

Using tempered Glass?

WHO WE ARE

AGNORA is an award-winning glass fabricator providing the largest, high-quality architectural glass in North America.

Known as an industry leading, team-based customer service company, AGNORA employs innovative production processes and invests in leading-edge machinery to push the boundaries of what is possible in architectural glass fabrication and meet challenging design objectives brought by their customers.



Louis Moreau
Head of Technology and Innovation, AGNORA

Louis brings a unique mix of international experiences in float manufacturing, high-performance vacuum coatings, large building glazing, and high-end glass fabrication.

Louis considers architecture as the purest form of art and loves glass. He explores the limits of materials and processes to create innovative solutions that can be easily built.



Adam Mitchell
Marketing Manager, AGNORA

Adam is a marketing professional focused on the manufacturing sector for over 10 years. He has a strong focus on building relationships and delivering value added content that support evolving partnerships.

Using Tempered Glass ?

Understand the risks
and how to avoid them!

Optical
distortion

Anisotropy

Spontaneous
breakage

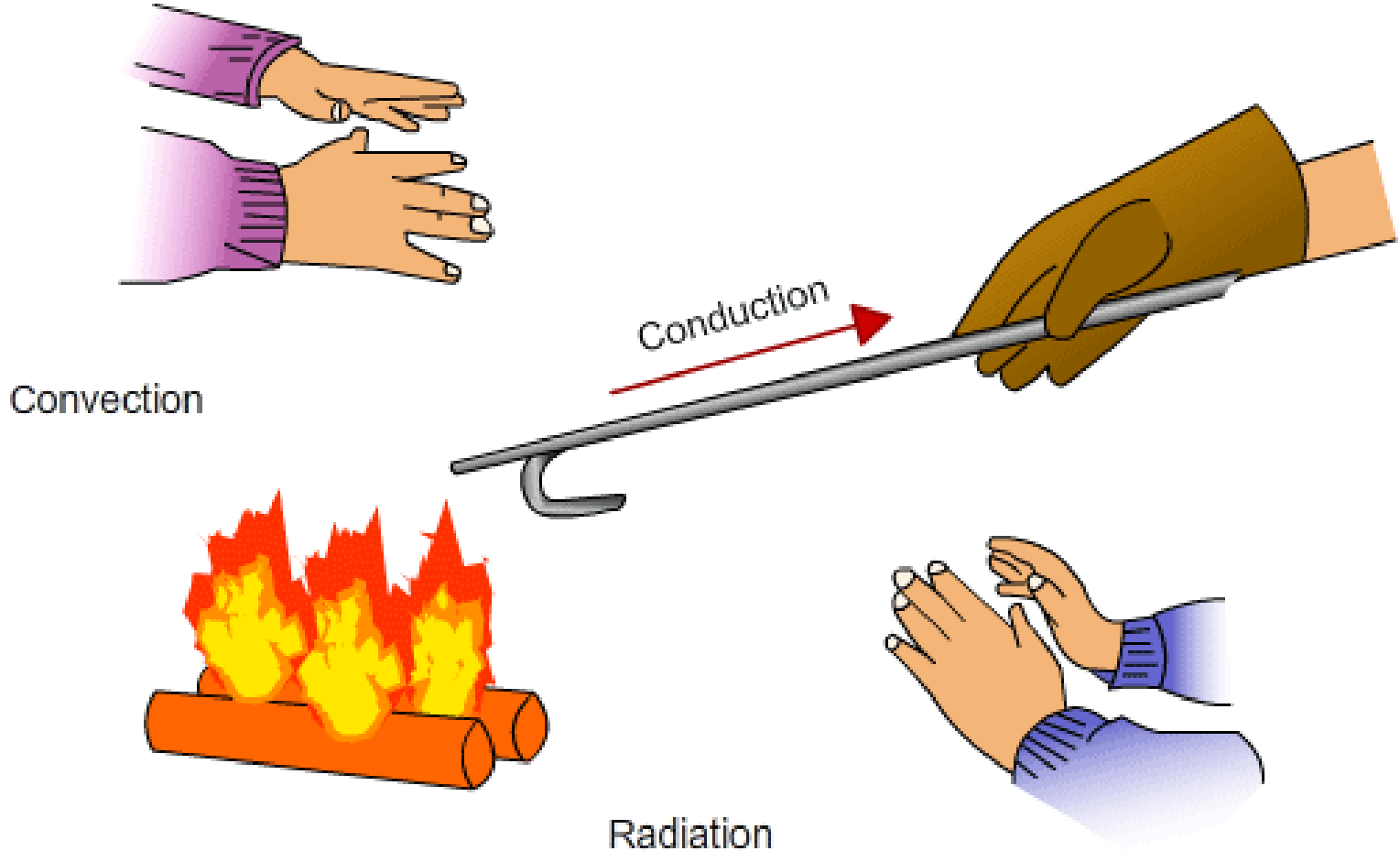
LEARN HOW TO SEE ROLLER WAVE



IT MIGHT COME IN HANDY ONE DAY

Optical Distortion

Convection, Conduction and Radiation



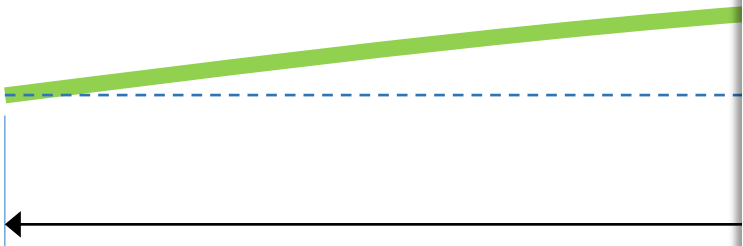
A photograph of a wooden baking tray lined with parchment paper, containing 14 cookies. The cookies are decorated with colorful M&M's candies and sprinkles. The text 'Challenges in the oven' is overlaid in yellow on the top left of the image.

Challenges in the oven

- Heat Distribution
 - Left ⇔ Right
 - Front ⇔ Back
 - Top ⇕ Bottom
- Also in Cooling!
- Amount of material
- Speed

- Good craftsmanship avoids
 - Overall bow
 - Distortion
 - Edge Lift
 - Pitting
 - Anisotropy

Overall Bow



- Important for two-side su
- Will likely be flatten on fo
- Limits established in both

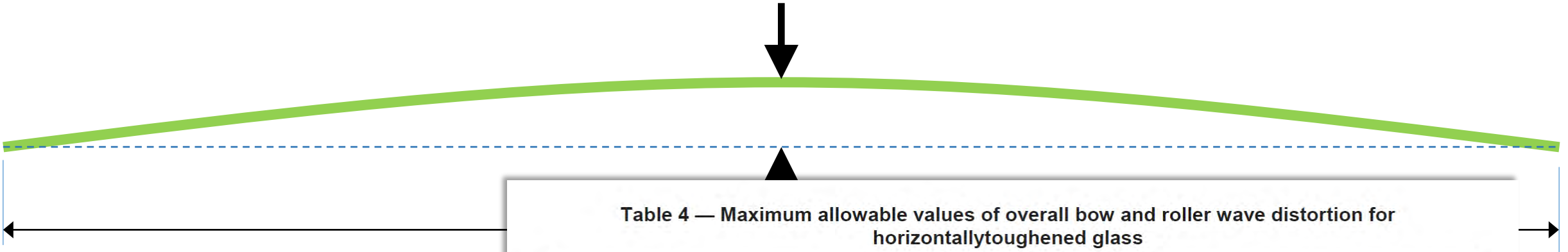


TABLE 2 Overall Bow, Maximum

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)
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.

Overall Bow



- Important for two-side support
- Will likely be flattened on four
- Limits established in both

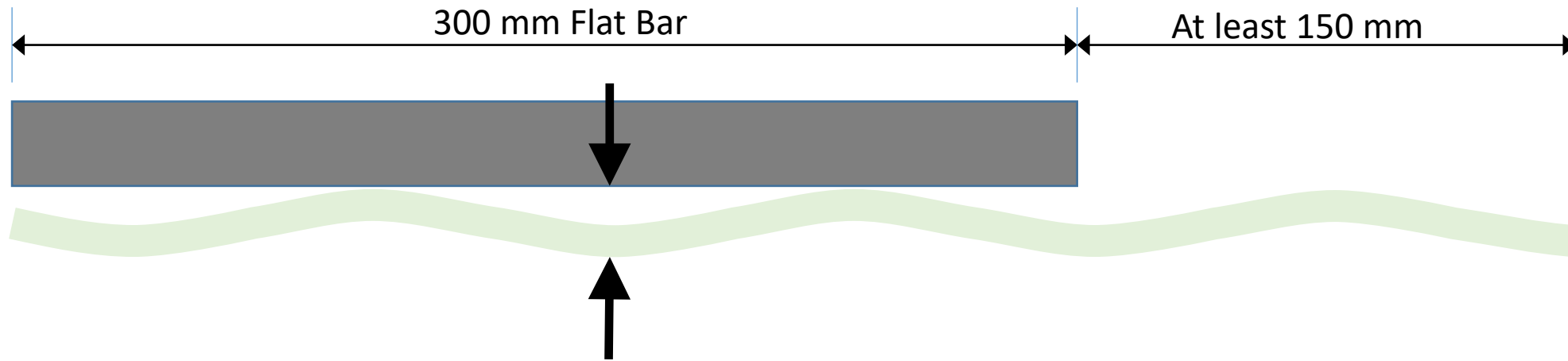
Table 4 — Maximum allowable values of overall bow and roller wave distortion for horizontally toughened glass

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

Roller wave



- External reflection is not pleasant
 - To minimize keep horizontal
- If vertical will be noticeable also from inside
- Limits established only in EN standards



"All of Wendy
spins off of a
word - FLES

Roller wave

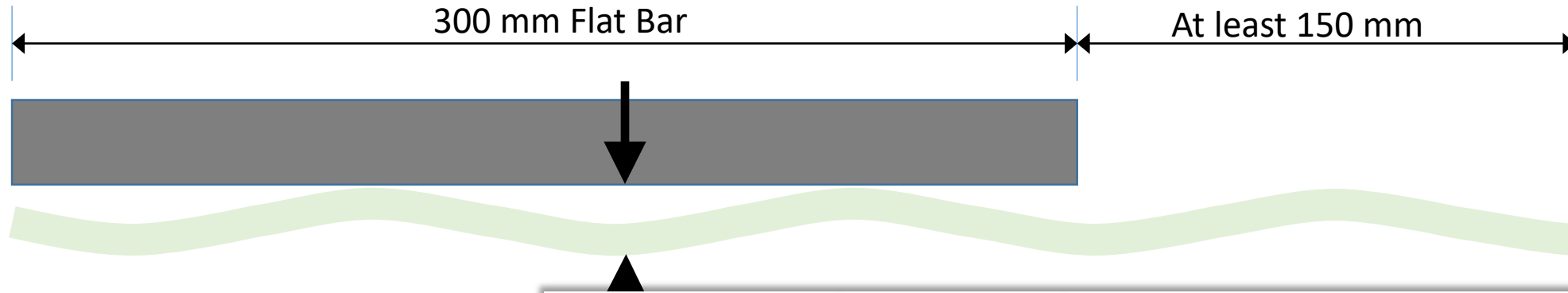
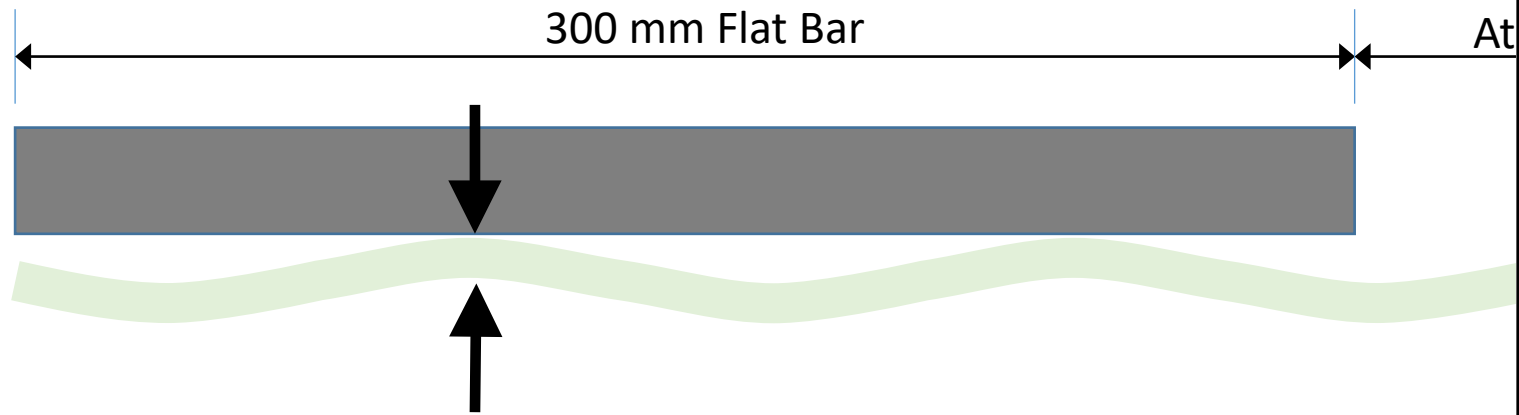


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Roller wave



- External reflection is not pleasant
 - To minimize keep horizontal



Edge Kink / Lift

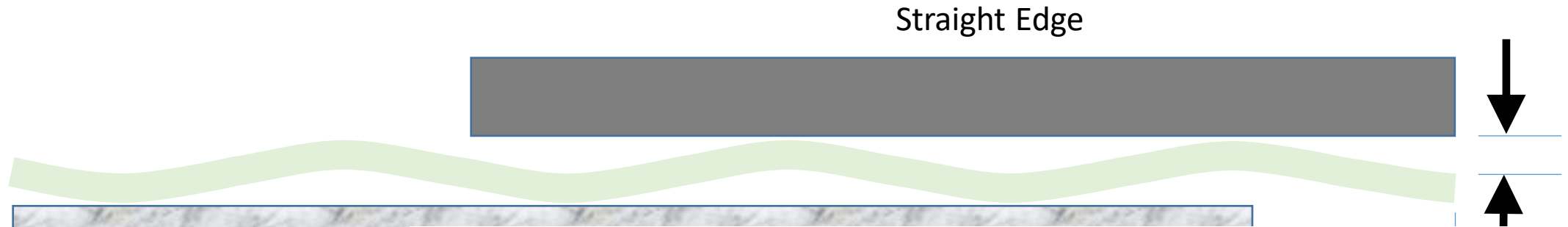


Table 5 — Maximum allowable values for edge lift for horizontally toughened glass

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		

- First and last wave on the
- Usually larger value than
- Because it is stronger, oft
- In heat treated laminate bubbles
- Limits established only ir

Edge Kink / Lift

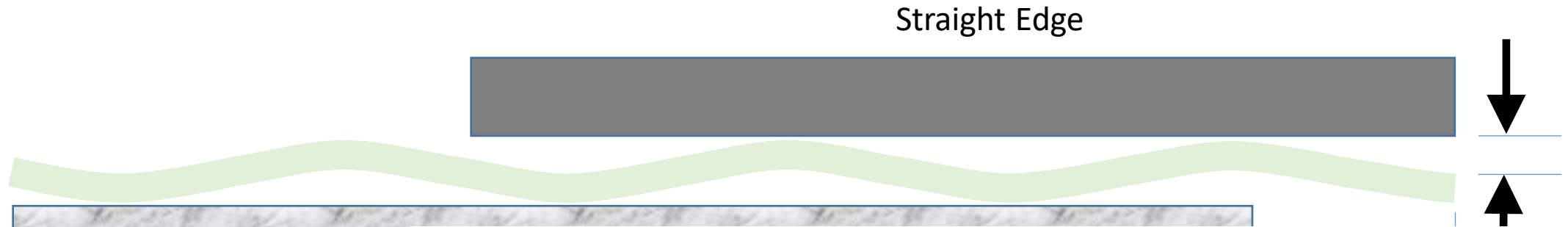
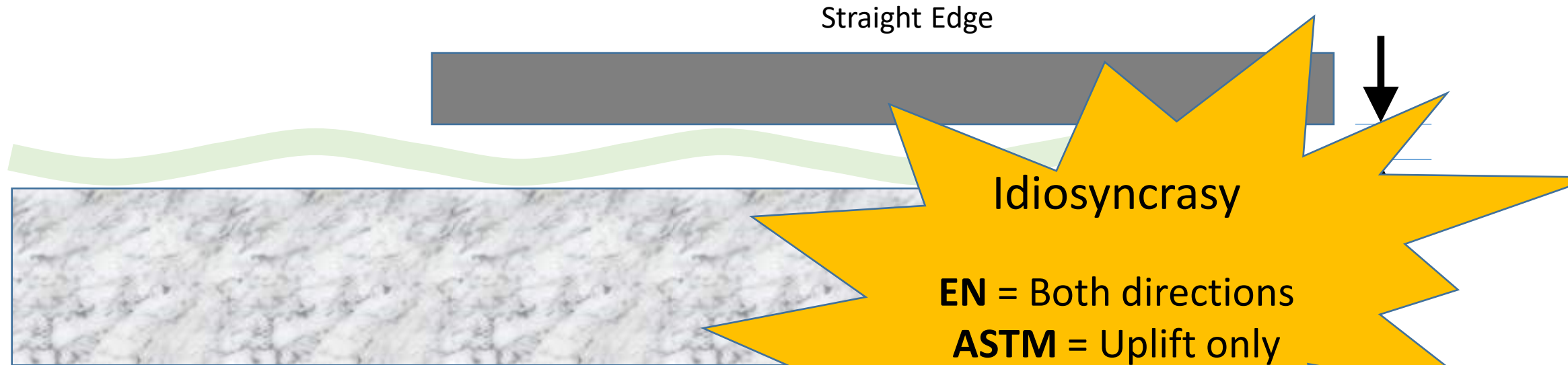


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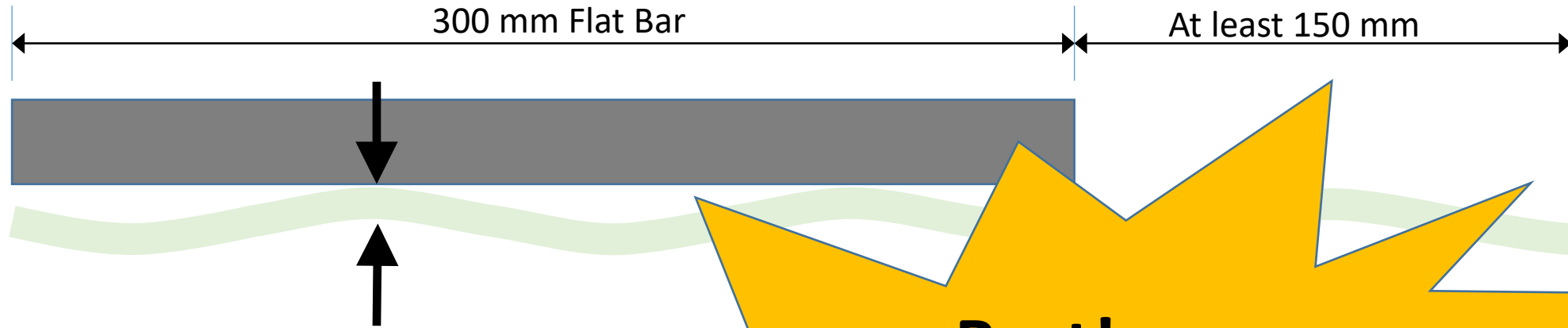


- First and last wave on the lite
- Usually larger value than roller wave
- Because it is stronger, often noticeable from inside
- In heat treated laminate can cause delamination and bubbles
- Limits established only in EN standards

<https://vimeo.com/432534989>

<https://vimeo.com/185532842>

Roller wave



- External reflection is not pleasant
 - To minimize keep horizontal
- If vertical will be noticeable also
- Limits established only in EN stan

Best!

Specify Optical Power
In millidiopter (mD)

Farnsworth



- **Original**

- **1/4" Annealed 112" x 112"**
- **15 PSF - 76 MPH**

- **Now**

- **1/4" Ultra-flat FT+ HST**
- **46 PSF – 134 MPH**

Farnsworth

- Original
 - 1/4" Annealed
 - 15 PSF - 76 M

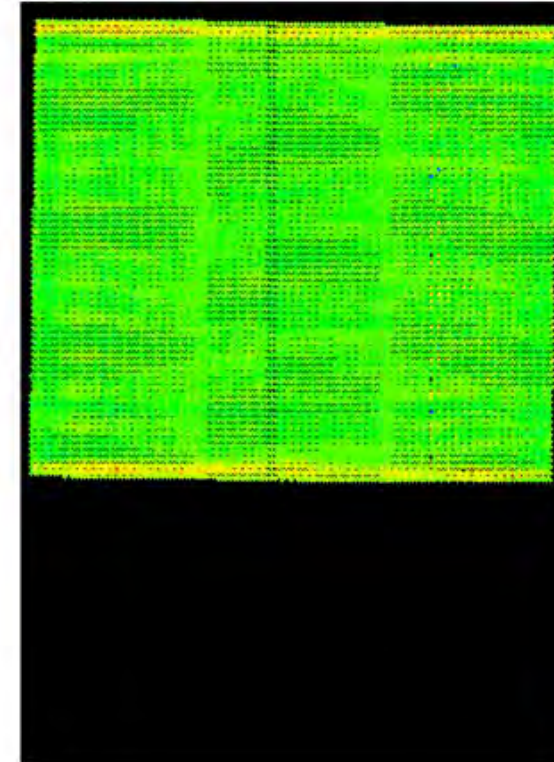
- Now
 - 1/4" Ultra-fla
 - 46 PSF – 134

Order 30921

Line 1

LiteSentry™ Osprey™ Rev1000 - session_0_290

File Help



Lite Summary:

Serial Number: 82605
Local Time: 2019-10-25 10:56:48
Thickness: 6.00mm
Approx. Width: 3282mm
Approx. Length: 2887mm
Min mD: -189
Max mD: 184
Average mD: -13
stddev mD: 28
lead mD: 137
middle mD: 47
trail mD: 150
PV: 0.066

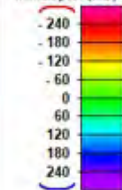
Mark Measurements above: 0

Redraw

Measurement Detail:

Popup Detail

millidiopter (mD)



Distribution of Measurements

(Absolute Distortion Values)

0 - 60 mD: 93.59%
60 - 120 mD: 5.85%
120 - 180 mD: 0.55%
180 - 240 mD: 0.01%
> 240 mD: 0.00%

LiteSentry

Osprey™ - Distortion Map

ID # 82605

Z-Scale

Save as

Save Movie

Save Movie

Save X3D

Color

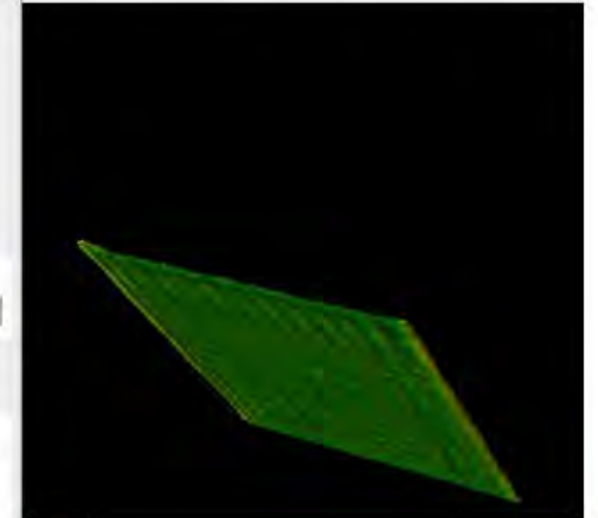
+ | -

JPEG

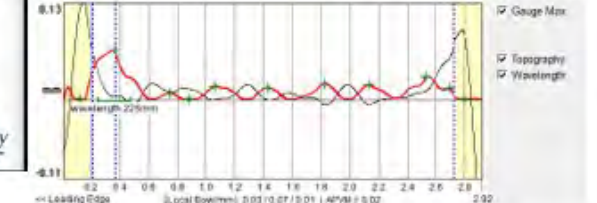
as AVI

Dir of JPGs

model



Osprey™ - PV



- 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

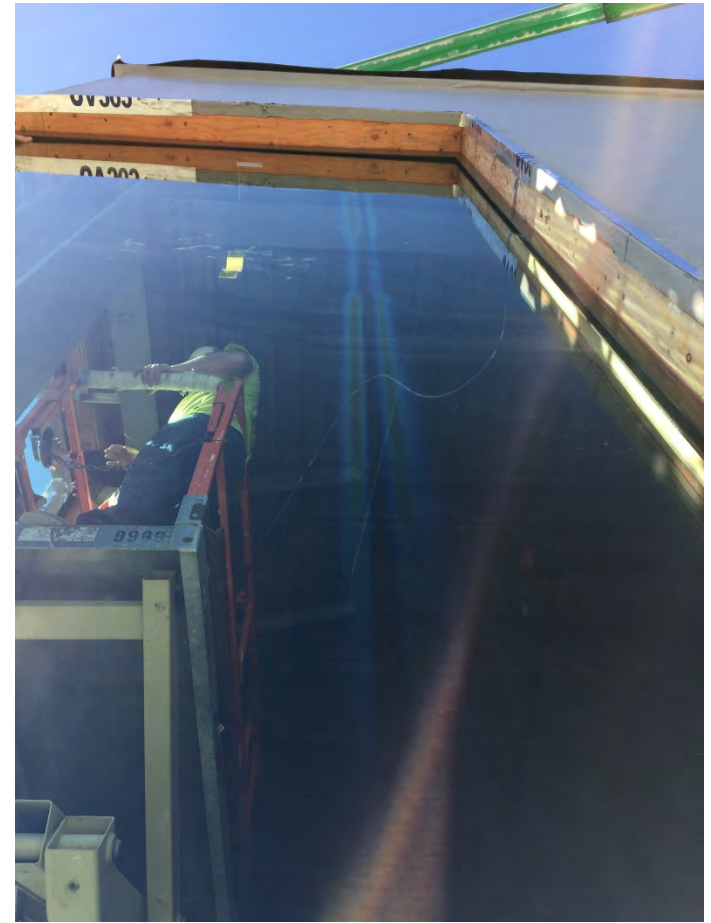
- **EN 1863-1**

Glass in building - Heat strengthened soda lime silicate glass

- **ISO 20657**

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

Anisotropy



Milwaukee, WI USA



Apple Store Yorkdale Toronto, ON Canada



Apple Store Legacy Boston, MA USA



With polarizing filter

Apple Store Glendale, AZ

The Word...

Anisotropy

What does it mean?

≠ Isotropy

- Water
- Vacuum
- Annealed glass

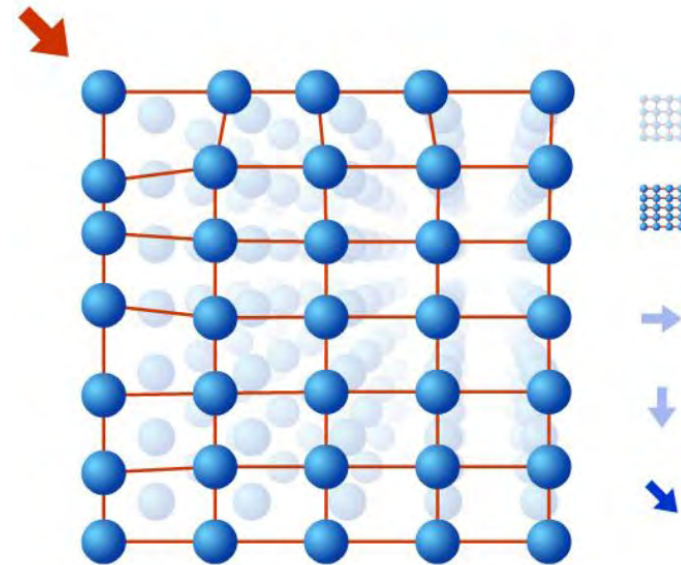


The Word...

Birefringence

What does it mean?

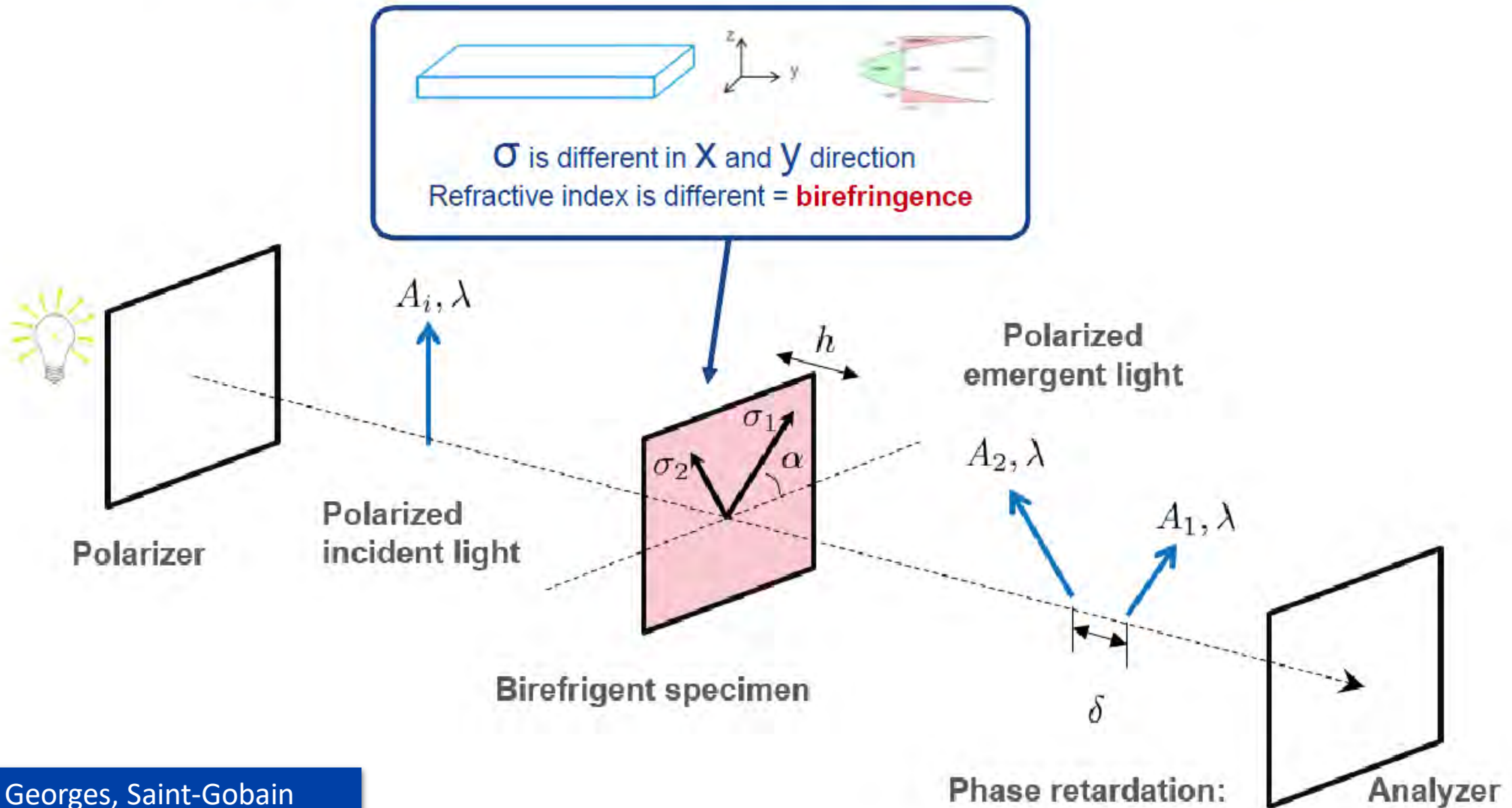
- Mechanical stress leads to deformation of the material structure and therefore changes the particle density and the velocity of light



- Refracts a single incoming ray in two directions
- Corresponds to the two different polarizations
- Noticeable under polarized light

BIREFRINGENT PROPERTIES OF HEAT TREATED GLASS

- POLARIZED LIGHT + STRESS-INDUCED BIREFRINGENCE = PHOTOELASTICITY



The Word...

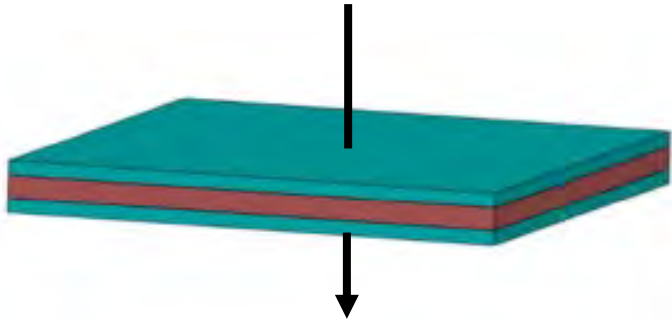
Birefringence

What does it mean?

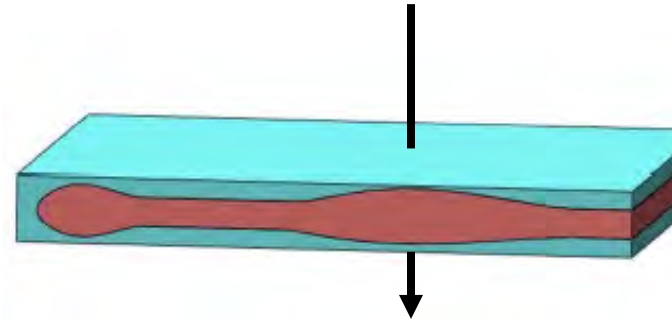
Optically anisotropic material

- Having differences of index of refraction
- Heterogenous stresses
 - Caused by not perfectly homogeneous heating and cooling in the tempering furnace
 - Or, for plastic, in the autoclave

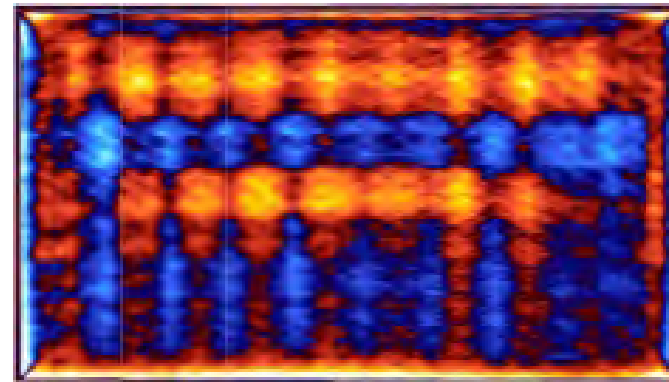
Area Stresses



Even though there are intentionally high surface and center stresses in tempered glass, the average stress is 0. So, it has no net effect on the P polarized light and does not reflect it.



Areas that have an imbalanced parabolic stress profile have a non-zero average stress through the thickness and are able to rotate the P polarized light for reflection.



The Word...

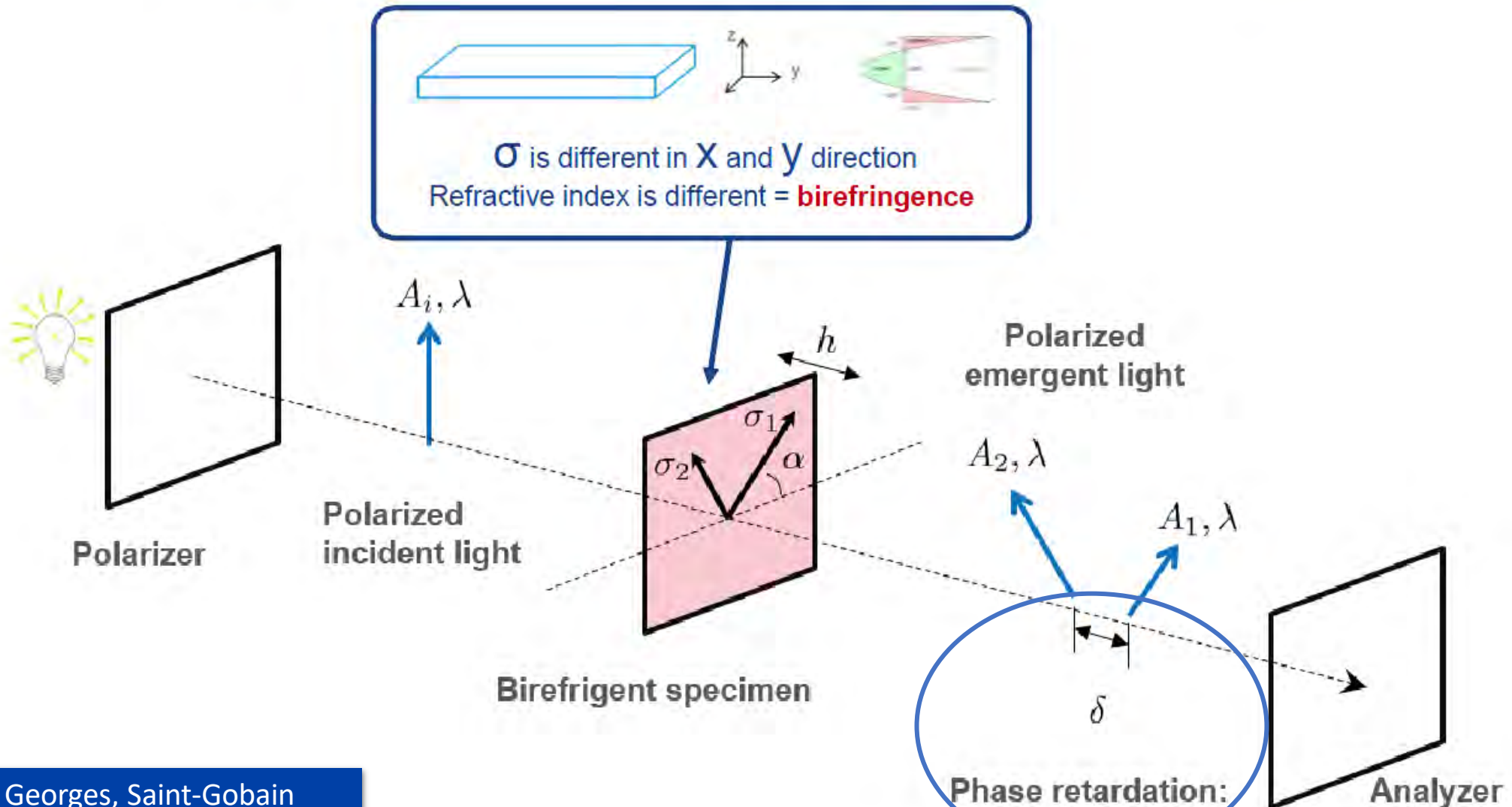
Retardation

What does it mean?

- In a birefringent material, the light waves propagate in the horizontal and vertical directions at different speeds, resulting in an optical path difference or optical retardation
- Measure of birefringence
 - Expressed in nanometer - nm

BIREFRINGENT PROPERTIES OF HEAT TREATED GLASS

- POLARIZED LIGHT + STRESS-INDUCED BIREFRINGENCE = PHOTOELASTICITY

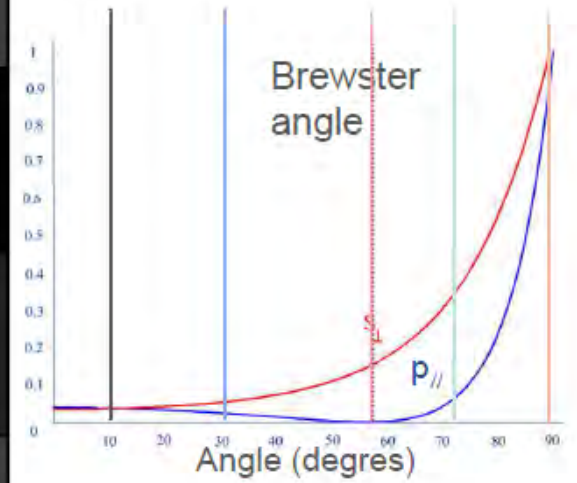


PERCEPTION = CONTRAST

p-polarized

Let us consider the illumination p-polarized.

When observing a facade with anisotropic glass, the observed pattern is directly linked to the reflectivity difference between s and p polarizations.



Black and white contrast

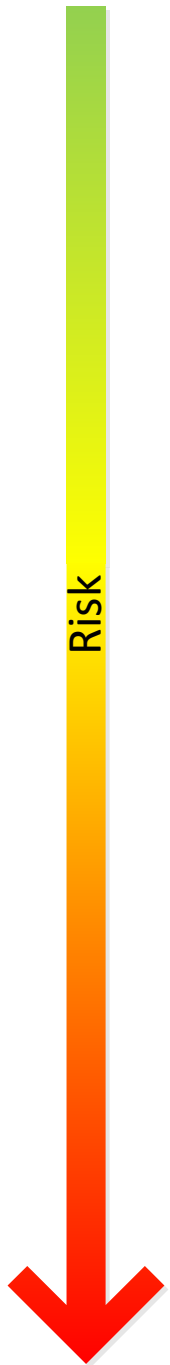


A typical example of iridescence

Eric Hegstrom, LiteSentry

*Stress
Photonics*

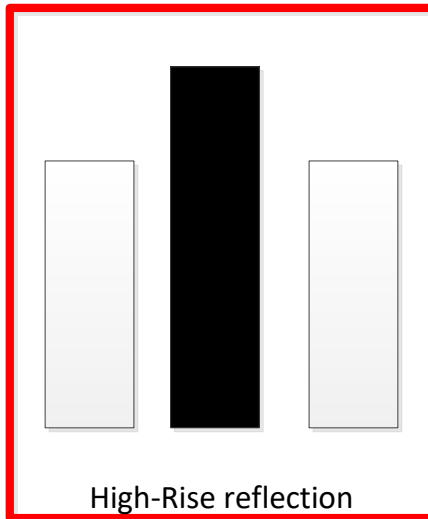
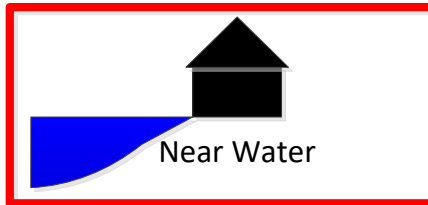
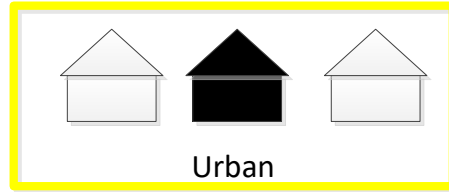
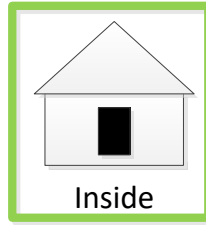
LiteSentry
Setting the Standard in Glass Inspection



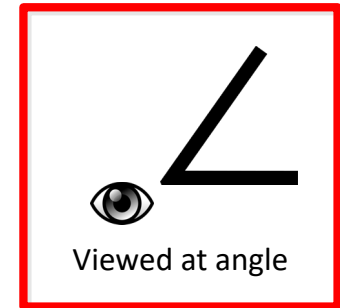
Type



Environment & Light Polarization



Viewing Condition



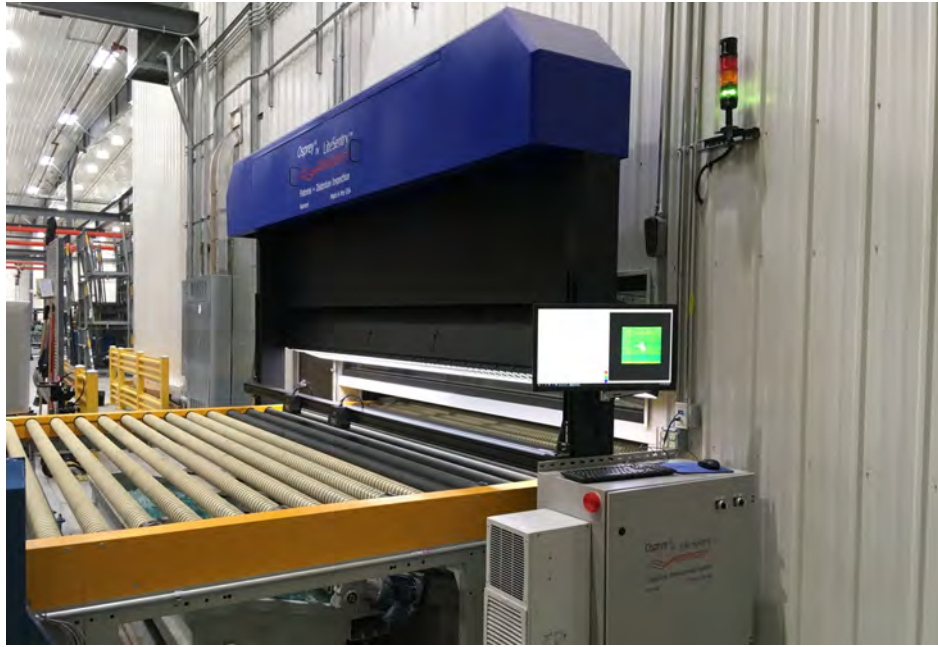


C1901-21

Standard Test Method for Measuring Optical Retardation in Flat Architectural Glass

- **Standard test method** for measuring optical anisotropy
- Heat treated flat monolithic glass
- Educate stakeholders on the phenomenon and on technology available
- Establish a language, a methodology
- Confirm that numerical values are expressed in a fundamental physic unit
- Certify that measurements are consistent, repeatable and traceable
- Building block that allows you to create a **specification**





Osprey 9 by LiteSentry



Ilis - Arcon

Commercial Anisotropy Scanners



SoftSolution



Viprotron

Quick comparison

Manufacturer	Light source	Type	Polarization	Captor	Extra function
Arcon <i>ilis</i>	LED Panels	Polarimeter	Circular	StrainCam cameras	
Glaston	LED Panels	Polariscope	Linear	High Resolution Cameras	Direct feedback to furnace operator
Lite-sentry <i>Stress Photonics</i>	Colour balanced	Polarimeter	?	Multiple Grey Field Polariscopes	Distortion Inspection
SoftSolution	Multi-colour telecentric	Polariscope	Circular	Linear sensor	Blemishes, Dimensioning, Edge stress
Viproton	Red stabilized LED	Polariscope	Circular	High Resolution Cameras	Bottom Haze

Next steps in our journey

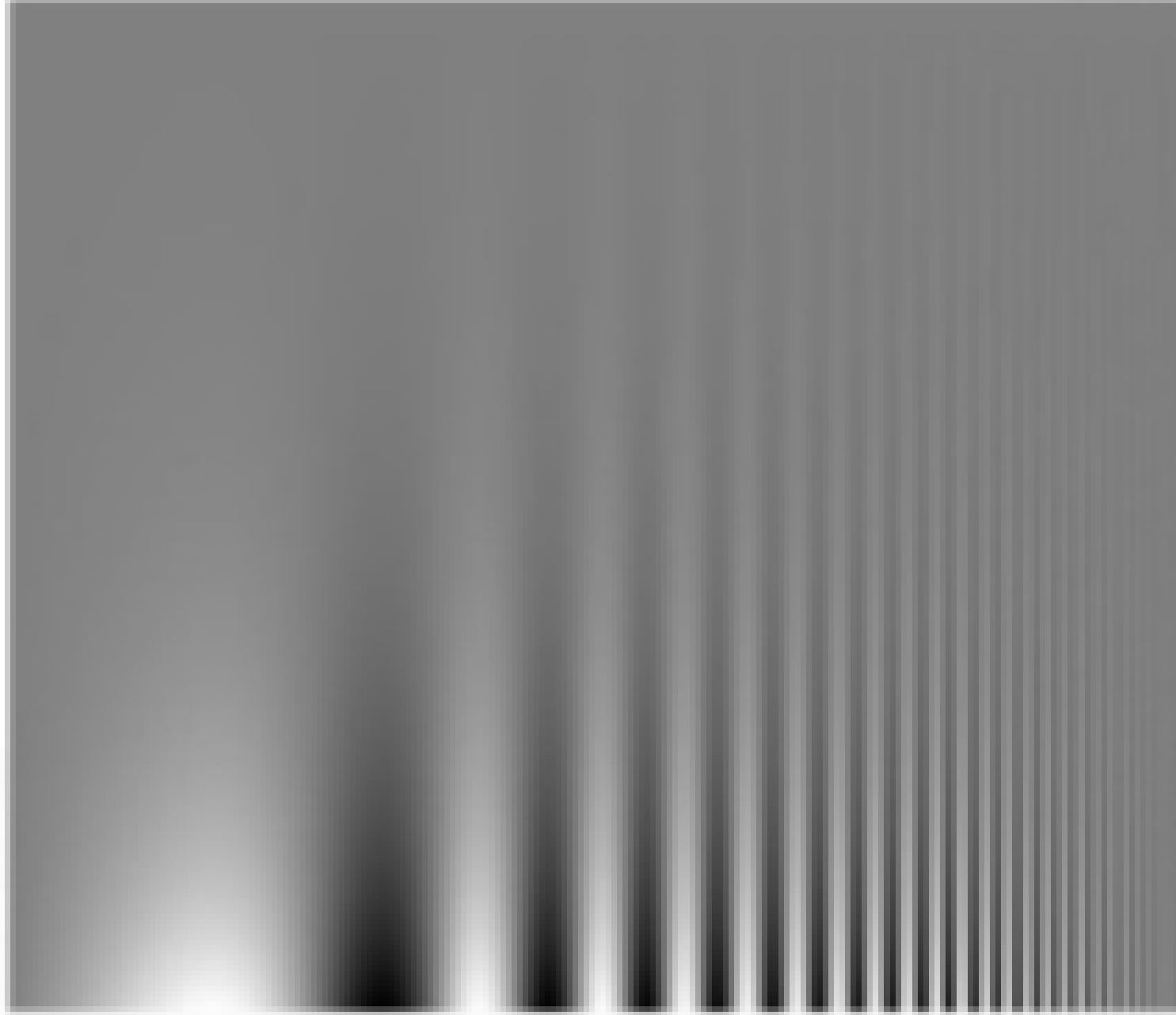
- R&D Watch
 - How to evaluate the retardation map
 - How to describe the light environment
 - Create realistic glass renderings
- How can we measure and describe the light polarisation environment of the building and catch the environments more susceptible to anisotropy?
- Better understand human eye perception
 - Contrast sensitivity

0.5 %

Contrast

100 %

Spatial frequency



Next steps in our journey

- Use human perception studies to see what is the most important data
 - Mathematical average
 - Island of high retardation
 - How to treat the edges, holes, notches
 - Geometry
- Define a mathematical method to work with the large array of retardation data
- Come up with guidelines per application

Next steps in our journey



Virtual prototyping and aspect prediction with OCEAN™

Preetham-Wilkie (Polarized) Sky

Sun position

Altitude = 0° Azimut = 0°

Next steps in our journey



Virtual prototyping and aspect prediction with OCEAN™

Preetham-Wilkie (Polarized) Sky
Sun position
Altitude = 15° Azimut = 292°

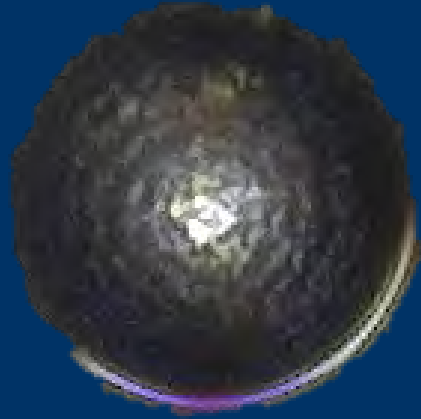
Takeaways for anisotropy

It takes two to tango


- Glass with anisotropy
- Polarized light environment
- Computing power and optical technology paved the way to online scanners
- Optical retardation mapping at zero degree is exact to quantify the tempering quality
- Now possible to have accurate and repeatable measurements
 - Objectively improve process
 - Quantify anisotropy between parties

Spontaneous breakage

<https://vimeo.com/185494434>



During tempering,
phase transformation
of NiS from α to β
decreases the volume
by $\sim 4\%$

A microscopic view of a crystalline structure, likely a metal or alloy, showing a complex network of interconnected, faceted grains. The grains are separated by grain boundaries, which appear as darker, more irregular lines. The overall structure is highly ordered and symmetrical, characteristic of a single crystal or a polycrystalline material. The image has a blue tint, giving it a cool, scientific appearance.

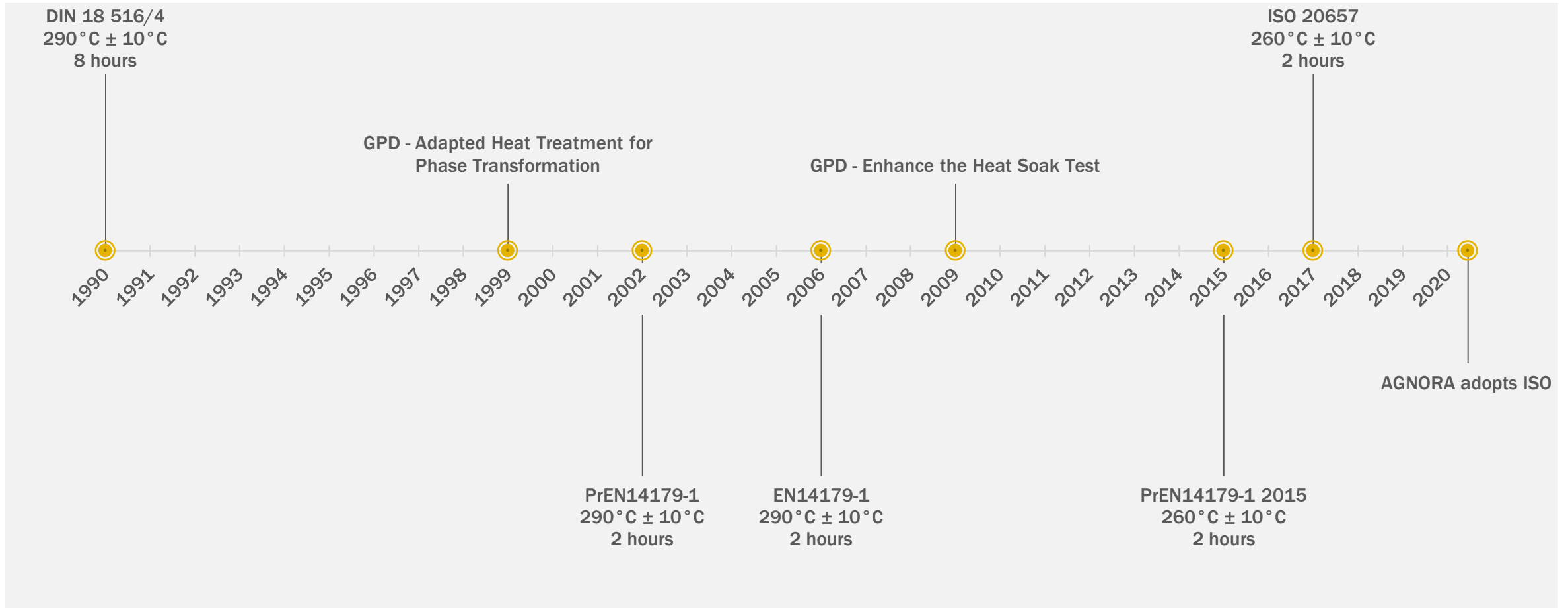
**Back to room
temperature the
particle dreams of
returning to their α
phase...**



Heat Soak Testing
make the dream come
true faster...

Heat Soak Test regulation a bit of history

No North American standard



stoichiometry

stoi·chi·om·e·try | \,ˈstɔɪ-kē-ˈä-mə-trē

Definition of *stoichiometry*

1 : a branch of chemistry that deals with the application of the laws of definite proportions and of the conservation of mass and energy to chemical activity

2a : the quantitative relationship between constituents in a chemical substance

b : the quantitative relationship between two or more substances especially in processes involving physical or chemical change

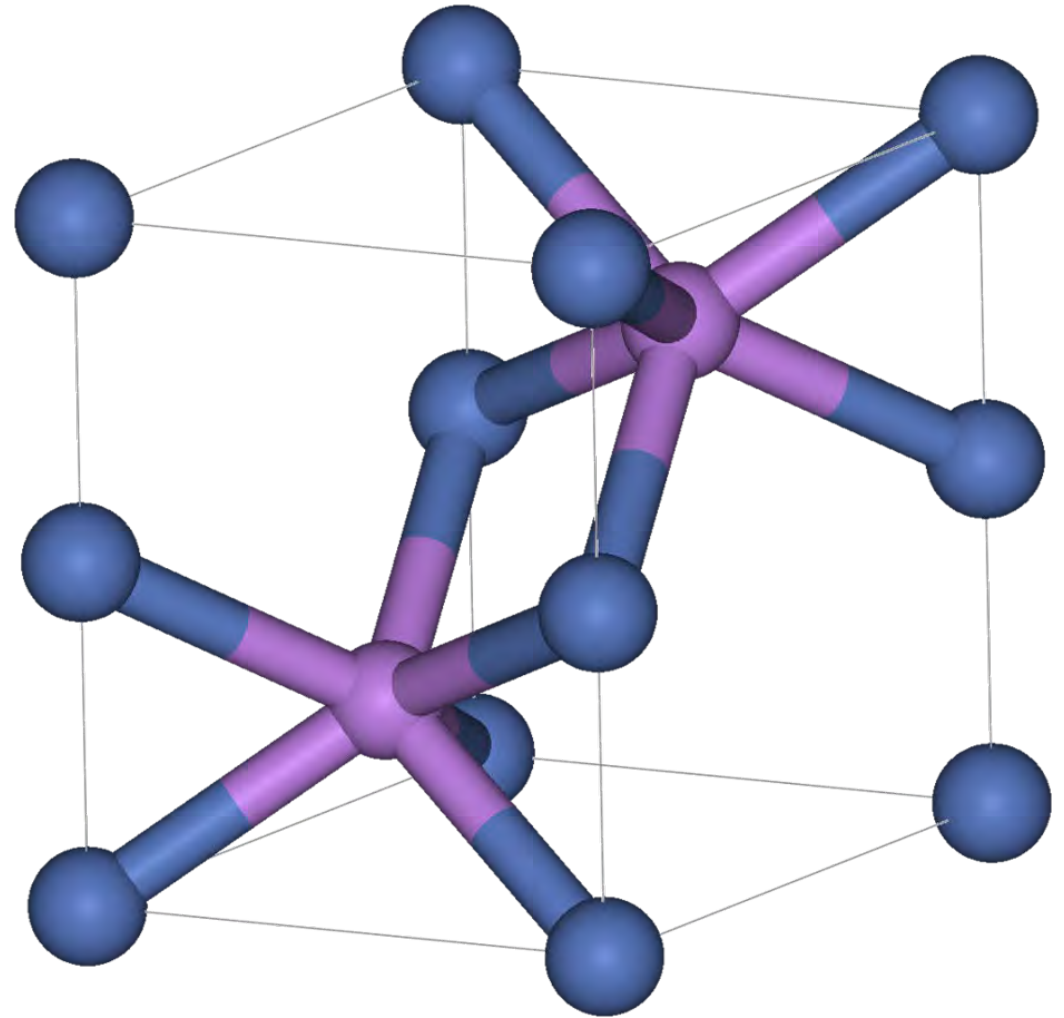
The Physic behind

NiS particles are not alike

- Some are contaminated with iron
- Some contain different proportions of Sulphur

NiS , Ni_7S_6 + NiS , $\text{NiS}_{1.01}$ + Ni_3S_4

- This change the transformation's dynamic
- Slowest transformation rate
 - High Sulphur %
 - Causes late NiS breakage
 - Might survive 290°C test



260°C ± 10°C

- Enhances safety
 - Eliminate more particles
- Reduce the soaking time
- Reduce the soaking cost
- Reduce environment impact due to reduced energy consumption
- Lessen the de-tempering effect
 - The surface compression level is slightly lower after HST

The Real Takeaway

This is a secret

Don't tell it to more than one person at the time

The Real Takeaway

Use
Annealed
Glass

Perfectly Flat

No Anisotropy

No NiS breakage

Merci

Louis Moreau

