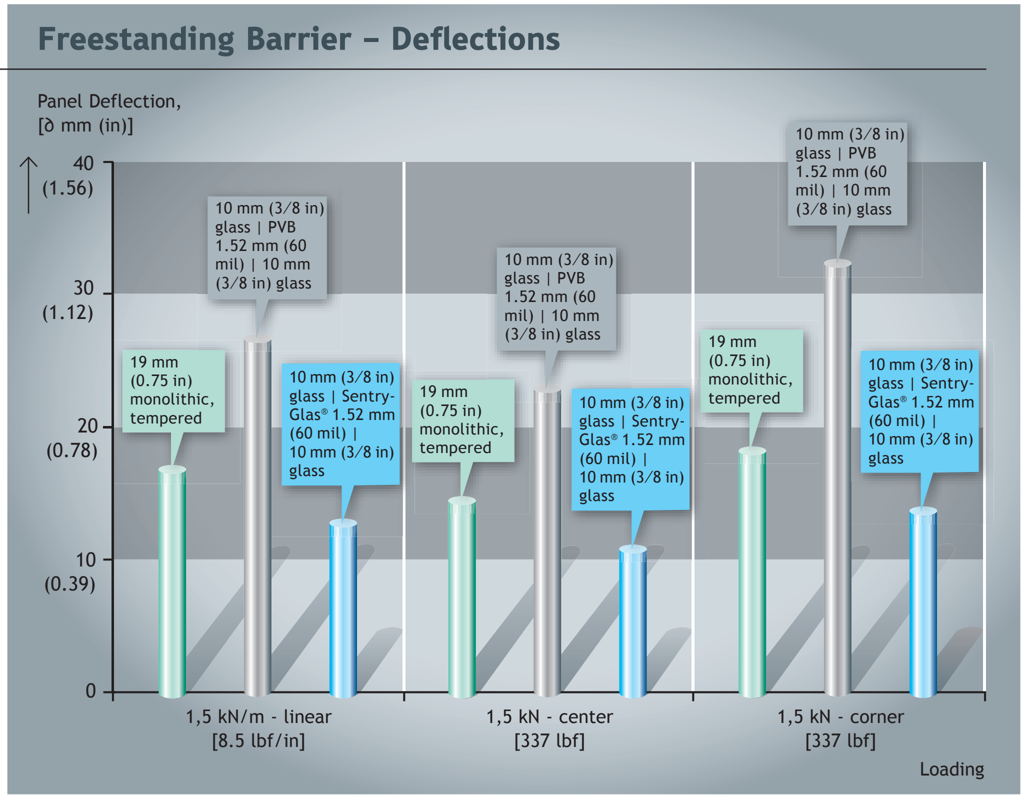
- 19 mm (3/4 in) tempered monolithic
- 10 mm (3/8 in) tempered | 1.52 mm (60 mil) PVB | 10 mm (3/8 in) tempered
- 10 mm (3/8 in) tempered | 1.52 mm (60 mil) SentryGlas® | 10 mm (3/8 in) tempered

These tightly controlled tests used common loading and support systems. Cantilever supports or bolted infill panels were used according to BS 6180. Line load and point load testing was carried out in accordance with BS 6399-1. Glass strength and deflection were measured at a temperature of 23 °C (73.4 °F).

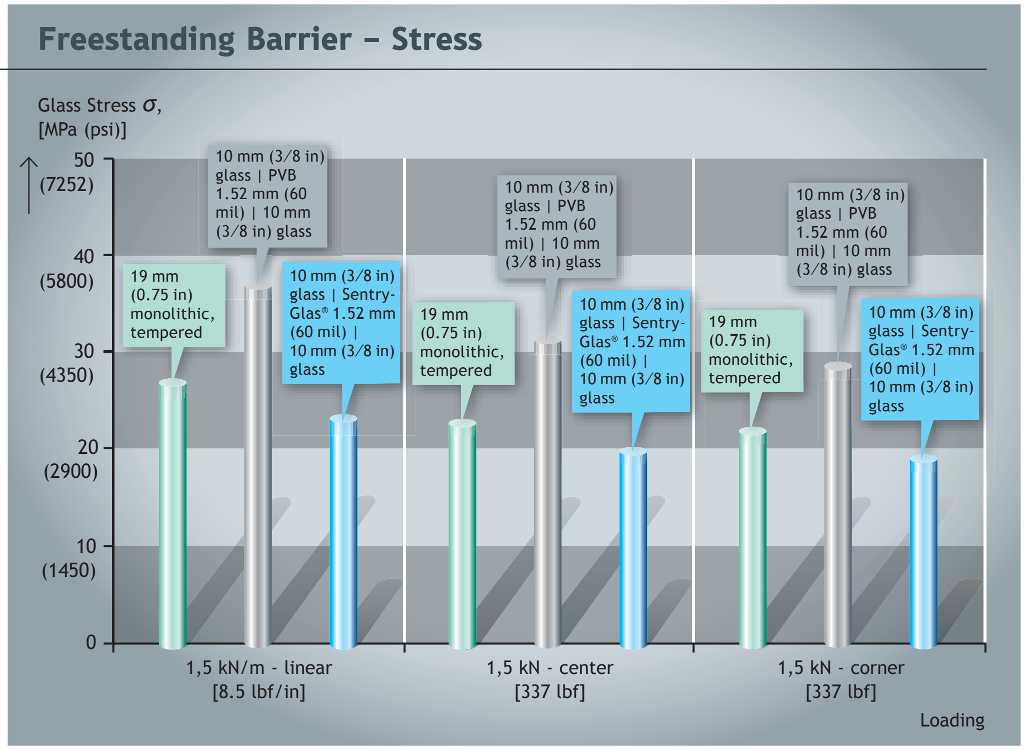
FREESTANDING BARRIER (CANTILEVER)



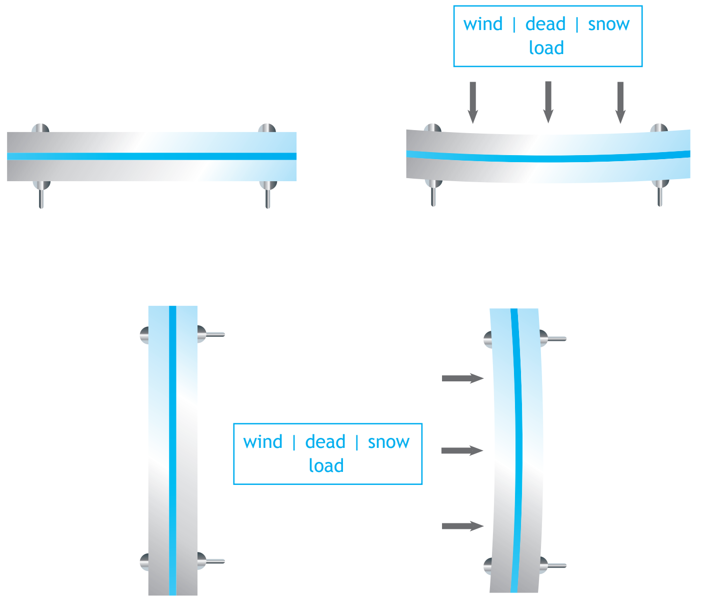
In these tests, a line load of 1.5 kN/m (8.5 lbf/in) was applied to the top edge of the glass panel. In the center and corners of the panel, concentrated load of 1.5 kN (337 lbf) was also applied.



The test results clearly demonstrate that laminates with SentryGlas® interlayer develops the least deflection under the same load conditions.



The test results also show that laminates with SentryGlas® interlayer develops the least glass stress under the same load conditions.



CONCLUSIONS

In both sets of tests, laminates with SentryGlas® interlayer performed in a manner that was similar to the equivalent thickness of monolithic glass, both in terms of the deflections and the stresses induced.

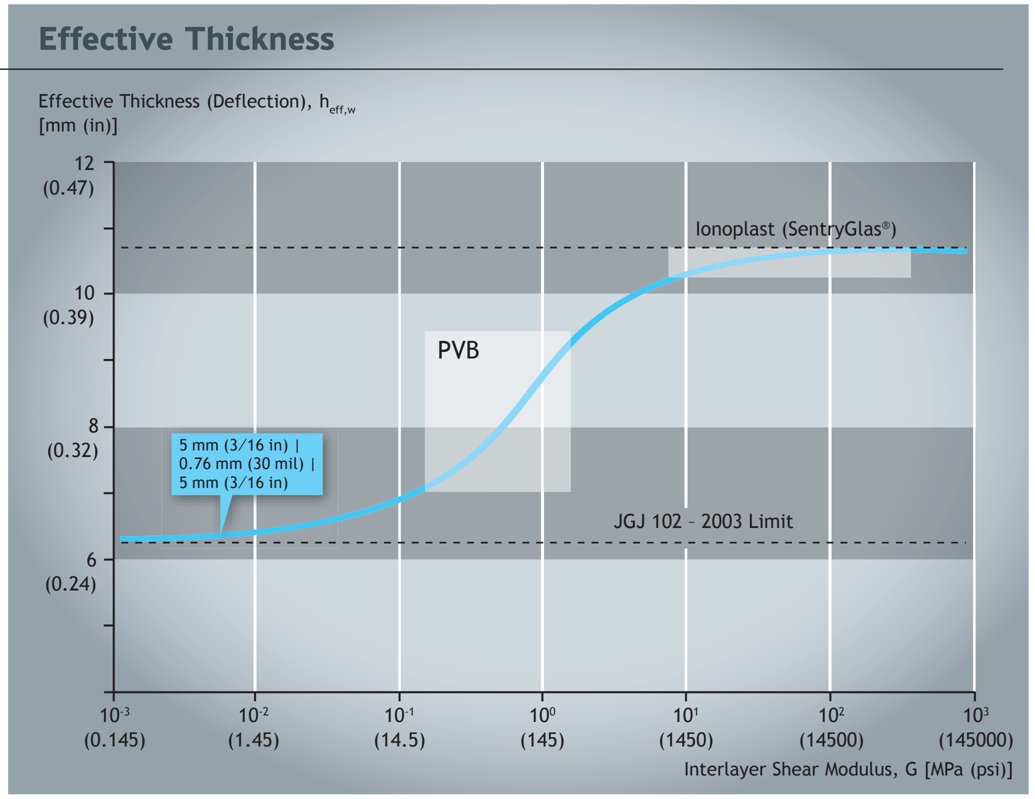
However, the PVB laminates developed significantly higher stresses and deflections than the equivalent thickness of monolithic glass. Therefore, laminated glass manufactured with PVB interlayer cannot be considered as having a performance equivalent to monolithic glass of similar thickness when it is used in barrier / balustrade glass panes, subject to concentrated loads and / or fixed loads at discrete points.

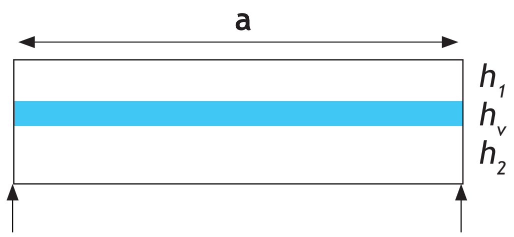
EFFECTIVE THICKNESS

The structural performance of laminated glass is commonly considered by defining the effective thickness, i.e. the thickness of a monolithic glass beam with equivalent bending properties in terms of stress and deflection. This method captures many of the important variables that influence performance. General expressions have been proposed on the basis of simplified models, but these are either difficult to apply or inaccurate.

How is it measured? In 2009, a method for determining the effective thickness for laminated glass for use in numerical analysis was added to ASTM E1300. A similar approach is also proposed in the latest European standard, prEN 13474 (2009), which uses OMEGA numbers for the ‘Coupling Approach’. Previously, glass thickness selection was limited to laminated glass charts presented in the ASTM E1300 Standard with a PVB interlayer. The effective thickness methodology provides an equivalent monolithic thickness based on the interlayer properties and glass geometry. Utilizing the effective thickness with a numerical analysis method, stresses and deflections for laminated glass can be easily modeled.

ASTM E1300 effective thickness approach with analytic expression for the bending case is an acceptable approach, but the key here is to have analytic expressions that are close to the problem being investigated.





$$h_{ef;w} = \sqrt[3]{h_1^3 + h_2^3 + 12\Gamma I_s}$$

$$I_s = h_1 h_{S;2}^2 + h_2 h_{S;1}^2$$

$$h_S = 0.5\,(h_1 + h_2) + h_v$$

$$\Gamma = \frac{1}{1 + 9.6\,\frac{E I_s h_v}{G h_S^2 a^2}}$$

$$h_{S;1} = \frac{h_S h_1}{h_1 + h_2}$$

$$h_{S;2} = \frac{h_S h_2}{h_1 + h_2}$$

Γ = Measure of shear transfer (0 → 1)

OTHER TEST METHODS

Other test methods for determining the structural properties of laminated safety glass include the use of 3D finite element analysis methods with full viscoelastic models. This method is accurate and captures the rate and temperature effects and is capable of modeling complex loading / support conditions. Test results can be validated for a range of rates, temperatures and bending states.

2D finite element methods with effective interlayer stiffness is also an acceptable method, although this method is conservative and so does tend to overestimate stress. However, it is useful for evaluating the effect of different interlayer types.

CALCULATING AND COMPARING THE STRENGTH OF DIFFERENT LAMINATES

GLASS STRENGTH CALCULATOR

In order to help designers and structural engineers estimate the stress and deflection behavior of glass laminates, Kuraray has developed an online software tool, which can be accessed via the Trosifol™ website. 'The Strength of Glass Calculator Tool' enables users to compare different types and thicknesses of laminates made from SentryGlas® or PVB interlayers.

The tool can be used to calculate the following:

- Maximum glass stress under load and comparison to design strength specified in various standards such as ASTM E1300
- Laminate deflection
- Effective laminate thickness
- Laminate behavior as a function of time and temperature

Trosifol™ GlasGlobal

For performing structural analysis for glass:
www.trosifol.com/trosifol-glasglobal

Trosifol™ WinSLT

For calculating the light, solar and heat parameters of glazing specifically containing films from the Trosifol™ product range:
https://www.trosifol.com/de/trosifol-winslt-tool/

STRUCTURAL BENEFITS OF SENTRYGLAS®

From the various tests outlined, it can be concluded that SentryGlas® interlayer extends the performance of laminated glass.

This enhanced structural performance allows laminate designs with:

- Thinner glass systems (Downgauging glass thickness)
- Larger panel sizes
- Extended pressure / temperature performance ranges
- Minimal support in frameless glazing systems

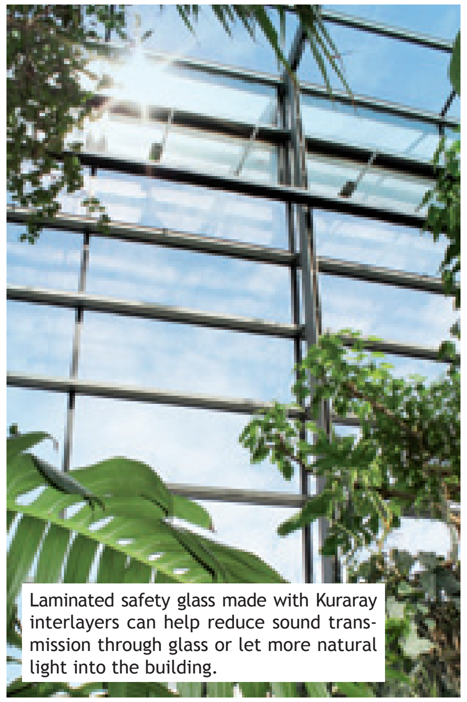
OPTICAL, VISUAL AND SOUND CONTROL PROPERTIES

Laminated architectural glass is being used increasingly to meet modern safety codes and to save energy through added daylighting and solar design.

INTRODUCTION

Laminated architectural glass also adds anti-intrusion security, sound reduction and protection from UV rays. Some applications require laminated glass with high UV-transmittance properties, allowing more natural light into the building.

Two common types of interlayer for laminated glass are films made from PVB and SentryGlas® ionoplast interlayers. The optical, visual clarity and acoustic performance of these interlayers are often critical design considerations for architects and structural designers.



Laminated safety glass made with Kuraray interlayers can help reduce sound transmission through glass or let more natural light into the building.

VISUAL CLARITY

In terms of architectural glazing applications, choosing the right laminated safety glass can improve the visual clarity (visibility) and visual comfort of people occupying the building, primarily by protecting the human eye from glare due to sunlight.

HOW IS VISUAL CLARITY MEASURED?

The visual clarity (transparency) of laminated glass is normally measured by using the Yellowness Index (YID). YID is a number calculated from spectrophotometric data that describes the change in color of a test sample from clear or white toward yellow. This yellowing / coloration process is described by the DeltaE value (see ASTM D1925 'Test Method for Yellowness Index of Plastics'). These tests are most commonly used to evaluate color changes in a material caused by real (or simulated) outdoor exposure.

DESIGNING WITH LOW-IRON GLASS

Visual clarity and optical quality are therefore important design considerations. Low-iron glass (i.e. glass with reduced iron content) provides improved visual clarity by increasing light transmission and reducing the greenish tint in clear glass that is most apparent when viewed from the edge. This green tint becomes more visible as the thickness of the glass increases.

Due to its high clarity, SentryGlas® ionoplast interlayers enable architects and structural designers to achieve their ultimate visions in low-iron safety glass. SentryGlas® interlayer eliminates the undesirable 'yellow' or 'greenish' tint that affects safety glass produced with conventional interlayers such as most PVB products, even at the outermost edge of weather-exposed laminates. This means that for the first time, designers can specify low-iron and safety glass, but still achieve the full clarity they require for the application, without sacrificing visibility, clarity or the overall beauty of their designs. This is particularly important in critical clarity applications such as skylights, doors, entranceways, display cases and retail storefronts.

For laminated safety glass products made of heat-strengthened or fully tempered glass, we also recommend high adhesion, e.g. Trosifol® UltraClear (formerly known as Trosifol® BG R20). Besides salt spray test demonstrates the outstandig open edge performance with Trosifol® Ultra Clear.

SENTRYGLAS® IONOPLAST INTERLAYER VS PVB

Not only does SentryGlas® interlayer start clearer than other safety glass interlayers, it also remains clearer throughout its life. With a Yellowness Index (YID) that starts at 1.5 or less (compared to 6-12 YID for PVB alternatives), SentryGlas® interlayer keeps its initial clarity after years of service. This means extra transparency and a more predictable color in laminated glass, which is more consistent with the glass color selected for the project.

With a higher YID than SentryGlas® interlayer, PVB interlayers often cause a 'greenish' tint effect in the glass after years of service, whereas SentryGlas® ionoplast interlayer takes on a more favorable 'blue' tint over time. The clarity of SentryGlas® interlayer is permanent and the laminate will under normal conditions such as proper lamination not turn yellow. SentryGlas® is therefore ideally suited to a wide range of architectural safety glass applications, including overhead glazing, façades, balustrades, staircases, flooring, storefronts (retail outlets), and other typical low-iron glass applications.

SOLAR ENERGY CONTROL

Architectural design is enhanced with an abundance of natural light. Energy savings can often be achieved by considering the solar control properties of glass design. Sunlight can cause heat gain within a structure, which is sometimes undesirable in terms of the costs of energy and air conditioning. However, at other times, for example in colder climates, it may be appropriate to maximize the heat retention in order to reduce heating costs. For laminated safety glass, there are no obvious technical advantages in terms of solar energy control by specifying either PVB, monolithic or SentryGlas® ionoplast interlayers.

Solar control characteristics of clear glass laminated with SentryGlas® interlayer

Nominal Laminate Thickness [mm]	[in]	SentryGlas® [mm]	[mil]	Glass Type	U-Value [W/m²K]	SHGC	SC	Tvis [%]
6	1/4	1.52	60	Clear	5.57	0.76	0.88	88
		2.28	90	Clear	5.39	0.74	0.86	85
11	7/16	1.52	60	Clear	5.49	0.73	0.84	86
		2.28	90	Clear	5.31	0.71	0.82	84
15	9/16	1.52	60	Clear	5.82	0.81	0.94	85
		2.28	90	Clear	5.82	0.81	0.94	85
6	1/4	1.52	60	Low-iron	5.90	0.91	1.04	91
		2.28	90	Low-iron	5.90	0.91	1.04	91
11	7/16	1.52	60	Low-iron	5.85	0.90	1.04	91
		2.28	90	Low-iron	5.31	0.81	0.94	87
15	9/16	1.52	60	Low-iron	5.43	0.84	0.96	90
		2.28	90	Low-iron	5.25	0.81	0.93	87

Solar control characteristics of tinted glass laminated with SentryGlas® interlayer

Nominal Laminate Thickness [mm]	[in]	SentryGlas® [mm]	[mil]	Glass Type	U-Value [W/m²K]	SHGC	SC	Tvis [%]
6	1/4	1.52	60	Bronze	5.57	0.58	0.67	49
		2.28	90	Bronze	5.39	0.57	0.66	47
6	1/4	1.52	60	Grey	5.57	0.53	0.62	40
		2.28	90	Grey	5.39	0.52	0.61	38
11	7/16	1.52	60	Bronze	5.49	0.51	0.59	37
		2.28	90	Bronze	5.31	0.50	0.59	36
11	7/16	1.52	60	Grey	5.49	0.46	0.54	28
		2.28	90	Grey	5.31	0.46	0.53	27
15	9/16	1.52	60	Bronze	5.43	0.47	0.55	31
		2.28	90	Bronze	5.25	0.47	0.55	30
15	9/16	1.52	60	Grey	5.43	0.43	0.50	22
		2.28	90	Grey	5.25	0.43	0.50	21

The tables above show the solar control values for a limited number of laminated glass configurations. These values were calculated using the LBNL (Lawrence Berkeley National Laboratory) OPTICS and WINDOW software calculation programs. The table only provides a subset of the possible configurations that can be calculated using this software. Specific configurations can be calculated by downloading the WINDOW software or by requesting help from Kuraray.

WINDOW is a publicly available software program for calculating total window thermal performance indices (i.e. U-values, solar heat gain coefficients, shading coefficients, etc.). The software allows users to model complex glazing systems using different glass types and to analyze products made from any combination of glazing layers, frames, spacers and dividers under any environmental conditions and at any tilt angle.

We also recommend WinSLT: New Mobile Calculation Tool from Trosifol™. WinSLT is a new app for calculating the light, solar and heat parameters of glazing containing interlayers from the Trosifol™ product range. What's new about this app is that the characteristics of specific laminated safety glass configurations can now be calculated for the deployment of laminates from the Trosifol™ product range. From various glass and interlayer thicknesses and compositions, the tool calculates all the relevant data inclusive of the Ug-value of the complete panel. With the aid of an intuitive input mask, Trosifol™ WinSLT determines the necessary light, solar and heat characteristics of any desired configuration. All the calculations are in line with the latest standards, such as EN ISO 673 (Ug-value), EN 410 (g-value, reflection, absorption, transmittance), EN ISO 52022-3 (gtotal-value, previously EN ISO 13363) and ISO 15099 / ASHRAE (Ug-value, SHGC-value, reflection, absorption, transmittance). For the last-mentioned standard, the radiative and thermal characteristics are determined in accordance with ISO 15099 and the stipulations of ASHRAE. All the relevant data for the various Trosifol™ PVB and ionoplast interlayers (SentryGlas®) have been preloaded and stored in an extensive database. For input, only the desired products have to be selected along with the thickness of the glass ply, gas space, laminated layer and the desired window composition. The app then outputs the functional data, calculating the reflection, transmittance and absorption and, in addition, the cross-sectional temperature curve.

DEFINITIONS

The U-Value is a measure of the rate at which heat is lost through a material.

The Solar Heat Gain Coefficient (SHGC) measures how well a product blocks heat caused by sunlight. The lower a window's SHGC, the less solar heat it transmits.

The Shading Coefficient (SC) is the ratio of total solar transmittance to the transmittance through 3 mm (⅛ in) clear glass.

The visible light transmittance (VLT or Tvis %) is the percentage of visible light that is transmitted through a material. The VLT is measured in the 380-780 nm wavelength range perpendicular to the surface. The higher the percentage, the more daylight. Also known as Tv, LT and VT.

Ultraviolet Elimination is the percentage of ultraviolet radiation eliminated by the glass, measured over the 290-380 nm wavelength range. The higher the percentage, the less UV is transmitted. This value is calculated from the percentage transmission of ultraviolet (TUV). Therefore UV Elimination = 100 - TUV.

Heat and light control characteristics – Trosifol® Clear PVB with clear glass

Nominal Laminate Thickness (2 lites) [mm]	[in]	Trosifol® Clear Interlayer	Designation	Visible Light Transmittance [%]	Solar Transmittance [%]	Shading Coefficient	Relative Laminate Instantaneous Heat Gain [BTU/hr/ft²]	[W/m²]
6	1/4	Clear	Clear	89	73	0.92	198	625
		Blue Green	0377300	73	65	0.85	185	584
		Azure Blue	0637600	76	67	0.86	187	590
		Bronze Light	0645200	52	49	0.72	160	505
		Translucent White*	0216500	65	58	0.77	168	530
		Soft White*	0218000	80	68	0.87	188	594
		Gray	0654400	44	50	0.73	160	505

*All specimens consisted of two plies of 3 mm (⅛ in) clear glass laminated with 0.38 mm (15 mil) Trosifol® Clear solid colored interlayer. Glass source may affect light transmission. The data values in this table are based on samples tested and may differ for other glass sources.

OPTICAL, VISUAL AND SOUND CONTROL PROPERTIES

Heat and light control characteristics – Trosifol® Clear PVB with tinted glass

Nominal Laminate Thickness (2 lites) [mm]	[in]	Clear Trosifol® Clear Interlayer Thickness [mm]	[mil]	Glass Color	Visible Light Transmittance [%]	Solar Transmittance [%]	Shading Coefficient	Relative Laminate Instantaneous Heat Gain [BTU/hr/ft²]	[W/m²]
6	1/4	0.38	15	Grey	60	54	0.75	165	521
		0.76	30	Grey	61	53	0.75	165	521
		1.52	60	Grey	60	52	0.74	163	514
6	1/4	0.38	15	Bronze	64	54	0.76	151	505
		0.76	30	Bronze	64	53	0.75	149	527
		1.52	60	Bronze	64	53	0.74	147	521
10	3/8	0.38	15	Grey	50	45	0.68	151	476
		0.76	30	Grey	50	44	0.67	149	470
		1.52	60	Grey	50	43	0.66	147	464
10	3/8	0.38	15	Bronze	56	47	0.70	155	489
		0.76	30	Bronze	56	46	0.69	153	483
		1.52	60	Bronze	56	45	0.68	151	476

All specimens consisted of two glass plies laminated with Trosifol® Clear, one clear and one colored glass ply with interlayer thickness tabulated. Glass source, type, color and thickness affect light transmission. Laminates prepared with commercial grey and bronze tint float glass. For close color matching, examine sample of desired construction.

- Minimum and maximum thickness tolerances are defined by ASTM C 1172. Actual laminates measured were within 8% of total nominal thickness.
- Nominal total visible light transmittance measured as CIE standard illuminate C. Actual values may vary.
- Shading Coefficients (SC) and summer U-values based on ASHRAE standard summer conditions where outdoor temperature is 32 °C (89 °F), indoor temperature is 24 °C (75 °F,) incident solar radiation is 248 BTU/hr/ft², and outdoor wind velocity is 7.5 mph; calculated per guidelines in 1985 ASHRAE Fundamentals Handbook, Chapter 27.
- Relative total instantaneous heat gain is: SC*SHGF + U-value* (To-Ti) Based on a Solar Heat Gain Factor (SHGF) of 200 BTU/hr/ft² and an outdoor temperature -10 °C (14 °F) higher than indoor (To-Ti).

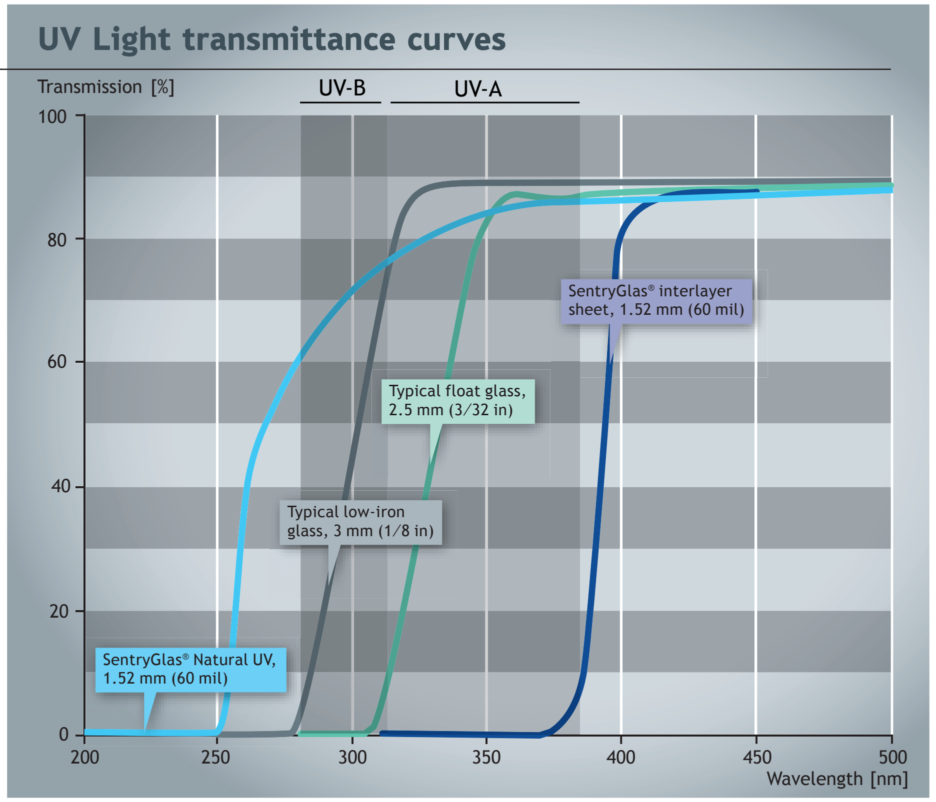
UV-TRANSMITTANCE

Some buildings require glass with high UV transmittance properties, others with low transmittance. For example, when designing controlled environments for animals or plants, extra caution must be taken to supply unfiltered, broad-spectrum light, as close as possible to the species' normal habitat and environmental conditions. Full spectrum light includes ultraviolet (UV) rays in wavelengths that are too short for the human eye to detect. Wavelengths of light in the UV-A and UV-B ranges, for example, are of particular interest to the health and survival of many natural species.

Other laminated glass applications may require lower transmittance properties. For example, a UV blocker may be used in the glass to minimize the amount of natural UV light through a retail storefront, in order to protect the textiles on display from being damaged.

SentryGlas® Natural UV is a structural interlayer for safety glass that combines the strength, safety and edge stability of SentryGlas® interlayer with increased transmittance of natural ultraviolet (UV) light. Unlike most safety glass interlayer technologies, SentryGlas® ionoplast requires no UV protection for lasting strength and clarity. SentryGlas® interlayer can be manufactured in a special, high UV-transmittance sheet, which is suitable for use in botanical gardens or other special environments where exotic plants, fish, reptiles and insects demand unique UV light requirements.

Using SentryGlas® interlayer Natural UV with float glass or low-iron float glass can dramatically increase the UV-transmittance through the resulting laminated glass panels. The UV-transmittance level of a glass laminate is highly dependent on the transmittance level of the chosen glass at the required thickness for a given structure. Generally, by specifying SentryGlas® Natural UV over other types of laminated glass, the level of UV light transmittance is inherently higher due to the reduced glass thickness required.



High levels of UV-A and UV-B light pass through a SentryGlas® Natural UV interlayer. However, other glazing materials, including monolithic glass, block out much of the UV-A and UV-B energy.

ACOUSTIC / SOUND PERFORMANCE

In architectural applications, improving the acoustic / sound insulation properties of the building and any glass structures is increasingly important. People in a building may need to be insulated from noisy traffic, aircraft from a nearby airport or simply from the noise generated by pedestrians walking by.

HOW IS IT MEASURED?

One test standard used for acoustical performance measurement is ASTM E90 'Laboratory Measurement of Airborne Sound Transmission of Building Partitions'. There are several ratings derived by testing according to this standard. Acoustical test results are presented below for both monolithic and insulating glass (IG) units made from Kuraray interlayers.

COMPARISON OF INTERLAYERS

In terms of architectural glass, there are many different methods of improving the acoustic properties of a building, including the use of double skin façades or double / triple insulated glazing units (IGU).

Trosifol® Clear PVB and SentryGlas® interlayers are used in many monolithic and insulated glass (IG) architectural applications where sound attenuation is desirable. One test standard used for acoustical performance measurement is ASTM E90 'Laboratory Measurement of Airborne Sound Transmission of Building Partitions'. There are several ratings derived by testing according to this standard. Acoustical test results are presented in the table below for monolithic and insulating glass (IG) units made with Kuraray interlayer.

Sound Transmission Loss (TL) Measurements: SentryGlas® and Trosifol® Clear PVB Laminated Glass Interlayers

Nominal Thickness [mm (in)]	Glass Make up [mm (in)]	Kuraray Interlayer [mm (mil)]	STC [a]	OITC [b]	80* [Hz]	100* [Hz]	125* [Hz]	160* [Hz]
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) Trosifol® Clear	37	34	25	25	30	29
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) SentryGlas®)	35	32	25	24	30	30
14.29 (9/16) lam	2 lites 6.35 (1/4)	0.89 (35) SentryGlas®	35	33	25	25	31	29
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) Trosifol® Clear	40	33	25	24	24	30
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) SentryGlas®	38	32	25	24	23	28
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 9.52 (3/8) lam	0.89 (35) SentryGlas®	38	32	24	24	26	28
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) Trosifol® Clear	41	33	25	25	26	30
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) SentryGlas®	39	33	25	25	25	29
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 12.7 (1/2) lam	0.89 (35) SentryGlas®	39	33	25	27	24	30

Nominal Thickness [mm (in)]	Glass Make up [mm (in)]	Kuraray Interlayer [mm (mil)]	200* [Hz]	250* [Hz]	315* [Hz]	400* [Hz]	500* [Hz]	630* [Hz]
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) Trosifol® Clear	30	30	31	33	35	36
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) SentryGlas®)	29	30	31	34	33	35
14.29 (9/16) lam	2 lites 6.35 (1/4)	0.89 (35) SentryGlas®	30	29	32	33	34	36
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) Trosifol® Clear	25	27	32	35	38	40
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) SentryGlas®	26	26	32	35	37	38
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 9.52 (3/8) lam	0.89 (35) SentryGlas®	25	26	31	34	37	39
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) Trosifol® Clear	27	28	33	35	38	39
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) SentryGlas®	27	28	33	34	35	37
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 12.7 (1/2) lam	0.89 (35) SentryGlas®	27	28	33	35	36	38

Nominal Thickness [mm (in)]	Glass Make up [mm (in)]	Kuraray Interlayer [mm (mil)]	800* [Hz]	1000* [Hz]	1250* [Hz]	1600* [Hz]	2000* [Hz]	2500* [Hz]
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) Trosifol® Clear	37	37	35	36	39	43
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) SentryGlas®)	34	33	31	34	37	41
14.29 (9/16) lam	2 lites 6.35 (1/4)	0.89 (35) SentryGlas®	35	33	31	35	38	42
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) Trosifol® Clear	42	44	45	44	43	43
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) SentryGlas®	39	39	40	40	40	40
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 9.52 (3/8) lam	0.89 (35) SentryGlas®	40	40	40	40	40	40
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) Trosifol® Clear	41	43	44	44	44	44
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) SentryGlas®	39	41	41	42	43	42
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 12.7 (1/2) lam	0.89 (35) SentryGlas®	39	41	41	43	43	43

Sound Transmission Loss (TL) Measurements: SentryGlas® and Trosifol® Clear PVB Laminated Glass Interlayers

Nominal Thickness [mm (in)]	Glass Make up [mm (in)]	Kuraray Interlayer [mm (mil)]	3150* [Hz]	4000* [Hz]	5000* [Hz]
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) Trosifol® Clear	46	49	52
14.29 (9/16) lam	2 lites 6.35 (1/4)	1.52 (60) SentryGlas®)	44	46	48
14.29 (9/16) lam	2 lites 6.35 (1/4)	0.89 (35) SentryGlas®	45	46	49
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) Trosifol® Clear	49	52	58
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 11.11 (7/16) lam	1.52 (60) SentryGlas®	44	48	53
30.23 (3/16) IG	6.35 (1/4) | 12.7 (1/2) air | 9.52 (3/8) lam	0.89 (35) SentryGlas®	45	47	53
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) Trosifol® Clear	49	52	57
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 14.29 (9/16) lam	1.52 (60) SentryGlas®	46	48	54
30.27 (5/16) IG	6.35 (1/4) | 12.7 (1/2) air | 12.7 (1/2) lam	0.89 (35) SentryGlas®	48	50	56

ATI Test Report 86743.01 completed 2008 at Architectural Testing, Inc. (ATI)

(a) Sound Transmission Class (STC) assesses privacy for interior walls. It is achieved by applying the Transmission Loss (TL) values from 125 Hz to 4 000 Hz to the STC reference contour found in ASTM E413. STC is the shifted reference contour at 500 Hz.

(b) Outside Inside Transmission Class (OITC) assesses exterior partitions exposed to outside noise. It covers the 80 Hz to 4 000 Hz range. The source noise spectrum is weighted more to low frequency sounds, such as aircraft, train, and truck traffic. The OITC rating is calculated in accordance with ASTM E1332.

STC and OITC values can be affected by glass thickness, interlayer thickness, air space and framing. An in-depth acoustical analysis may be required to understand project-specific factors.

EDGE STABILITY, DURABILITY AND WEATHERING

Despite the long history of the use of laminated glass in buildings, there is still a concern for some architects and designers about the potential for serious delamination problems, durability and edge stability of laminated glass, as well as how well the laminated glass will perform under different climatic conditions, including high humidity, tropical climates, storm zones, low and high temperatures, and high salt-water conditions.

INTRODUCTION

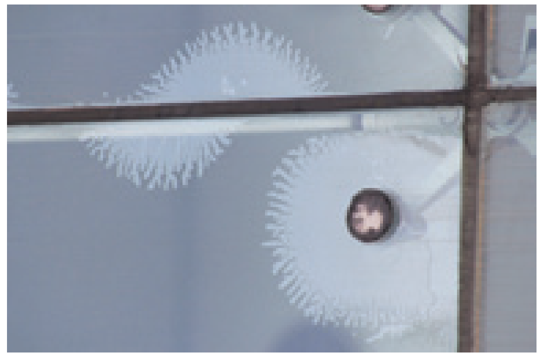
This chapter provides some examples of test data on the edge stability and weathering performance of SentryGlas® interlayer, as well as salt spray fog tests, sealant compatibility, ceramic frit compatibility, high temperature bake tests and adhesion to low-E and other solar glass coatings.

EDGE STABILITY, DURABILITY AND WEATHERING

WHAT IS EDGE STABILITY?

Edge stability is defined as a laminate's resistance over time to form defects along its edge. These defects can arise in the form of small 'bubbles' in the laminate or as discoloration of the laminate itself. For designers and architects, edge stability is therefore critical. Ideally, laminated glass should show no signs of delamination over the complete life of the building.

Typcial defects caused by delamination.



TESTS AND COMPARISON OF INTERLAYERS

Compared to standard conventional laminated glass interlayers, SentryGlas® ionoplast is more resistant to moisture and the effects of weather, particularly at temperatures between -50 °C (-58 °F) and +82 °C (180 °F). These are the consistent findings of laboratory tests and research in real-life projects.

Due to the exceptional edge stability of SentryGlas® interlayer, no undesired changes such as delamination have been found to date on any of its applications, even on panels with open edges that have been exposed to hot and humid climates such as Florida. This proven edge stability opens up many new design possibilities for SentryGlas®, enabling designers to create stronger, larger expanses of safety glazing including openedged, structural and butt-glazed installations.

When used in combination with standard silicon sealing material, butt-joined glass elements with SentryGlas® interlayers show no discoloration or other forms of damage to their edges, even after years of weathering. Years later these interlayers still provide the same level of safety and feature the same intact edging, as they did when they were first installed.

FLORIDA 20 YEAR TEST

In 1997 a test programme for laminated glass with SentryGlas® interlayer was started in Florida. The open-edge test samples are installed in open air conditions, fully exposed to the Florida climate. Since their installation, the samples with SentryGlas® interlayer have been tested annually for signs of weathering and delamination.

After 20 years of exposure to the weather, the edges of the laminates with SentryGlas® showed no visible sign of weathering, including no visible moisture ingress or delamination effects in open edge applications. In addition, with silicone butt-joined applications, the edges of the laminated glass also showed no visible moisture intrusion or delamination effects.

The table below shows test results after 149 months of exposure. After this time, SentryGlas® was assigned an Edge Stability Number (ESN). This weighted system assigns higher importance to progressively deeper defects. A laminate with no defects would have an ESN of 0 (zero), while the maximum would be 2,500 (equivalent to continuous defects measuring > 6.4 mm [¼ in] around the entire perimeter).

EDGE STABILITY, DURABILITY AND WEATHERING

Edge Stability Number (ESN) RWB-824

Laminate ID Number	Exposure Time [yts]	Laminate Perimeter [mm]	[in]	Defect Length [in] 1/16“	1/8“	3/16“	1/4“	> 1/4“	ESN	Comments
63-1	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
48-3	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
46-4	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
97-5	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
74-13	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
71-10	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
56-11	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed
75-12	20.5	3912	154	0	0	0	0	0	0	No edge bubbles or delaminations observed

ESN data in the table above includes test samples with open-edge exposure, as well as samples that are butt-joined using silicone sealant.

WEATHERING TEST REPORT FOR LAMINATED GLASS WITH SENTRYGLAS®

Samples of laminated glass with SentryGlas® interlayer were weathered according to a test method outlined in ANSI Z97.1: ‘Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test’. The test results are shown below.

Xenon-Arc Type Operating Light Exposure

Apparatus	Atlas Ci5000 Xenon Weather-Ometer®
Exposure Time	Specimens were exposed for 3 000 hours
Filter Type	Borosilicate inner and outer
Cycle	102 mins of irradiation, 18 mins of irradiation & water spray
Black Panel Temp	70 °C ± 3 °C (158 °F ± 5 °F)
Relative Humidity	50 % ± 5 %
Spray Water	De-ionized
Level of Irradiance	0.35 W/m² @ 340 nm
Exposure	Xenon-Arc Exposure: 3780 kJ/m² @ 340 nm

Note: on average, a 3 000-hour Xenon arc exposure approximates to a one-year direct South Florida exposure at 26° North Latitude, facing South.

RESULTS

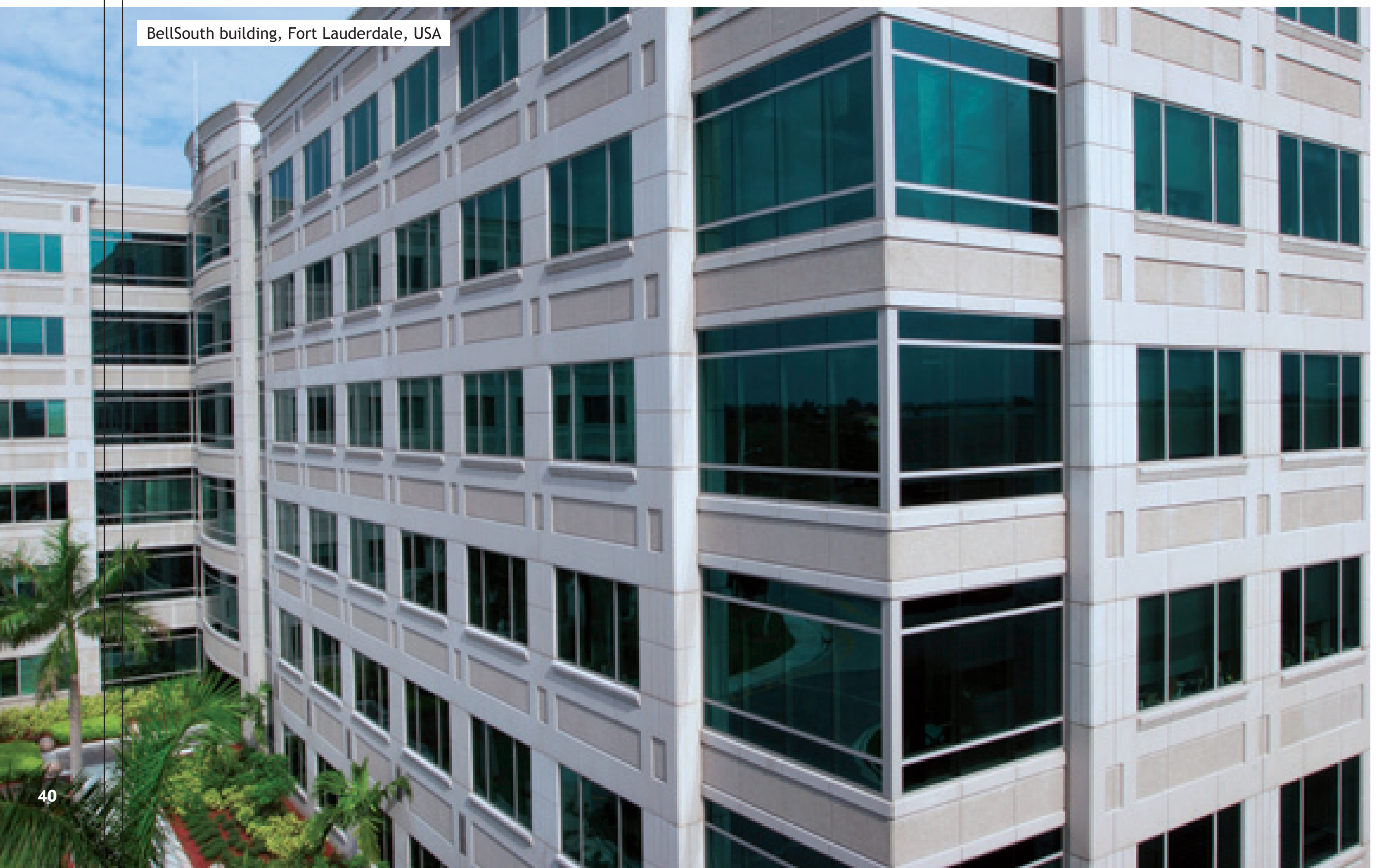
After the samples of laminated glass with SentryGlas® interlayer were irradiated and conditioned, the exposed samples were examined and compared visually with unexposed controls, as detailed in ANSI Z97.1. These samples were found to be visibly acceptable. No bubbles or delamination effects were visible and no crazing, cracking or discoloration was observed.

APPLICATION EXAMPLES OF THE SUPERIOR EDGE STABILITY OF SENTRYGLAS® INTERLAYER

As well as test reports supporting the superior edge stability performance of SentryGlas®, there are numerous real life examples to support the test data.

For example, the BellSouth building in Fort Lauderdale, USA, silicone sealed, butt joined safety glass made with SentryGlas® helped the architects deliver panoramic corner office views, while meeting tough wind and storm protection codes.

Elsewhere in the USA, cold winters, shadeless summer heat and occasional Mississippi River floodwaters were among the design challenges for a bandshell built on an island in St Paul, Minnesota. Open edged, buttsealed glazing panels made with SentryGlas® interlayer remain free of any visual defects after years of exposure. The extra strength of the interlayer also helped to create a uniquely shaped overhead structure.



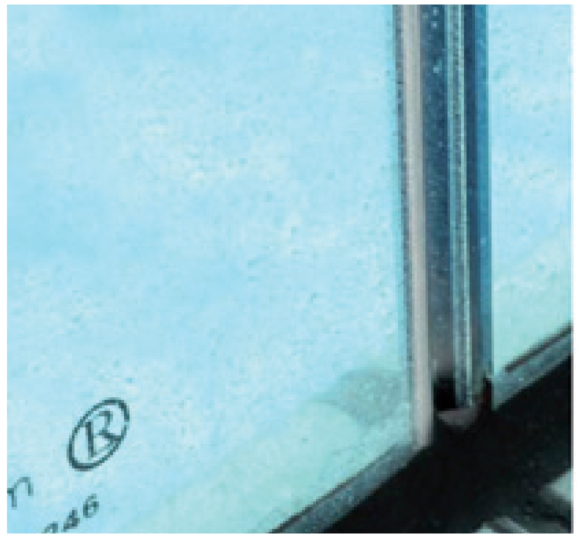
BellSouth building, Fort Lauderdale, USA

Marina Bay Sands SkyPark Infinity Pool, Singapore

EDGE STABILITY OF LAMINATES WITH SENTRYGLAS® IN COASTAL CLIMATIC CONDITIONS

For all marine and some architectural applications, prolonged exposure to salt water can cause defects in the laminated glass. However, laminates with SentryGlas® demonstrate excellent durability performance in coastal regions or landscapes with high concentration of salt water (e.g. due to high use of road salts due to snow). Extensive product testing, including salt spray fog testing (carried out by TÜV Süd Singapore, according to ASTM B 117-11) during which the glass panels laminates with SentryGlas® with open edges were exposed to salt spray solution continuously for 3,000 hours. Three 15 by 10 cm (5.93 by 3.93 in) glass panels were placed in a climatic chamber for 3,000 hours under the following experimental conditions:

- NaCl-concentration: 5 %
- Volume of condensate: 1.0-2.0 ml/HR/80 cm^2
- pH of the solution: between 6.5 and 6.9
- Test chamber temperature: 35 +/- 2°C



After the test, the glass panels were visually inspected and evaluated. The results showed that the panels remained unchanged in terms of their transparency. The PVB laminates showed edge clouds after 500 hours of testing. Due to the excellent edge stability of SentryGlas® interlayer, no undesired changes such as edge cloudiness, delamination caused by the humidity occur. Copies of the test report are available on request. Other salt spray tests have been conducted on laminated glass with SentryGlas® interlayer. In Germany for example, similar tests were carried out on SentryGlas® ionoplast interlayer by the Fachhochschule München as part of a DIBT approval for SentryGlas® ionoplast interlayer(Germany's regulatory body for products used in the construction industry).

SEALANT COMPATIBILITY OF SENTRYGLAS® INTERLAYER

A wide variety of sealants are used by the glazing industry and it is therefore critical to understand the chemical and mechanical compatibility of these sealants with the interlayer produced in a glass laminate. Laminates prepared with SentryGlas® demonstrate excellent compatibility with different types of sealants used in glazing applications. This is supported by tests conducted internal method but also by studies carried out by sealant manufacturers. These tests include accelerated QUV weathering and modified ASTM C1087 compatibility test methods as well as DI guideline, IFT Rosenheim, UVradiation tests, high-temperature and high humidity test scenarios.

OUTDOOR TESTING

Laminates with SentryGlas® show no edge defect formation, even after 15 years of natural outdoor weathering in Florida when tested with different types of sealants. In these tests, laminates with SentryGlas® have shown no signs of degradation from interactions with any of the sealants tested. Details of all sealant compatibility tests carried out by Kuraray and by sealant manufacturers are available on request from Kuraray. For a complete list of compatible sealants for SentryGlas® interlayer, please refer to the following table.

For a complete list of Compatible Sealants for SentryGlas® interlayer, please refer to the following table:

Company / Grade	Description	Test Method
ARBOSIL		
Arbosil 1096	1-component silicone sealant, neutral-cure	
C.R. LAURENCE		
C.R. Laurence 33SC	1-component silicone sealant, acetic-cure	
C.R. Laurence RTV408AL 999-A, 1199	1-component silicone sealant, neutral-cure	
DOWSIL™		
DOWSIL™ 756	1-component silicone sealant, neutral-cure	
DOWSIL™ 756-SMS	1-component silicone sealant, neutral-cure	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
DOWSIL™ 757	1-component silicone sealant, neutral-cure	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
DOWSIL™ 790	1-component silicone sealant, neutral-cure	
DOWSIL™ 791	1-component silicone sealant, neutral-cure	
DOWSIL™ 791-T	1-component silicone sealant	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
DOWSIL™ 795	1-component silicone sealant, neutral-cure	
DOWSIL™ 895	1-component silicone sealant, neutral-cure	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
DOWSIL™ 983	2-component silicone sealant, neutral-cure	
DOWSIL™ 993	2-component silicone sealant, neutral-cure	
DOWSIL™ 994	Ultra Fast, 2-component silicone sealant, neutral-cure	

EDGE STABILITY, DURABILITY AND WEATHERING

Company / Grade	Description	Test Method
DOWSIL™ 995	1-component silicone sealant, neutral-cure	
DOWSIL™ 999-A	1-component silicone sealant, neutral-cure	
DOWSIL™ 1199	1-component silicone sealant	
DOWSIL™ 3362	2-component silicone sealant	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
DOWSIL™ 3356 HD	2-component silicone sealant	ASTM C1087, ETAG 002, IFT-Guideline DI-02engll/1
GE ADVANCED MATERIALS		
GE Silglaze® II SCS2802	1-component silicone sealant, neutral-cure	
GE SilPruf® NB SCS9000	1-component silicone sealant, neutral-cure	
GE UltraGlaze® SSG4000	1-component silicone sealant, neutral-cure	
GE UltraGlaze® SSG4400	2-component silicone sealant, neutral-cure	
KÖMMERLING		
GD 116	2-component polysulfide sealant, solvent-free	IFT Guideline DI-02/1
GD 677	2-component polyurethane sealant, solvent-free	IFT Guideline DI-02/1
GD 920	2-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
GD 823 N	1-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
GD 826 N	1-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
Ködiglaze	S 2-component silicone sealant, neutral-cure	IFT Guideline DI-02/1
Ködiglaze P	1- or 2-component polyurethane, sealant solvent free	IFT Guideline DI-02/1
PECORA		
Pecora 895 NST	1-component silicone sealant, neutral-cure	
SIKA		
Icosit® KC-340/7	2-component polyurethane sealant, solvent-free	CQP 593-7
SikaGLaze® GG-735	2-component polyurethane sealant, solvent-free	CQP 593-7
Sikasil® GS-621	1-component silicone sealant, acetic-cure	CQP 593-7
Sikasil® IG-16	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® IG-25	2-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® IG-25 HM Plus	2-component silicone sealant, neutral-cure, high modulus	CQP 593-7
Sikasil® SG-18	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® SG-20	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® SG-500	2-component silicone sealant, neutral curing	CQP 593-7
Sikasil® SG-500 CN	2-component silicone sealant, neutral-cure, high modulus	CQP 593-7
Sikasil® SG-550	2-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-305 CN	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-355	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-605 S	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WS-680 SC	1-component silicone sealant, neutral-cure	CQP 593-7
Sikasil® WT-480	2-component silicone sealant, neutral-cure, high modulus	CQP 593-7
Sikasil® WT-485	2-component silicone sealant, neutral-cure	CQP 593-7
TREMCO		
Spectrem 1	1-component silicone sealant, neutral-cure	
Spectrem 2	1-component silicone sealant, neutral-cure	
Tremglaze S100	1-component silicone sealant, neutral-cure	
Vulkem 116	1-component polyurethane sealant	

HIGH TEMPERATURE PERFORMANCE OF SENTRYGLAS® INTERLAYER

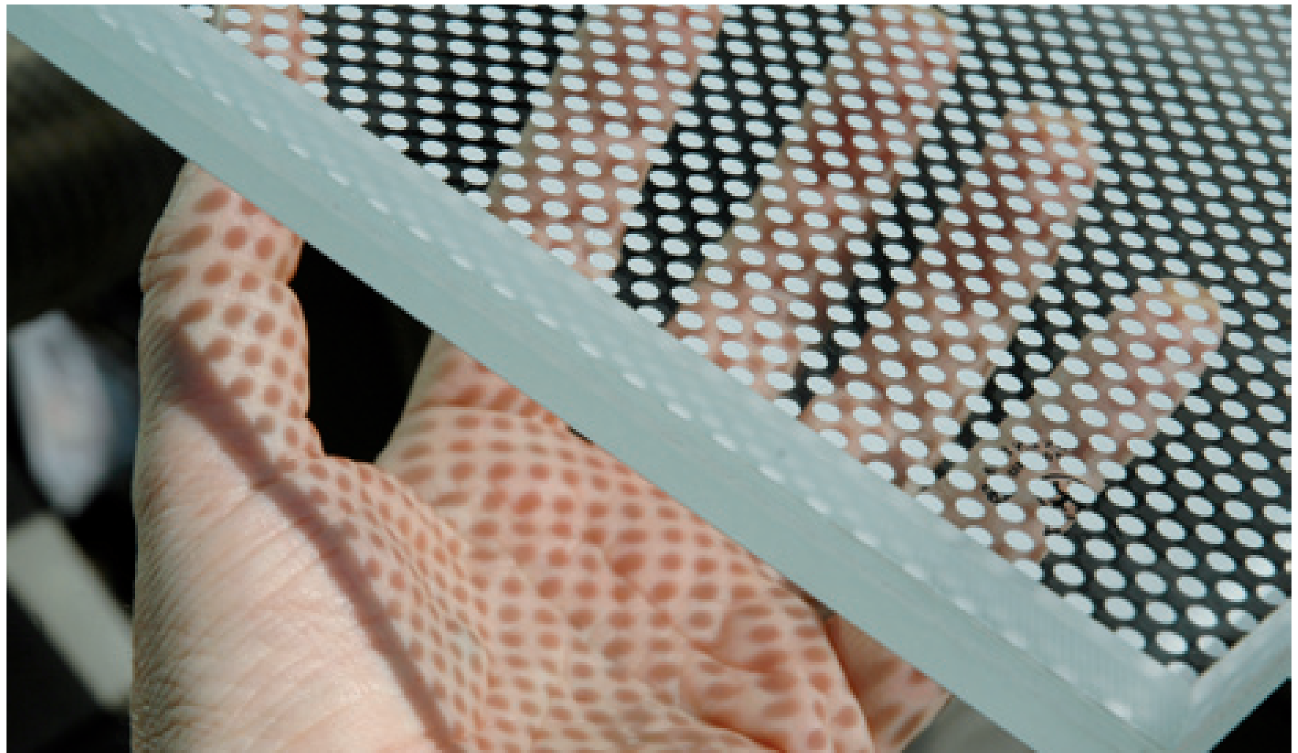
Properly laminated glass made with SentryGlas® interlayer has demonstrated capability of withstanding an environment of 100°C (212°F) for at least 16 hours, without bubble formation in the major viewing area. For more prolonged periods of time, of greater than 16 hours, a temperature limit of 82°C (180°F) 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°C (212°F). Bubble formation within the major viewing area of the laminate (typically excluding 12 mm or ~½ in from the laminate edge) constitutes a failure of this test. Based on this limited data, properly laminated specimens with SentryGlas® 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.

COMPATIBILITY WITH CERAMIC FRIT COATINGS

Used for both internal and external decorative glass, ceramic frit coatings can be specified in a wide variety of colors and patterns for improved aesthetics or solar control in laminated glass. These vitreous compounds are applied to the glass by screen-printing, roll coating, spraying or curtain coating, closely following the frit supplier's processing instructions. These are then heat-treated in order to create a permanent coating. When such a fritted surface comes into contact with the glass laminate interlayer, it is important to verify the lasting compatibility between the frit and the interlayer. Moisture and salts, for example, can be detrimental to frit coatings over time. Testing therefore requires extended contact between materials under controlled conditions. The table next page lists the various tests that Kuraray uses to assess the compatibility of interlayers and ceramic frit.



EDGE STABILITY, DURABILITY AND WEATHERING

Tests to assess the Compatibility of Interlayers and Ceramic Frit

Method	Standard	Intervals
76 Bake Test	Internal Method	500 & 1 000 hour
Coffin	ANSI Z26.1 (5.3 -3)	2, 5 & 10 weeks
UV (UVA-340)	ASTM G151, 154-06, ISO4892-1 & 4582	30 days
Natural Weathering	ASTM G 7-05 and G 147-02	1 year

Kuraray has conducted these tests on laminates made with SentryGlas® ionoplast and fritted glass, in order to observe changes in color, appearance or defects such as corrosion of the coating, bubbles, delaminations and other defects.

Ceramic Frits compatible with SentryGlas®

Manufacturer	Product Code	Product Name
FERRO	20-8496-1597	20-8496 ETCHIN 1597, 24-8029 BLACK IN 1544
FERRO	24-8029-1544	Medium, 24-8075 WARM GREY IN
FERRO	24-8075-1544	1544 Medium
Glass Coating Concept (GCC)	SX8876E808	SPANDREL WHITE
Glass Coating Concept (GCC)	SX3524E808	WARM GRAY

In the tests above, SentryGlas® interlayer showed no visual defects. In addition, adhesion was assessed before and after testing and no measurable differences were found. For other types of frit coatings not listed above, users should conduct their own tests or seek guidance from Kuraray. To ensure that glass meets safety codes, additional testing, including adhesion strength tests, may be required.

COMPATIBILITY WITH SOLAR SHADING OR GLASS COATINGS


Telecom, Maroc

The growing importance of the environment, energy efficiency and renewable building technologies are creating added value for glass manufactured with low-E (low emissivity) coatings. Often, in architectural applications, this coated glass also requires high impact strength, which can be achieved by laminating with SentryGlas® ionoplast interlayers.

When placing any interlayer into contact with a glass coating, it is critical to test the chemical and mechanical compatibility between the materials. Moisture and salts can be detrimental to coatings over time. SentryGlas® interlayer shows excellent compatibility with many different low-E coatings, and this compatibility is enhanced by the interlayer's low moisture absorption and low ionic content. Listed below are low-E coatings that have been independently tested by their manufacturers and shown to be compatible with SentryGlas® interlayer.

Low-E Coatings

Manufacturer	Product
AGC	Comfort Ti-AC 23™, Comfort Ti-AC 36™, Comfort Ti-AC 40™
Cardinal	Cardinal LoE3-366® Glass
Guardian	Guardian SunGuard® SN-68, SunGuard® SN-68 HT
Vitro	Vitro Solarban® 60, 70, 70XL and R100, Sungate® 400

The long-term performance of a coated glass laminate depends greatly on the laminator's care taken to preserve the integrity of the topcoat that protects the delicate metalized layers of the low-E coating stack. Any compromise of the coating – such as scratches, scuffs, pinholes and fingerprints – will cause the coating to corrode over time.

COMBINING KURARAY PRODUCTS IN BALLISTICS-RESISTANT LAMINATES

SentryGlas® ionoplast interlayers, Trosifol® Clear PVB interlayers and Spallshield® composites are used in a variety of architectural and automotive applications where resistance to bullet penetration and spall is desirable.

When properly designed and manufactured, glass laminates made with these interlayer products can meet ballistics-resistance test standards in constructions that are lighter-weight, thinner and more durable than traditional all-glass and glass-clad polycarbonate alternatives.

Several test methods exist for assessing the ballistics resistance of glazing materials. This bulletin lists selected performance levels from three of the most frequently referenced test standards, where tests have been performed showing that Kuraray Trosifol™ Solutions products can be used in wellconstructed laminates to help achieve the desired level of ballistics resistance.

For each tested construction, the glass laminate design is provided so that you can consider a suitable glass thickness and laminate configuration with which to conduct your own similar testing.

Test Standards Covered in this Bulletin

- Underwriter's Laboratories (UL) 752 Indoor, Standard for Bullet Resisting Equipment
- National Institute of Justice-NIJ 0108.01, Ballistic Resistant Protective Materials
- EN 1063 Glass in Building: Security Glazing, Testing and Classification of Resistance Against Bullet Attack

Bullet resistant configurations that have been tested and found to comply with commonly specified Indoor UL Standard threat levels are shown below:

Indoor UL 752 Standard for Bullet Resisting Equipment

Threat Level	Ammunition	Nominal Bullet Mass [g]	[grains]	Required Velocity [mps]	[fps]	Composition	Thickness [mm]	[in]	Weight [kg/m²]	[lbs/ft²]	Number of shots
1	9 mm Full Metal Copper Jacket with Lead Core	8.0	124	358-394	1175-1293	6 mm (¼“) Annealed Glass/ 0.9 mm (35 mil) SentryGlas®/ 6 mm (¼“) Annealed Glass/ 4.5 mm (177 mil) SentryGlas®/ 3 mm (⅛“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	21.6	0.85	44.24	9.1	3
2	.357 Magnum Jacketed Lead Soft Point	10.2	158	381-419	1250-1375	3 mm (⅛“) Annealed Glass/ 0.9 mm (35 mil) SentryGlas®/ 5 mm (3/16“) Annealed Glass/ 0.9 mm (35 mil) SentryGlas®/ 5 mm (3/16“) Annealed Glass/ 4.5 mm (177 mil) SentryGlas®/ 3 mm (⅛“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	22.4	0.88	44.78	9.17	3
3	.44 Magnum, Lead Semi-Wadcutter Gas Checked	15.6	240	411-441	1350-447	4 mm (5/32“) Annealed Glass/ 0.9 mm(35 mil) SentryGlas®/ 6 mm (¼“) Annealed Glass/ 0.9 mm (35 mil) SentryGlas®/ 6 mm (¼“) Annealed Glass/ 4.5 mm (177 mil) SentryGlas®/ 3 mm (⅛“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	25.4	1.00	52.20	10.7	3
4	.30-60 Caliber Rifle Lead Core Soft Point	11.7	180	774-852	2540-2794	8 mm (5/16“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 10 mm (⅜“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 3 mm (⅛“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	36.4	1.43	79.63	16.3	1
5	7.62 mm Rifle Lead Core Full Metal Copper Jacket, Military Ball	9.7	150	838-922	2750-3025	8 mm (5/16“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 10 mm (⅜“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 3 mm (⅛“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	36.2	1.43	78.67	16.1	1
6	9 mm Full Metal Copper Jacket with Lead Core	8.0	124	427-469	1400-1540	8 mm (5/16“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 10 mm (⅜“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 3 mm (⅛“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	36.5	1.44	79.42	16.3	5

BALLISTICS-RESISTANT GLAZING COMPOSITIONS

Bullet resistant configurations that comply with several of the NIJ Standard threat levels are shown below:

NIJ 0108.01 Ballistic Protective Glazing Materials

Threat Level	Ammunition	Nominal Bullet Mass [g]	[grains]	Required Velocity [mps]	[fps]	Composition	Thickness [mm]	[in]	Weight [kg/m²]	[lbs/ft²]	Number of shots
I	.22 Long Rifle High Velocity Lead .38 Special Round Nose Lead	2.6 10.2	40 158	320±12 259±15	1050±40 850±50	3 mm (⅛“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 0.94 mm (37 mil) Spallshield®	11.6	0.46	19.92	4.1	5
II-A	.357 Magnum Jacketed Soft Point 9 mm Full Metal Jacket	10.2 8.0	158 124	3281±15 332±12	1250±50 1090±40	4 mm (5/32“) Annealed Glass/ 1 mm (39 mil) SentryGlas®/ 4 mm (5/32“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 1.7 mm (67 mil) Spallshield®	18	0.71	33.5	6.9	5
II	.357 Magnum Jacketed Soft Point 9 mm Full Metal Jacket	10.2 8.0	158 124	425±15 358±12	1395±50 1175±40	4 mm (5/32“) Annealed Glass/ 1 mm (39 mil) SentryGlas®/ 4 mm (5/32“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 1.7 mm (67 mil) Spallshield®	18	0.71	33.5	6.9	5
III-A	.44 Magnum Lead Semi-wadcutter Gas Checked 9 mm Full Metal Jacket	15.5 8.0	240 124	426±15 426±15	1400±50 1400±50	6 mm (¼“) Annealed Glass/ 1 mm (39 mil) SentryGlas®/ 6 mm (¼“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 1.7 mm (67 mil) Spallshield®	21.4	0.84	42.2	8.6	5
III	7.62 mm (.308 Winchester) Full Metal Jacket	9.7	150	838±50	2750±50	2.5 mm (3/32“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 0.76 (30 mil) mm Trosifol® Clear/ 10 mm (⅜“) Annealed Glass/ 0.76 (30 mil) mm Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 1.7 mm (67 mil) Spallshield®	37.9	1.49	81.2	16.63	5

Bullet resistant configurations that comply with two of the EN 1063 Standard threat levels are shown below:

European Standard EN 1063

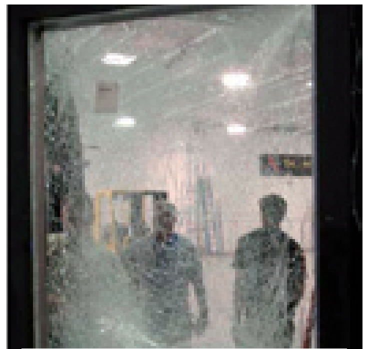
Threat Level	Ammunition	Required Velocity [mps]	[fps]	Composition	Thickness [mm]	[in]	Weight [kg/m²]	[lbs/ft²]	Number of shots
BR 4 NS	.44 Magnum	430-450	1411-1476	6 mm (¼“) Annealed Glass/ 1 mm (39 mil) SentryGlas®/ 6 mm (¼“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 1.7 mm (67 mil) Spallshield®	21.3	0.84	41.72	8.5	3
BR 6 NS	7.62 x 51 mm (M80)	820-840	2690-2755	8 mm (5/16“) Annealed Glass/ 0.76 (30 mil) mm Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 8 mm (5/16“) Annealed Glass/ 0.76 mm (30 mil) Trosifol® Clear/ 6 mm (¼“) Annealed Glass/ 5 mm (3/16“) SentryGlas®/ 2.5 mm (3/32“) Annealed Glass/ 1.7 mm (67 mil) Spallshield®	39.5	1.55	85.92	17.6	3

BLAST PERFORMANCE OF LAMINATED GLASS

In blast-resistant glazing materials and systems, laminated glass can be used to reduce the hazards associated with an explosion.

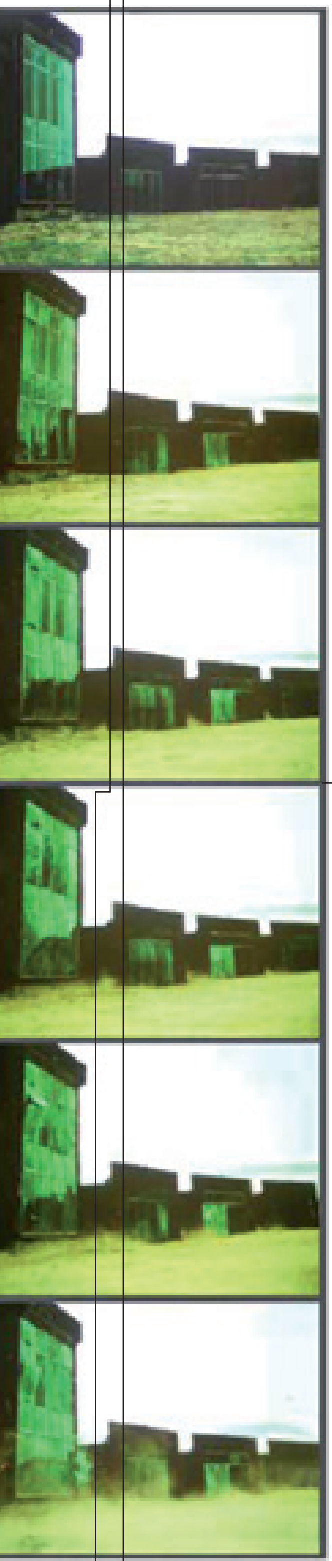
Laminates made with Trosifol® Clear PVB or SentryGlas® ionoplast interlayers are typically used in window, door, curtain wall, and storefront systems designed to provide a higher level of performance than standard systems. Shock tube and arena test results support the use of both PVB and ionoplast interlayers in blast-resistant glazing. This section summarizes blast resistance test results for glazing systems made with PVB and SentryGlas® ionoplast interlayers.

A shock tube focuses a blastlevel pressure wave against a mounted glass sample. Outdoor arena testing (right) exposes full-scale facade glazing to an actual explosion.



A laminated glass panel is inspected after shock tube blast testing (above), to assess glass fragmentation.

SHOCK TUBE TESTING



Laminated glass panels made with Trosifol® Clear PVB and SentryGlas® ionoplast interlayers were tested in a shock tube at ATI Laboratories in York, Pennsylvania. A peak pressure of 41 kPa (6 psi) and impulse of 282 kPa-msec (41 psi-msec) were chosen to represent performance levels found in the Unified Facilities Design Criteria (UFC) of the U.S. Department of Defense. The test specimens were 126 cm (49.72 inches) x 172 cm (67.75 inches), wet-glazed in a wooden frame.

Blast testing was conducted according to ASTM F1642 Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings. This standard enables the user to determine a hazard rating for the glazing or system utilizing either a shock tube or arena test. ASTM Hazard Ratings are expressed differently than those of the U.S. General Services Administration (GSA). GSA Condition 3a equates to the Very Low Hazard level defined in ASTM F1642 where the glass cracks, and fragments land on the floor no further than 1 meter. GSA Condition 2 equates to ASTM F1642 No Hazard, where glass cracks but is retained in the frame. The results of the test program are presented in Table 1.

In addition, WINdow Glazing Analysis Response and Design (Wingard) software was used to compare the actual shock tube results to those predicted by the software. The study confirmed a high level of correlation between the two. All three versions of the Wingard software (Wingard LE, PE, and MP) contain PVB and SentryGlas® ionoplast interlayer properties data.

Summary of results from ATI shock tube testing

Glass [mm]	Glass [in]	Interlayer Thickness [mm]	Interlayer Thickness [mil]	Interlayer Type	Hazard Rating	GSA Performance Condition
3 - 3	1/8 - 1/8	0.76	30	Trosifol® Clear	Very low hazard	3a
3 - 3	1/8 - 1/8	1.52	60	Trosifol® Clear	None	2
3 - 3	1/8 - 1/8	0.96	35	SentryGlas® ionoplast	None	2
6 - 6	1/4 - 1/4	0.76	30	Trosifol® Clear	None	2
6 - 6	1/4 - 1/4	1.52	60	Trosifol® Clear	None	2
6 - 6	1/4 - 1/4	0.96	35	SentryGlas® ionoplast	None	2

Blast level: 41 kPa (6 psi) 282 kPa-msec (41 psi-msec)

ARENA TESTING

The overall performance of a selection of glazing systems was evaluated in arena tests conducted by HTL Laboratories in Lubbock, TX, according to ASTM F1642 Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings. Results of the arena test program are shown in Table 2. Note that these systems also are designed to perform to various hurricane test protocols required for construction in certain regions of the United States.

In an arena test (right), fully installed glazing systems are exposed to an actual explosive blast, under controlled conditions at a high-security open-air test site.

BLAST PERFORMANCE OF LAMINATED GLASS

Summary of results from arena testing of several commercial glazing systems incorporating various constructions of laminated glass using a SentryGlas® ionoplast interlayer

Manufacturer	System tested	Glass Construction	SentryGlas® Thickness [mm]	SentryGlas® Thickness [mil]	UFC 4-010-01 Level of Protection	ASTM Hazard Rating	GSA Performance Condition
ALUMIGLASS, INC.	6400 Curtain wall	IGU	2.28	90	Medium	No Hazard	2
CORAL INDUSTRIES	FL550 Storefront	IGU	1.52	60	Medium	Minimal	2
	Series 381 Entrance	Monolithic Laminate	1.52	60	Medium	Minimal	2
CRAWFORD TRACEY CORP.	ProTech 7SG Storefront	IGU	0.96	35	Medium	Minimal	2 & 3b
	ProTech 7SG Storefront	IGU	2.28	90	Medium	Minimal	3b
	ProTech 45S G Storefront	IGU	0.96	35	Medium	Minimal	2
	ProTech 45S G Storefront	IGU	2.28	90	Medium	Minimal	2
EFCO CORP.	5600 Series Curtain wall	IGU	2.28	90	Medium	Minimal	2
	D500 Entrance	IGU	0.96	35	Medium	Minimal	2
	Concealed Vent				Medium	Minimal	2
ES WINDOWS	ES-7525 Curtain Wall	IGU	2.28	90	Medium	Minimal	2
	ES-7530 Unitized Curtain Wall	IGU	2.28	90	Medium	Minimal	2
	ES-9000 Entrance	IGU	2.28	90	Medium	Minimal	2
PGT INDUSTRIES	PW-3020	Monolithic Laminate	2.28	90	High	No break	1
WEST TAMPA GLASS	WTG-500 Curtain Wall	Monolithic Laminate	0.96	35	Medium	Minimal	2
	WTG-500 Curtain Wall	Monolithic Laminate	2.28	90	Medium	Minimal	2
	WTG-500 Curtain Wall	IGU	0.96	35	Medium	Minimal	2
	WTG-500 Curtain Wall	IGU	2.28	90	Medium	Minimal	2
	WTG-700 Curtain Wall	Monolithic Laminate	0.96	35	Low	Low	3b
	WTG-700 Curtain Wall	Monolithic Laminate	0.96	35	Medium	Minimal	2
	WTG-700 Curtain Wall	Monolithic Laminate	4.56	180	Medium	No Hazard	2
	WTG-700 Curtain Wall	IGU	0.96	35	Medium	No Hazard	2
	WTG-700 Curtain Wall	IGU	2.28	90	Medium	No Hazard	2
	WTG-700 Curtain Wall	IGU	2.28	90	Medium	No Hazard	2
	WTG-700 Curtain Wall	IGU	4.56	180	Medium	Minimal	2
	WTG-700 Curtain Wall	IGU	4.56	180	Medium	No Hazard	2
	WTG-900 Curtain Wall	Monolithic Laminate	0.96	35	High	No break	1
	WTG-900 Curtain Wall	Monolithic Laminate	2.28	90	High	No break	1
	WTG-900 Curtain Wall	IGU	0.96	35	High	No break	1
	WTG-900 Curtain Wall	IGU	2.28	90	High	No break	1
TUBELITE	Forcefront Blast Curtain Wall	IGU	1.52	60	Low	Very low	3A
	Forcefront Blast Curtain Wall	IGU	0.96	35	Low	Very low	3A
	Forcefront Blast Entrance	IGU	1.52	60	Medium	Minimal	2
	Forcefront Blast Entrance	IGU	0.96	35	Medium	Minimal	2

Blast level: 41 kPa (6 psi) 282 kPa-msec (41 psi-msec)

FIRE PERFORMANCE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The U.S. codes have fire performance requirements for doors and other areas. In hazardous locations, the glass must be able to pass the fire test and comply with safety glazing standards (CPSC 16 CFR 1201).


Photo: © Komsan Loonprom/shutterstock.com

A hose stream test follows the fire test to demonstrate the response of the glass to water after it has been exposed to high temperatures during the fire test. There are many standards to which the glass is tested. Fire resistant glass is tested and labeled by a third party as part of a certification process. Neither laminates with SentryGlas® ionoplast interlayer nor with PVB interlayer are not fire rated products.

SentryGlas® shows better performance than PVB in terms of flame spread and flammability, indicated by testing done on the interlayers. Below is a table comparing PVB and SentryGlas® interlayer properties according to flammability ASTM standard tests. Please note that these are not tests of laminates. Actual performance of laminates may vary.

Comparing the Properties of PVB and SentryGlas® Interlayers according to ASTM Standard Flammability Tests

Test Description	Test Method	Trosifol® Clear	SentryGlas®
Self Ignition Temperature	ASTM D1929	410 °C (770 °F)	470 °C (878 °F)
Flame Spread Index	ASTM E84	60	30
Smoke Developed Index	ASTM E84	350	215
Burning Rate	ASTM D635	6.6 mm/min	0 mm/min

ASTM Standards

- ASTM D1929: Standard test method for determining ignition temperature of plastics
- ASTM E84: Standard test method for surface burning characteristics of building materials
- ASTM D635: Standard test method for rate of burning and / or extent and time of burning of plastics in a horizontal position

Emergency Access:

For information regarding fireman or other emergency access through laminated glass, refer to the following reference:

- 'Emergency Egress Through Laminated Glazing Materials', which can be found on website: www.glasswebsite.com
- 'Forcible Entry Demonstrations Airblast Resistant Window Systems', which can be found in the reference section of the following website: www.oca.gsa.gov


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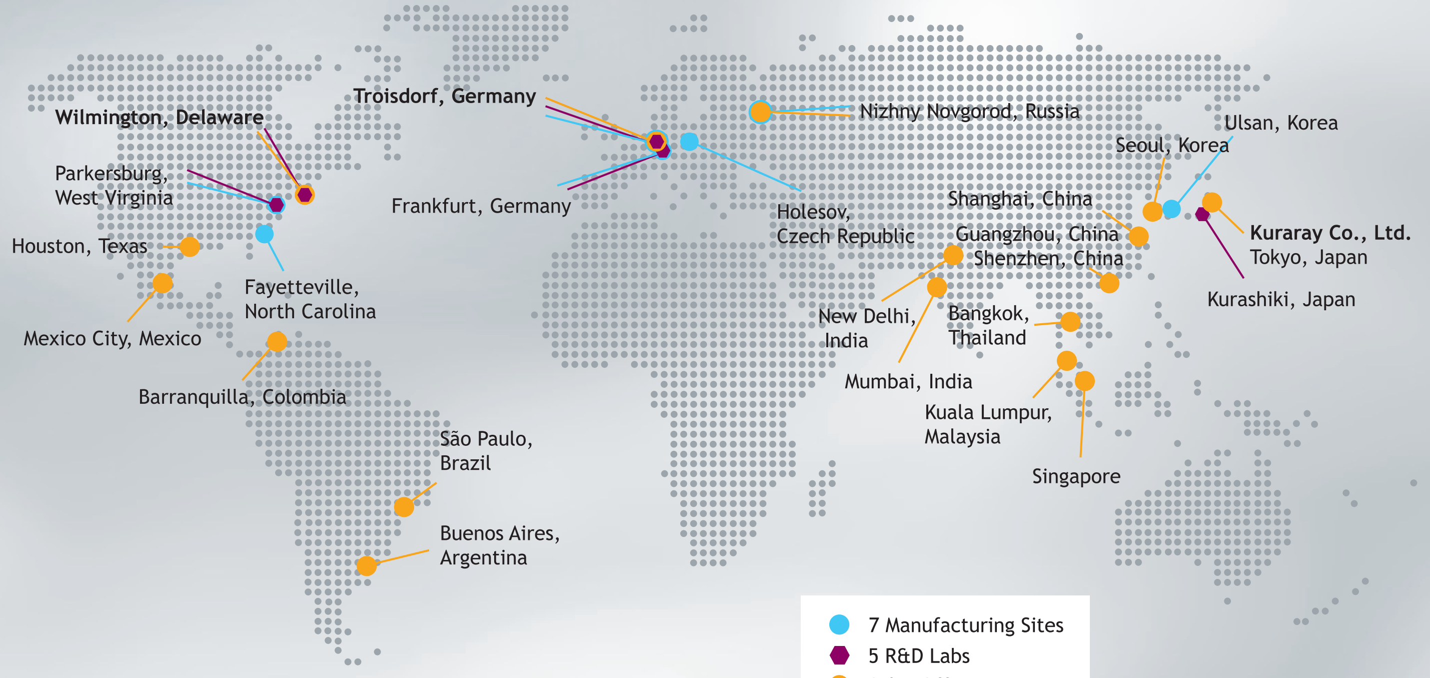

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