AGNORA

ARCHITECTS QUICK FACTS

TEMPERING

-

Distortion

Anisotropy

Nickel Sulfide

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REVIEW

A fundamental understanding of key concepts is required to realize the relationship between the tempering process and its anomalies. The following information provides a suitable framework.

CHALLENGES OF TEMPERING GLASS
Tempering glass is a lot like baking cookies. An excellent cookie, requires even heating throughout the dough. To limit distortion and anisotropy in architectural glass tempering "recipes" are used to output the best possible visual characteristics.

Good craftsmanship avoids:

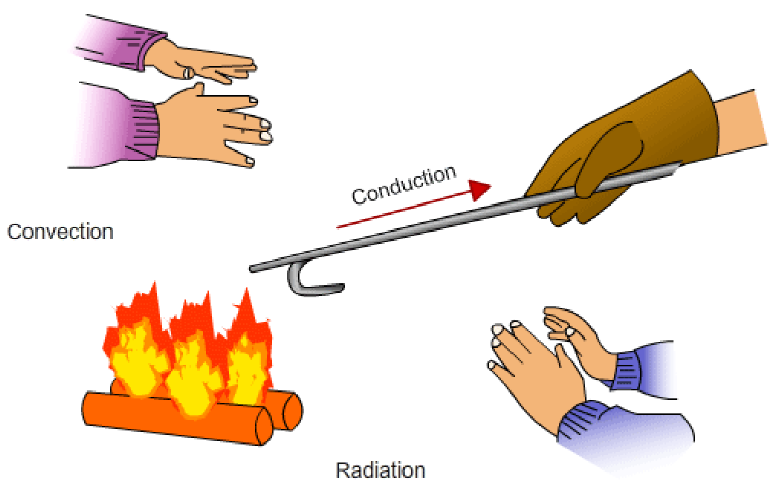
- Distortion
- Edge Lift
- Anisotropy
- Overall bow
- Pitting

MODES OF ENERGY TRANSFER
Within a tempering oven, the following modes of energy (heat) transfer occur:

Convection - Transfer of heat through a fluid (liquid or gas) caused by molecular motion

Conduction - Transfer of heat or electric current from one substance to the other by direct contact

Radiation - Energy that is radiated or transmitted in the form of rays or waves or particles



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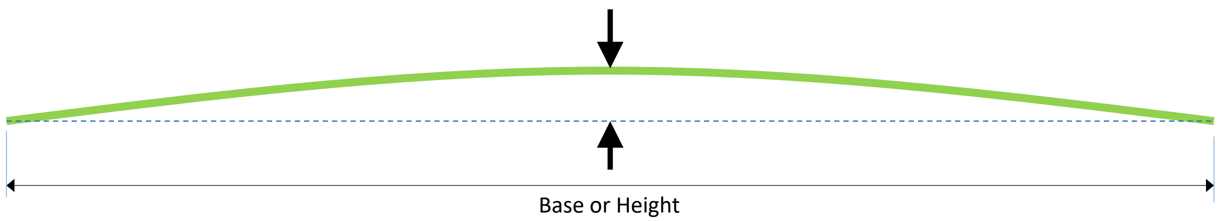
DISTORTION

BOW

Bow is the overall lift of the glass lite. Both ASTM and EN standards exist to limit this. Fabricators can achieve better values than standard, and should be discussed between parties.



C1048 – 18

TABLE 2 Overall Bow, Maximum

Nominal Thickness Desig., mm (in.)	Edge Dimension, cm (in.) 0–50 (0–20)	>50–90 (>20–35)	>90–120 (>35–47)	>120–150 (>47–59)	>150–180 (>59–71)	>180–210 (>71–83)	>210–240 (>83–94)	>240–270 (>94–106)	>270–300 (>106–118)	>300–330 (>118–130)	>330–370 (>130–146)	>370–400 (>146–158)
	Maximum Bow, mm (in.)											
3 (1/8)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	. . .	. . .	. . .
3 (1/8) Alternate Method[A]	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	8.0 (0.31)	10.0 (0.39)	. . .	. . .	. . .
4 (5/32)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	. . .	. . .	. . .
5 (3/16)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	. . .	. . .	. . .
6 (1/4)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)	21.0 (0.83)	24.0 (0.94)
8 (5/16)	2.0 (0.08)	2.0 (0.08)	3.0 (0.12)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	8.0 (0.31)	10.0 (0.39)	13.0 (0.51)	15.0 (0.59)	18.0 (0.71)	20.0 (0.79)
10 (3/8)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	6.0 (0.24)	7.0 (0.28)	9.0 (0.35)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)	19.0 (0.75)
12–22 (1/2 –7/8)	1.0 (0.04)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	5.0 (0.20)	5.0 (0.20)	7.0 (0.28)	10.0 (0.39)	12.0 (0.47)	14.0 (0.55)	17.0 (0.67)

[A] Values apply to 3 mm (1/8 in.) thickness only when the alternative checking procedure in 10.7.2 is used.

Table 4 — Maximum allowable values of overall bow and roller wave distortion for horizontallytoughened glass

Glass Type	Maximum allowable value for distortion Overall bow mm / m	 Roller Wave mm
Uncoated float glass in accordance with EN 572-1 and EN 572-2	3,0	0,3
Others [a]	4,0	0,5
[a] For enamelled glass which is not covered over the whole surface the manufacturer should be consulted.		
NOTE Dependant upon the wave length of the roller wave an appropriate length of gauge has to be used		

DISTORTION

ROLLER WAVE

Roller wave is the evident as it can impact the aesthetic of glass. In an effort to minimize roller wave, architectural glass should be installed so roller wave runs horizontally. Limits established only in EN standards. Fabricators can achieve better values than standard, and should be discussed between parties.

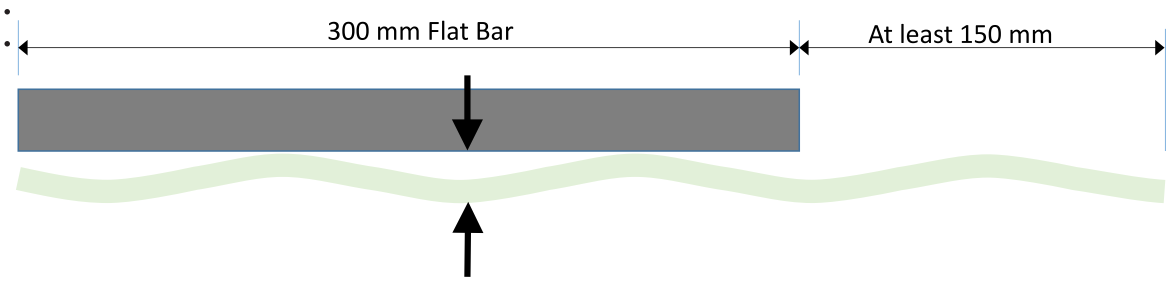


Table 4 — Maximum allowable values of overall bow and roller wave distortion for horizontallytoughened glass

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	Overall bow mm / m	**Roller Wave** mm
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DISTORTION

EDGE KINK / LIFT

Edge kink is the first and last wave on the lite and is usually a larger value than roller wave. Because it is stronger, it can be noticeable from the inside of a building. In a heat treated laminate, too much lift can cause delamination and bubbles. Limits established only in EN standards. Fabricators can achieve better values than standard, and should be discussed between parties.

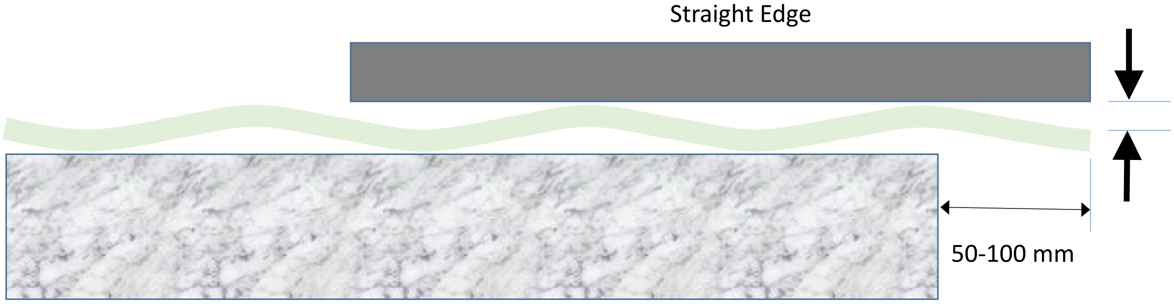


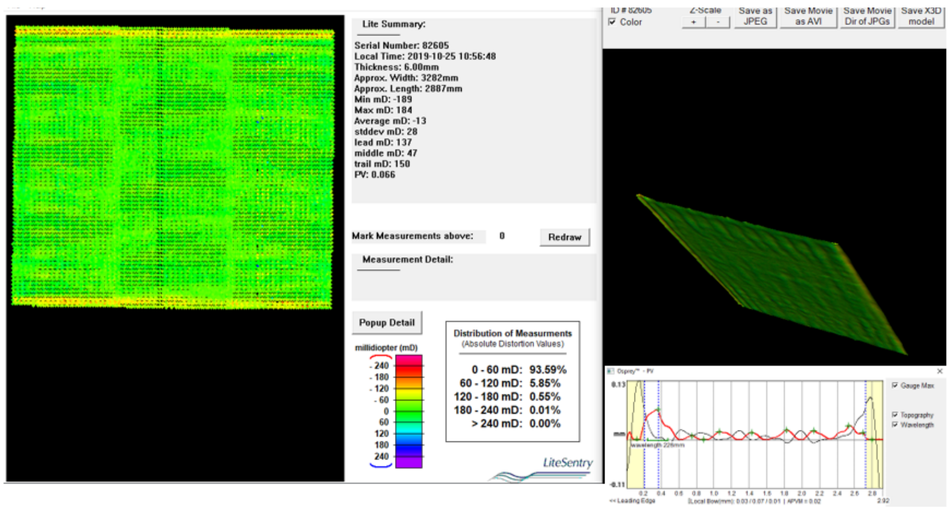
Table 5 — Maximum allowable values for edge lift for horizontally toughened glass

Type of glass	Thickness of glass mm	Maximum allowable values mm
Uncoated float glass in accordance with EN 572-1 and EN 572-2	3	0,5
	4 to 5	0,4
	6 to 25	0,3
Others [a]	all	0,5
[a] For enamelled glass which is not covered over the whole surface the manufacturer should be consulted.		
NOTE Dependant upon the wave length of the roller wave an appropriate length of gauge has to be used		

DISTORTION

SCANNING

The use of digital photography scanners has allowed for a more complete overview of glass as it is output from the furnace. Fabricators and buyers may agree on a percentile millidiopter value or decide on a maximum Peak-to-Valley measurement. Fabricators often use the C1652 test methodology to obtain results.



- 126-3/8" X 112-9/16"
- PV = 0.066mm – 0.0026" Maximum Peak to Valley measurement.

STANDARDS

ASTM C1048-18

Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass

ASTM C1651-11

Standard Test Method for Measurement of Roll Wave Optical Distortion in Heat-Treated Flat Glass

ASTM C1652

Standard Test Method for Measuring Optical Distortion in Flat Glass Products Using Digital Photography of Grids

EN 14179-1

Glass in building — Heat soaked thermally toughened soda lime silicate safety glass

EN 1863-1

Glass in building - Heat strengthened soda lime silicate glass

ISO 20657

Glass in building — Heat soaked tempered soda lime silicate safety glass

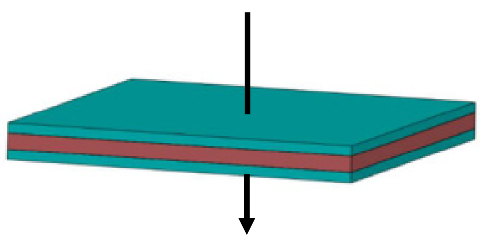
ANISOTROPY

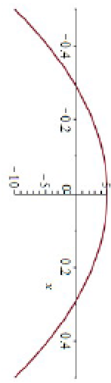
DEFINITION

Mechanical stress leads to deformation of the material structure and inflict changes the particle density, thus light passing through a birefringent specimen will exhibit phase retardation. This phenomenon can be seen as “leopard spotting” in polarized light conditions.

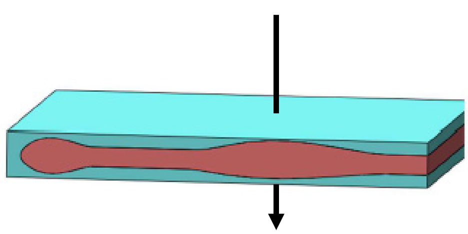
AREA STRESSES

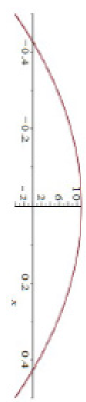
The tempering process is not perfect. The act of “tempering” a lite of glass is to induce surface tension and increase strength. If tempering was uniform, the average stress would be 0, and would not cause visual anomalies.

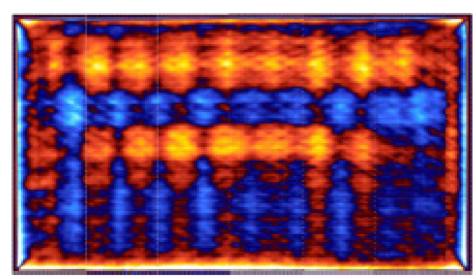




In reality, the tempering process is not uniform and has imbalanced stresses, causing an visual anomalies in polarized lighting conditions.







LAMINATION

Laminated glass may also cause anisotropy. Thus it is important that a fabricator measure for anisotropy at the end of both the heat treatment or lamination process.

BREWSTER ANGLE

Also known as the polarization angle, incident light reflected from the surface at this angle is perfectly polarized, leading to visible anisotropy. For glass, the Brewster angle is approximately 56 degrees.   On a large building facade, anisotropy could be noticeable when looking up. This is compounded be the reflected, polarized light from neighboring buildings.

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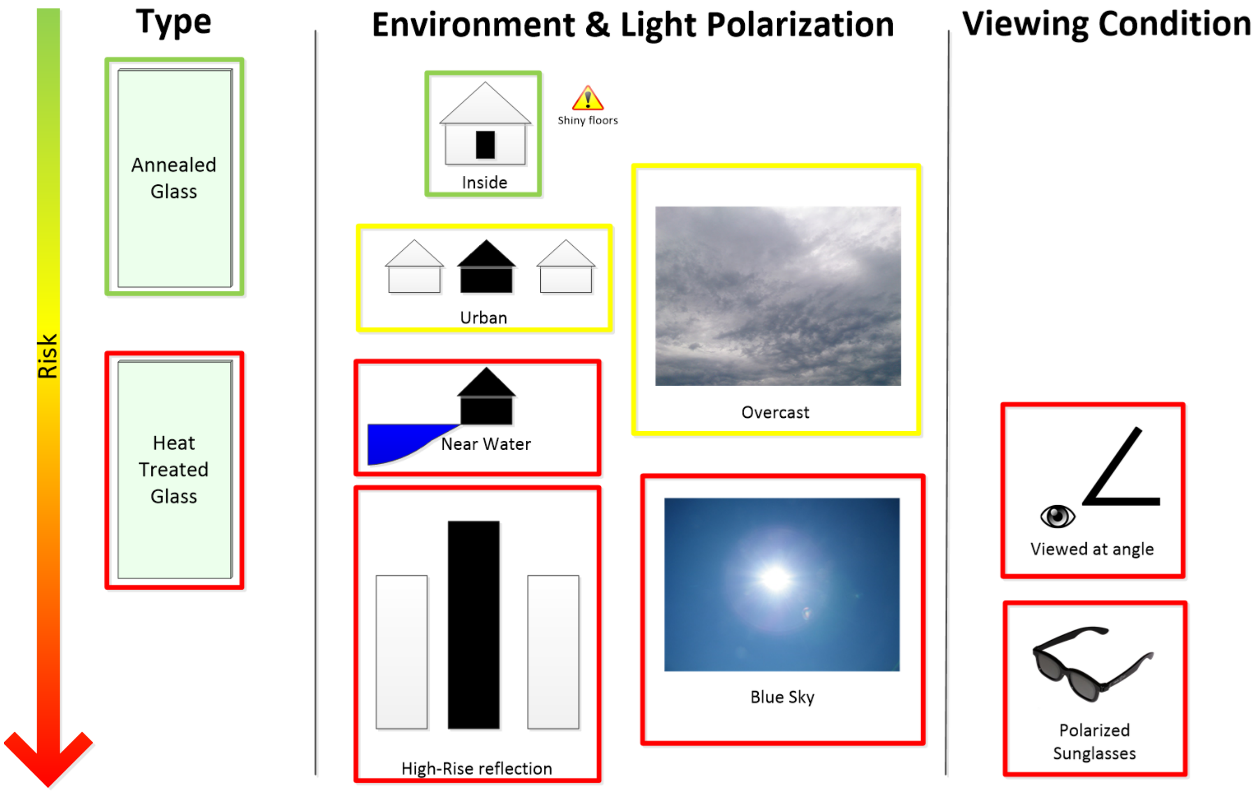
ANISOTROPY

BEST-TO-WORST



ASTM C1901
Standard test method for measuring optical anisotropy in heat treated flat monolithic glass. It is expressed as numerical value of nanometer (nm). The level of anisotropy of a lite of glass can be agreed upon between the fabricator and buyer.

Anisotropy measurement 95% quantile of a chosen nm value by the client and fabricator, not including allowable margins and borders. Measurement methodology from C1901.

To capture localized peak values that may influence aesthetic of glass, the fabricator and client may agree on values outside of the C1901-21 methodology. This may including using output histogram or cumulative chart data to ensure a determined nm value limit.

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NiS INCLUSIONS

HEAT SOAK TESTING

NiS inclusions are extremely small particles that occur in the manufacturing process of glass. Very seldom, these inclusions find their way into the glass ribbon, and become part of the product shipped to the fabricator.

Expansion and contraction properties of the NiS inclusions differ to that of glass, and failure can occur to glass that has had thermal stress (ie. heat strengthening or tempering) applied. The failure is not immediate, and may result many days, months, or years later as the NiS attempts to expand back to its original state against the glass.

Failure will result in total breakage of the glass, and can cause personal or property damage and be expensive to replace.

Heat Soak Testing accelerates NiS expansion and causes failure in a contained, safe space.

Heat Soak Testing of any tempered glass is your best insurance.

AGNORA is accredited for the new heat soak testing (HST) standard **ISO 20657**. The new standard is an evolution of the EN14179-1:2005 standard following scientific publications, which proved a slightly lower HST temperature is effective for testing. The EN14179 is now under revision.