
SHIFT YOUR STRATEGY
GLASS PROCESSING AUTOMATION
GPAD
March 5-6, 2024
Nashville
glass.org

Advanced Distortion Analysis:

Moving Beyond Edge Lift and Roll Wave

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Learning Objectives

By the end of this presentation, participants will:

1. Understand the difference between Peak-to-Valley and millidiopter (mD) measurements.
2. Recognize different types of distortion in glass.
3. Understand how the different radius of curvatures affect the image quality on the glass surface via optical distortion.
4. Have the ability to discuss different criteria for specifying objective and quantifiable means for evaluating the distortion of architectural glass.

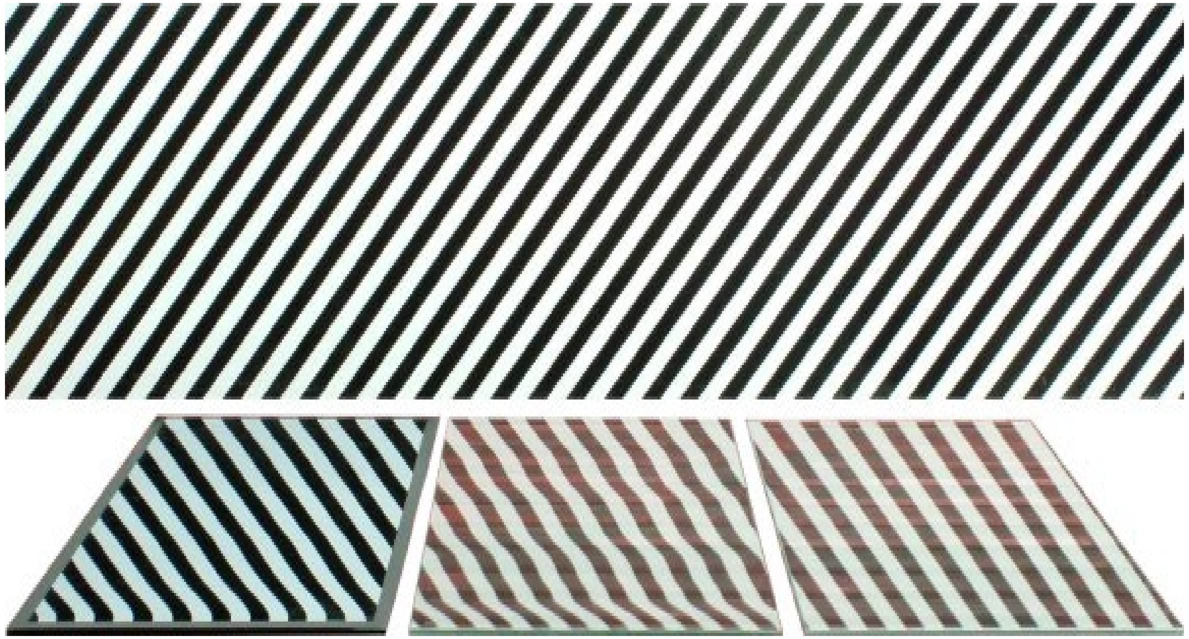
Trends Driving Improved QC

- **Higher Quality Specifications** – Market is more educated/demanding
- **More Controllable Processes** – Furnaces are much more controllable
- **Automation / Less Experienced Workers** – Fewer “experts” on the line
- **Higher Throughput** – QC Systems needed to maintain peak efficiency

Glass Distortion

Subjective Visual Evaluation

- Zebra board.

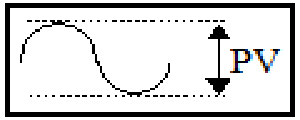


Edge Kink   Roll Wave   Flat Glass

Image from Strainoptics

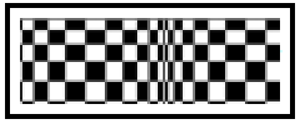
Two Fundamental Distortion Metrics

Roll Wave and Edge-Lift Peak to Valley (PV)



- 2-dimensional wave in direction of travel
- Sample of a single strip of measurements
- Highly dependent on type/size of gauge used
- Does **not** measure what the eye sees

Optical Power in millidopter (mD)

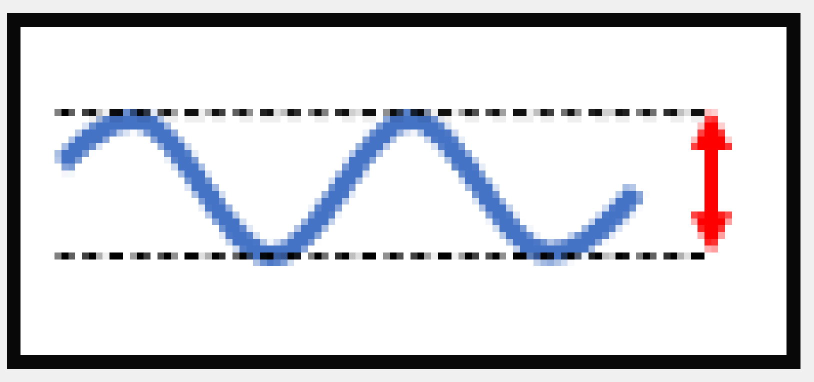


- Measurement of optical power at 1000’s of locations
- 100% inspection - quantifies ALL types of distortion
- **Measures what the eye sees**

Glass Distortion

Roll Wave

- 2-dimensional wave in direction of travel.
- Sample of a single strip of measurements.
- Highly dependent on type/size of gauge used.
- Does not measure what the eye sees.



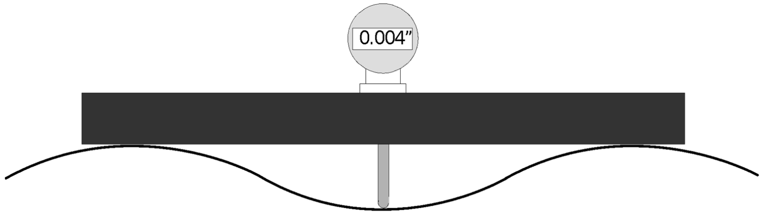
Peak-to-Valley (PV)

Figure courtesy of GlassQuality.com

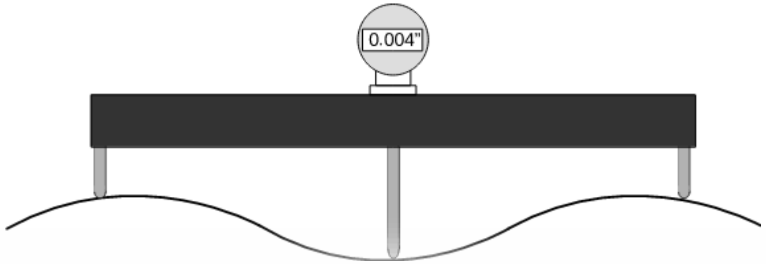
Glass Distortion

Roller Wave

- Flat bottom gauges.



ASTM 1651 - Flat Bottom Gauge
- Only measures valleys (peaks are zeroes)
- Only measures top side
- Does not measure edge lift (lead/trail 6” skipped)



ASTM 1651 - Three Point Gauge
- Measures both peaks and valleys
- Only measures top side
- Does not measure edge lift (lead/trail 6” skipped)

EN12150 - Bar and Feeler Gauges
- Measures both peaks and valleys
- Measures both sides
- Measures edge lift

Figures courtesy of GlassQuality.com

Glass Distortion

Shortcomings of Roll Wave

- Single 2D strip sample
- Operator / gauge repeatability issues
- Does not accurately represent what the human eye observes
- Measures only one very specific type of distortion
  - Blind to hammer/pocket distortion, center kink, picture framing, etc…
- Flat bottom and three-point gauge do not quantify edge lift
  - EN12150 Feeler gauge is only method will measure edge lift

Glass Distortion

Optical Distortion

- Electronic scan of 100% of the glass surface at 1,000’s of locations.
- Quantifies ALL types of distortion and measures what the eye sees!

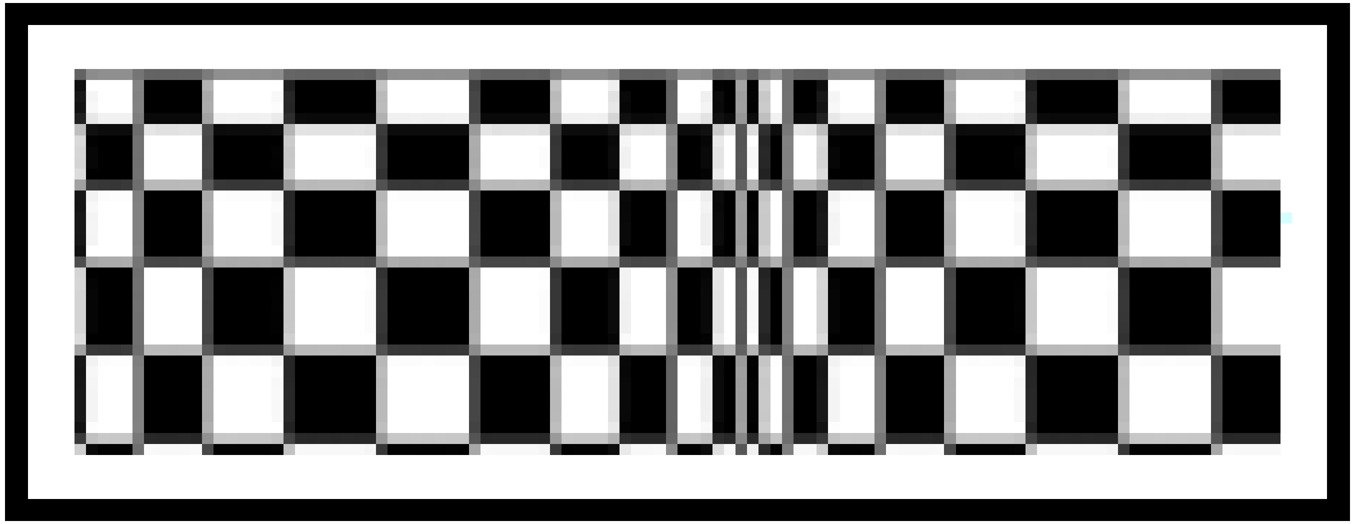
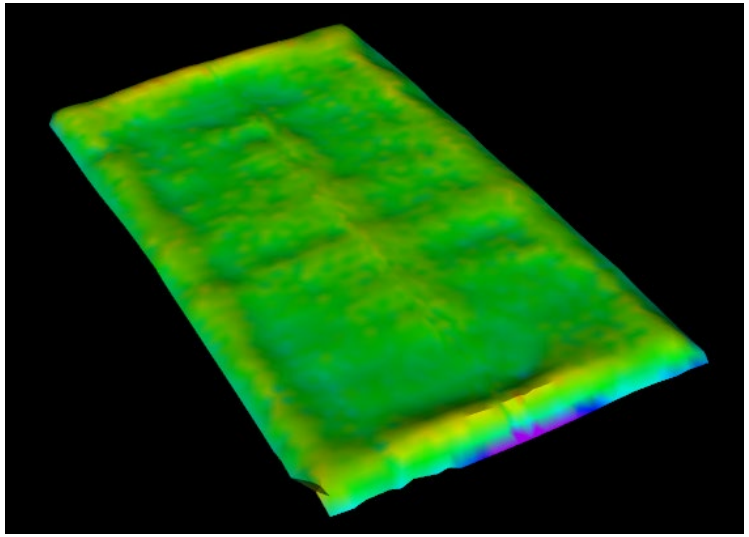


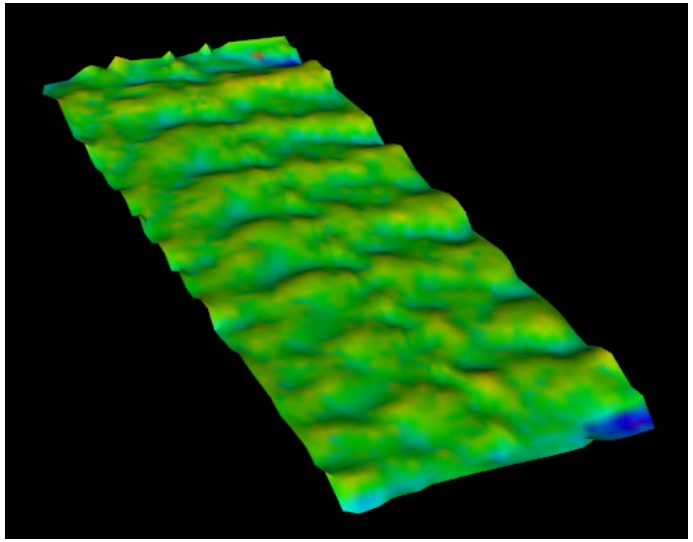
Figure courtesy of GlassQuality.com

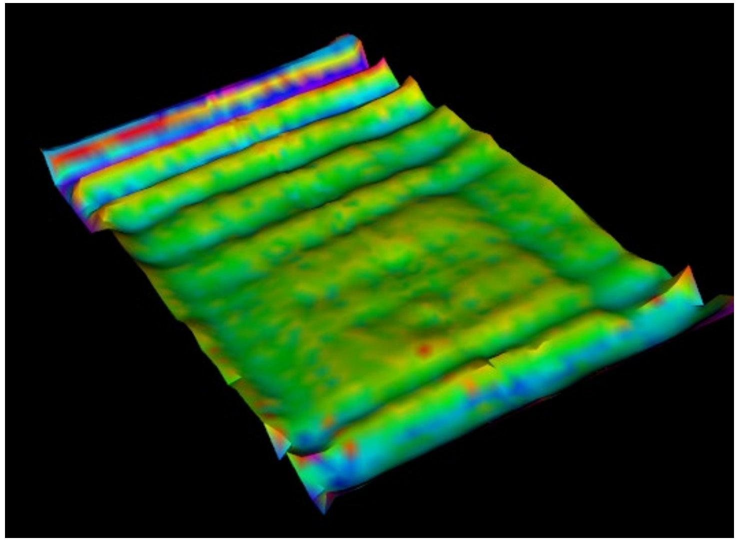
Optical Power Map in millidopters (mD)

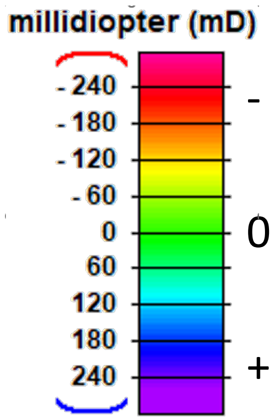
NGA
NATIONAL GLASS ASSOCIATION with GANA

Electronic 3D Scan Measures **ALL** types of distortion
over complete part









- Convex (**-mD**) = Demagnifies Image

0 Flat (0 **mD**) = No Distortion

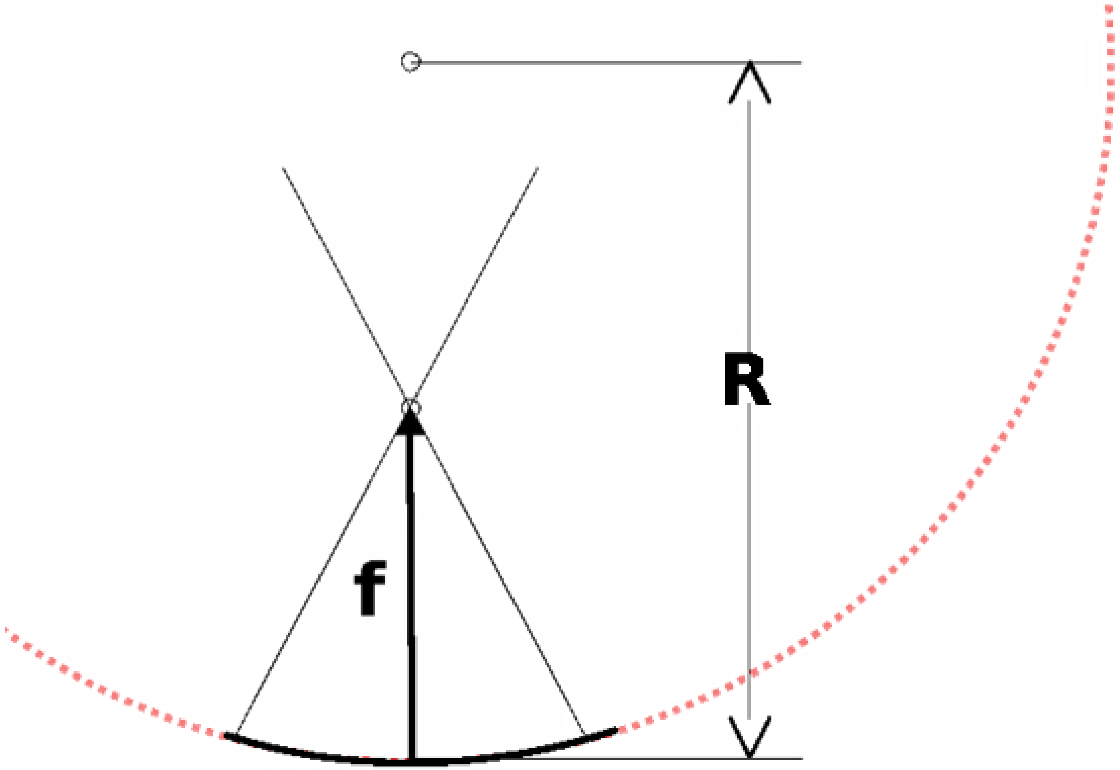
+ Concave = (**+mD**) = Magnifies Image

Definition: millidopter (mD)

A diopter is the measure of lens power or curvature of a glass mirror.

1 millidiopter (**mD**) = 0.001 Diopter (**D**)
D = (1 / **f**) Where f is focal length in meters
radius of curvature (**R**) = 2 x **f**

mD	D	f meters	R meters	R feet
0	0.000	∞	∞	∞
20	0.020	50.0	100.0	328.1
50	0.050	20.0	40.0	131.2
100	0.100	10.0	20.0	65.6
200	0.200	5.0	10.0	32.8
300	0.300	3.3	6.7	21.9
400	0.400	2.5	5.0	16.4
500	0.500	2.0	4.0	13.1



Optical Distortion

Simplified Equation

D = 2,000 / R

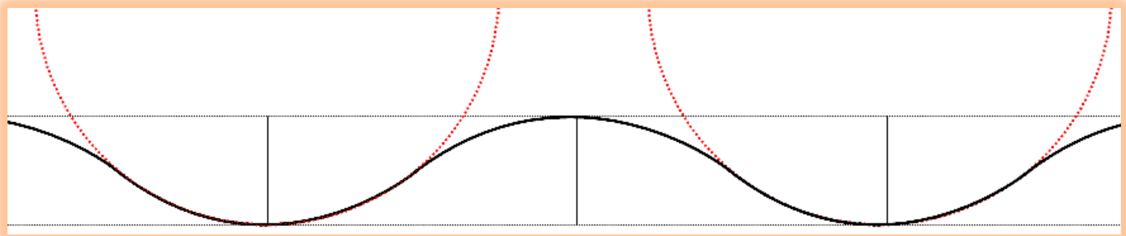
- Optical distortion (mD) in units of millidiopters.
- Radius of glass curvature (R) in units of meters.

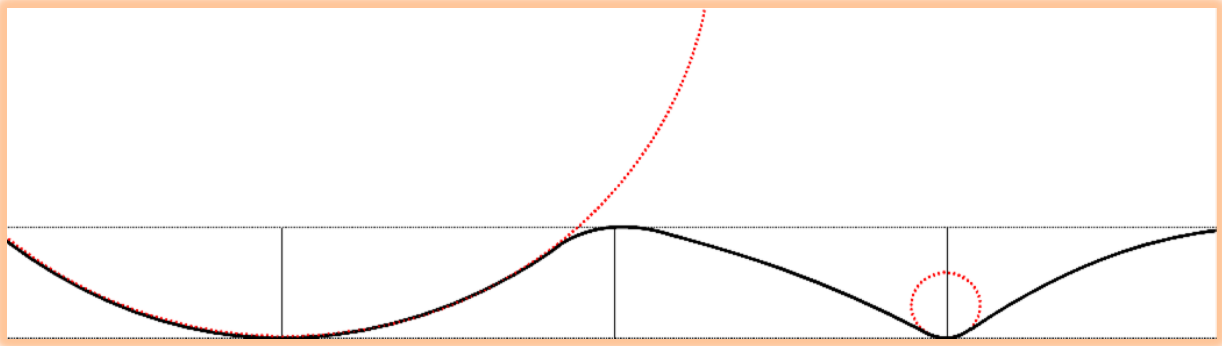
Radius of Curvature (meters)	Optical Distortion (mD)
∞ (flat glass)	0
100	20
40	50
20	100
10	200
6.7	300
5	400
4	500

Converting between mD and PV ?

ASTM 1651 and 1652 suggest an equation to convert between PV and mD but beware this makes the erroneous assumption that glass deforms as a mathematically perfect sinewave and results from this equation are often inaccurate by a factor of 2X or more!

Theoretically perfect sinewave assumed by equations. Note the unrealistic assumption of consistent mD (as show by consistent radius of curvatures)

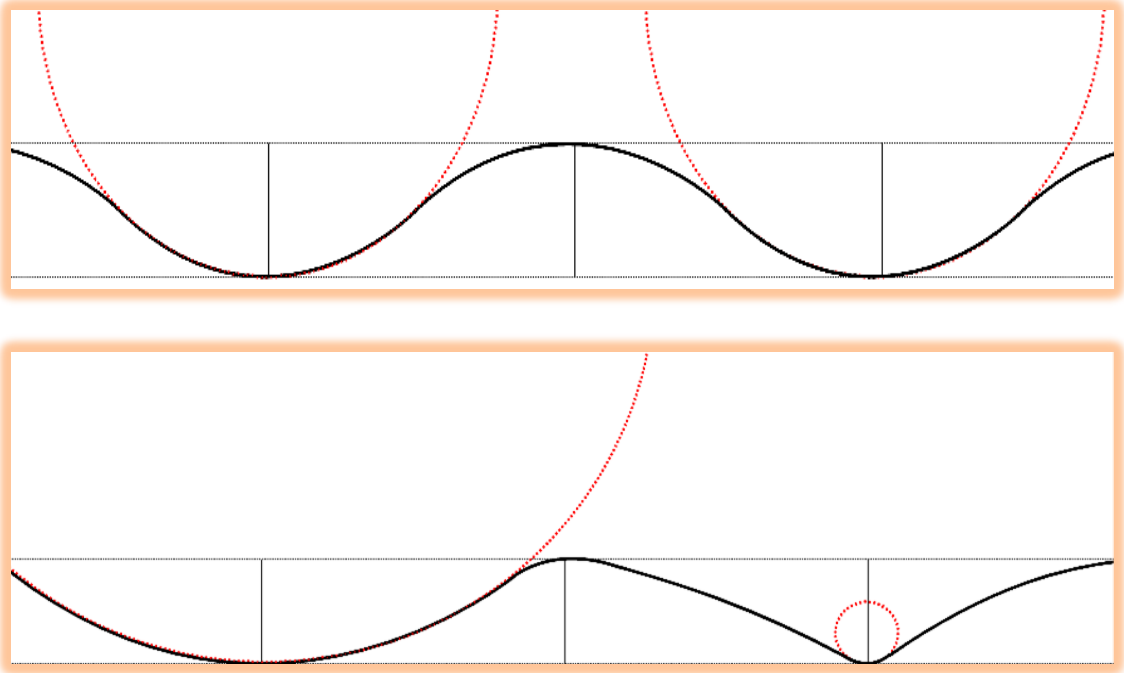




An example of a more realistic deformation with same PV and wavelength but a large variation in mD (as evidenced by varying radius of curvatures)

Glass Distortion

Comparison of Roll Wave Distortion Measurements



Both figures have the same peak-to-valley roll wave, but a much different value for optical distortion.

Figures courtesy of GlassQuality.com

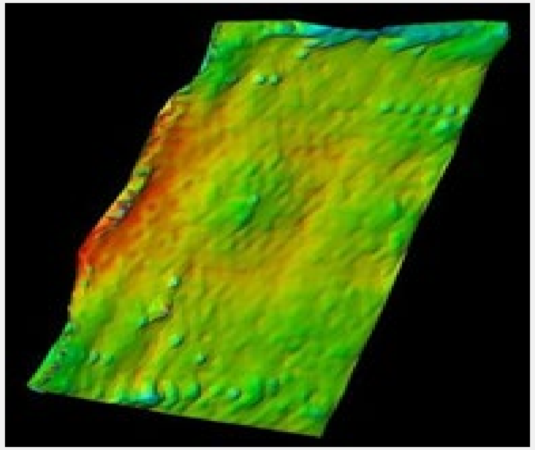
Distortion vs PV Conclusion

Roller wave (PV) is severely limited.

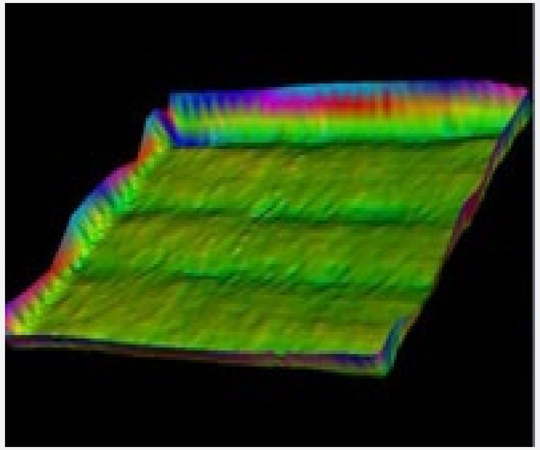
Optical Power in **millidiopters (mD)** is often the better measurement to rely upon.

Glass Distortion Comes in Many Flavors

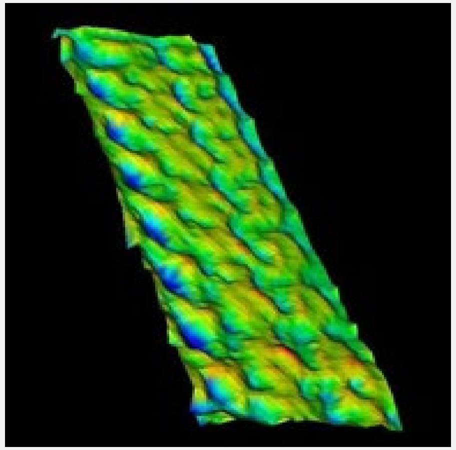
Possible Cold Center Bi-stability



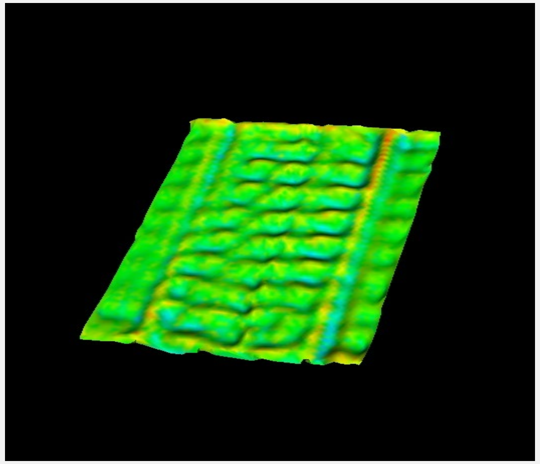
Picture Framing



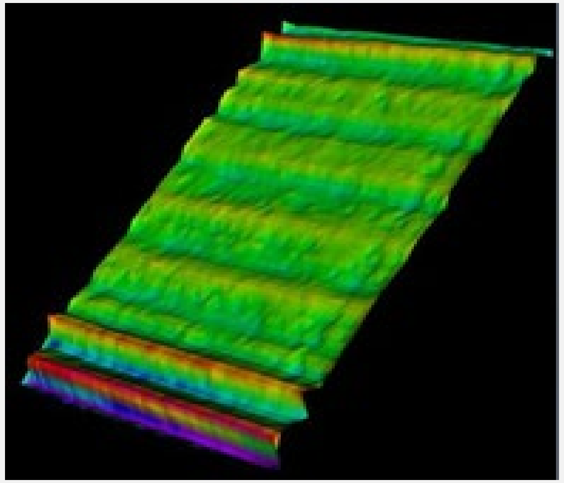
Heavy Pocket Distortion



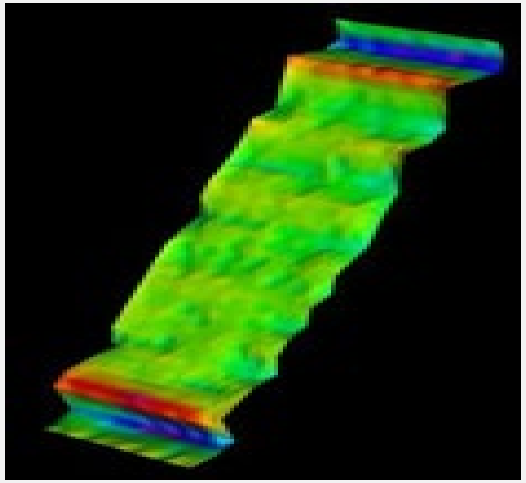
Cross Conveyor (w/Light Pocket)



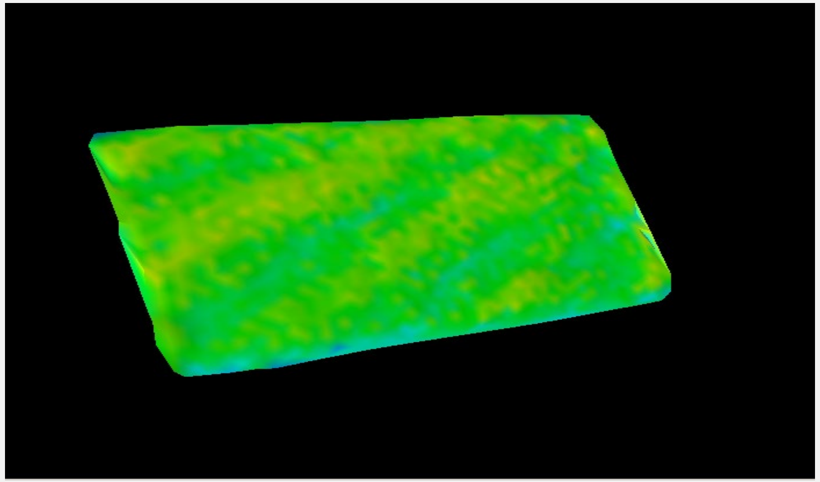
Classic Roller Wave & Edge-Lift



Edge-Lift

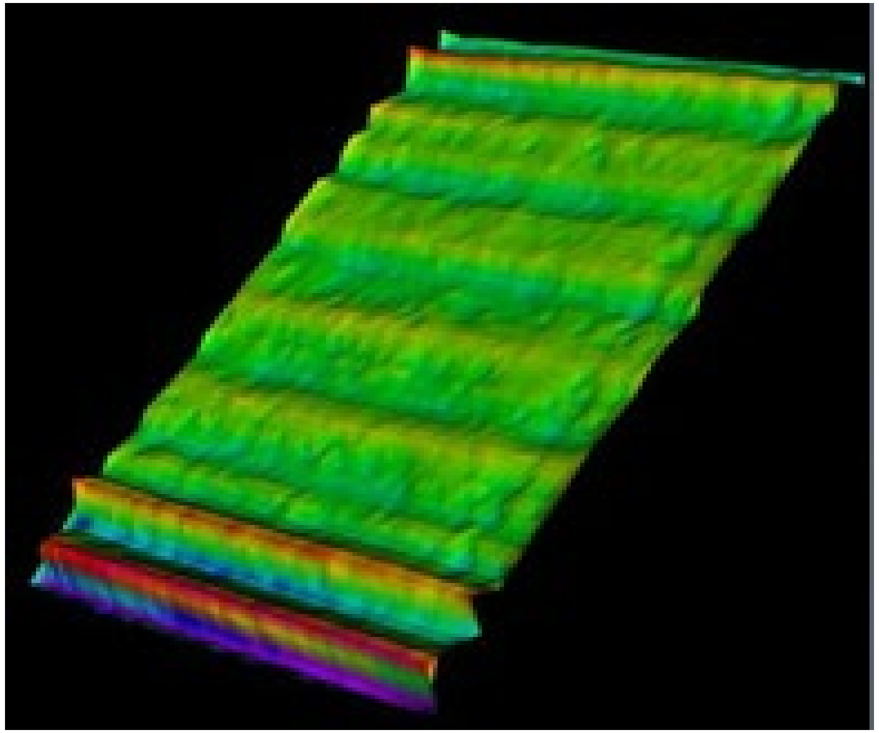


Low Distortion – High Quality



Glass Distortion

Common Types of Distortion

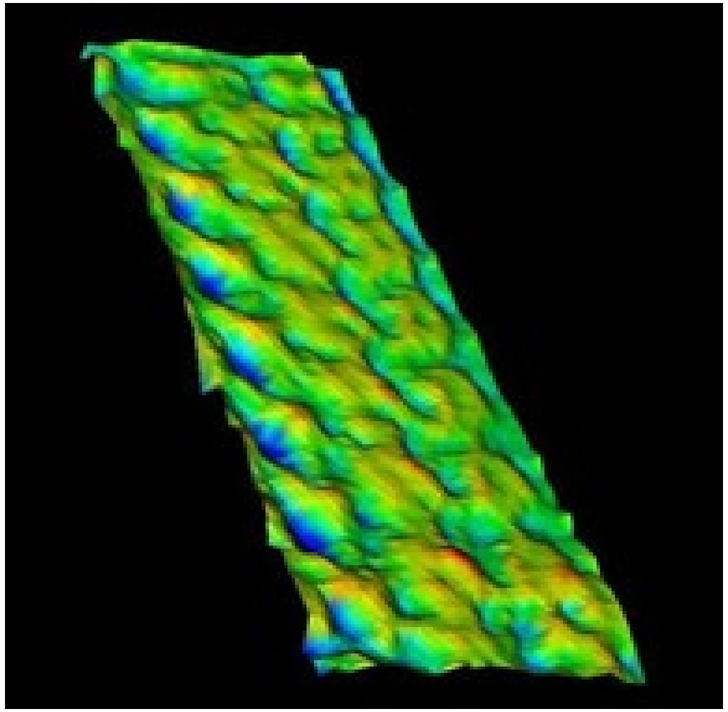


Roll Wave and Edge Lift

Photograph courtesy of GlassQuality.com

Glass Distortion

Other Types of Distortion

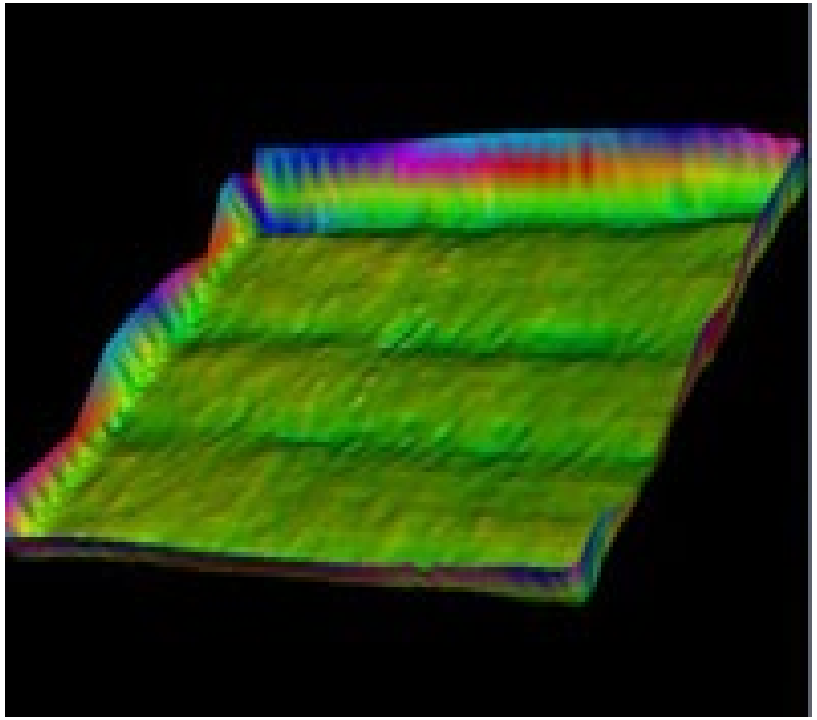


Pocket Distortion

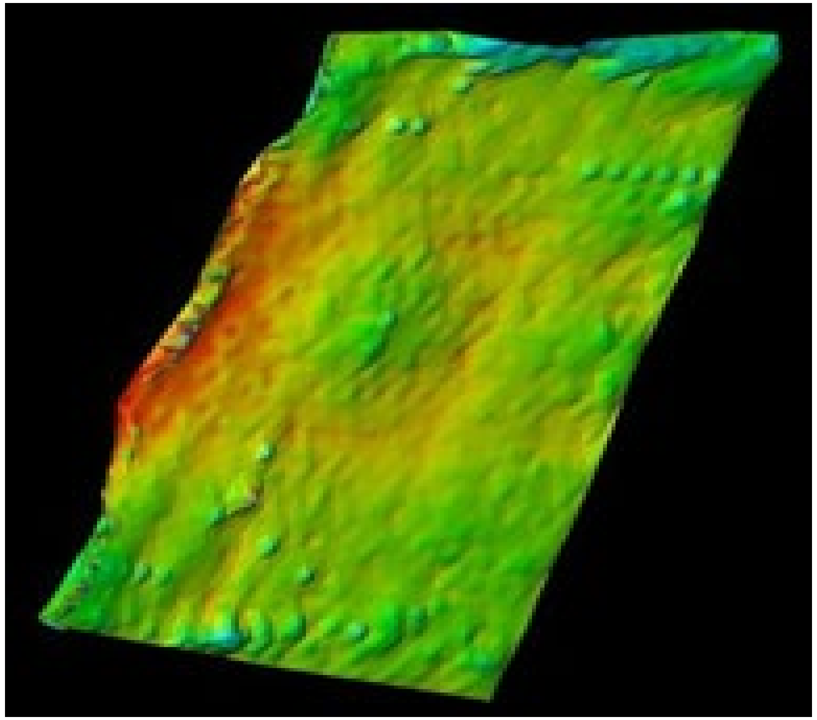
Photograph courtesy of GlassQuality.com

Glass Distortion

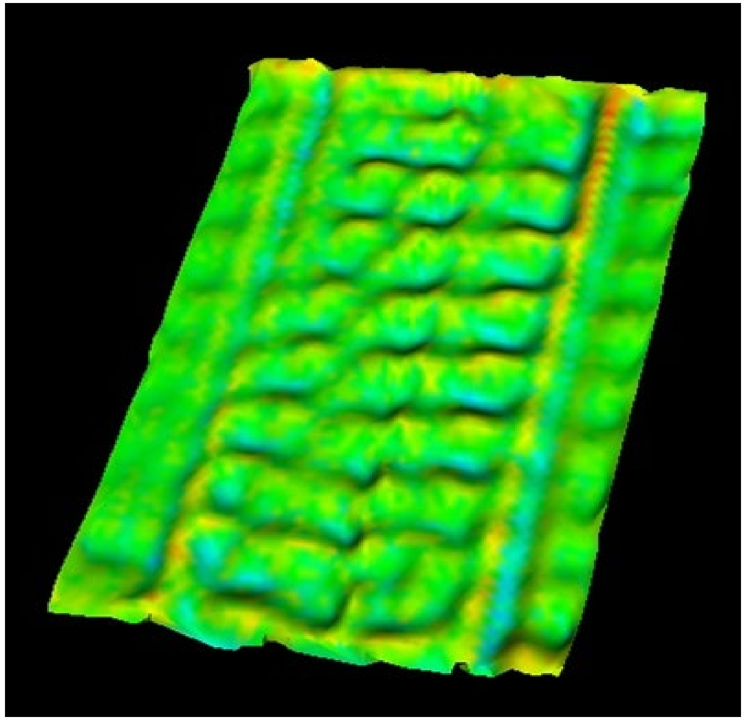
Other Types of Distortion



Picture Framing



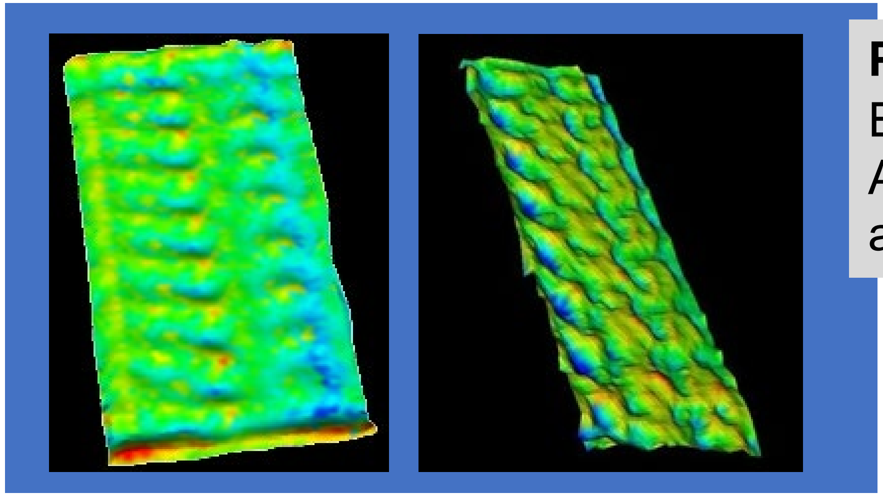
Bi-Stability



Cross Conveyor

Advanced Distortion Analysis Examples

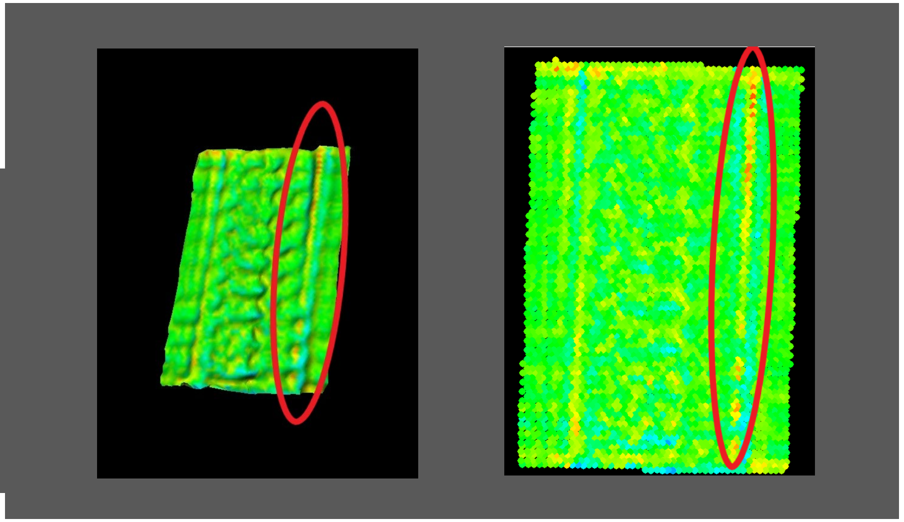
Two examples of distortion that pass basic cumulative percentile distortion, roller wave, and edge-kink tests!



Pocket Distortion Analysis
Each distorted area is of relatively low levels of absolute distortion. A real-time analysis of the objectionability of the pattern provides an accurate metric so this can be flagged in real-time.

Center Kink Distortion Analysis

This quality test is for distortion across the conveyor (90 degrees to the direction of glass travel). This distortion is often very hard to detect until final installation.



Adaptive Quality Control

Quality Control Test Limits may require constant adjustment depending on the mix of products, customers and applications.

Customer / Project Specifications

For Example, Guardian Elite Quality Specifications

Specifier: If "Optical Distortion Limits" listed below are instead measured in millidiopters, modify below to indicate that 95 percent of the glass surface is not to exceed + or – 100 millidiopters. Limit described below applies only to 1/4 inch (6 mm) to 3/8 inch (10 mm) thick float glass without ceramic frit or ink.

3. Optical Distortion Limits:
   a. Maximum peak-to-valley roll wave 0.003 inch (0.08 mm) in the central area of the glass lite, and 0.008 inch (0.20 mm) within 12 inches (305 mm) of the leading and trailing edge of the lite, measured in accordance with ASTM C 1651.
   b. Maximum center-kink of 0.001 inch (0.025 mm) when roll wave is measured over the surface of the glass perpendicular to the direction of travel through the heat treatment furnace.
   c. Maximum localized and overall bow (warp) per lite shall each be one-half of maximum allowed by ASTM C 1048.
   d. Measure glass lites for optical distortion using Osprey® (version 7 or higher, by Lite Sentry) online distortion measurement system (or equivalent approved in writing by industrial coated glass supplier). Retain test reports for three years following substantial completion. Submit test reports upon Architect's request.

Part Geometry

Part size and shape can determine whether specific tests are applicable and what thresholds to apply.

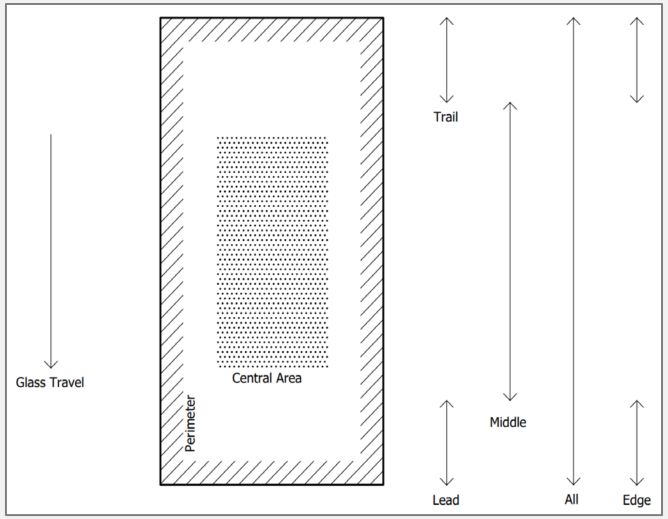
For example:

- Larger parts are often set to tighter distortion tolerances
- Parts near square (aspect ratio near 1.0) are more susceptible to cold center issues that can lead to bi-stability

Inspection Locations

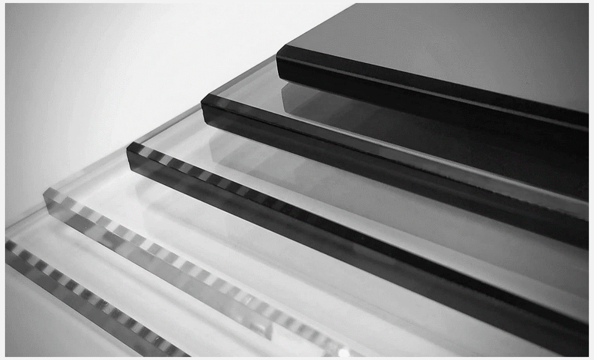
Quality Control Analysis can be limited to specific areas on the glass to target:

- Specific phenomena (e.g., picture framing)
- Specific Application – Lamination
- Limit test to viewing area



Part Thickness and Coating

- **Capability**: Thinner glass and certain coating are harder to control distortion and therefore more distortion may be allowed. Just the opposite is true for anisotropy.
- **Objectionability**: This is a complex subject but in general more reflective coatings will make a given level of anisotropy or distortion more visible.



Adaptive Quality Control Based on Coating

Put simply:

Reflective coatings = more visible Distortion and Anisotropy

It has been widely known in the industry (and makes intuitive sense) that more reflective coatings make reflected distortion more noticeable.

Coating Sensitivity to Quench Marks
by Saint-Gobain Research Paris (Glass on Web 15 July 2022)

This article does a very thorough job of explaining the science behind quantifying the perceived sensitivity to anisotropy and introduces a value called quench marks sensitivity (sigmaQM or σQM) that is a function of the transmission and internal reflection coefficients of the coatings.

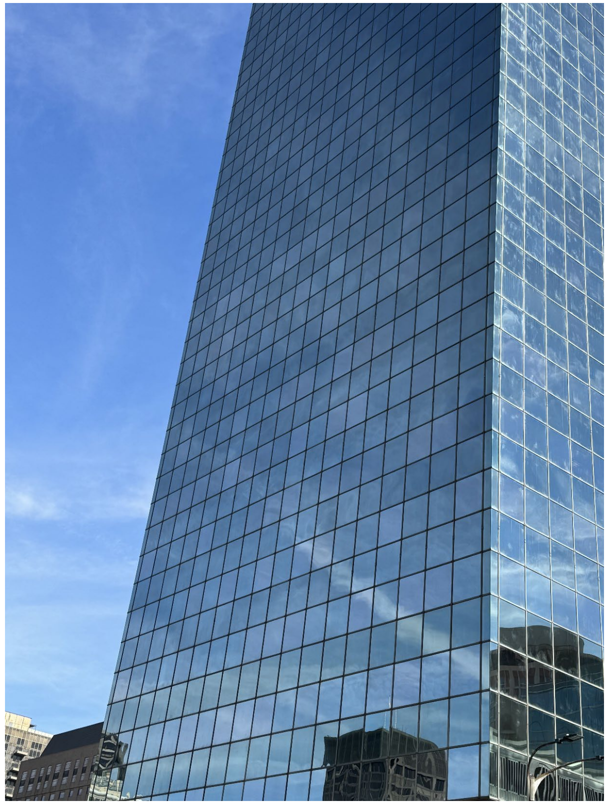
> By means of an observation poll on different solar controls we have validated the reliability of the σQM in evaluating the coating sensitivity to the optical anisotropy.
>
> www.glassonweb.com/article/coatings-sensitivity-quench-marks

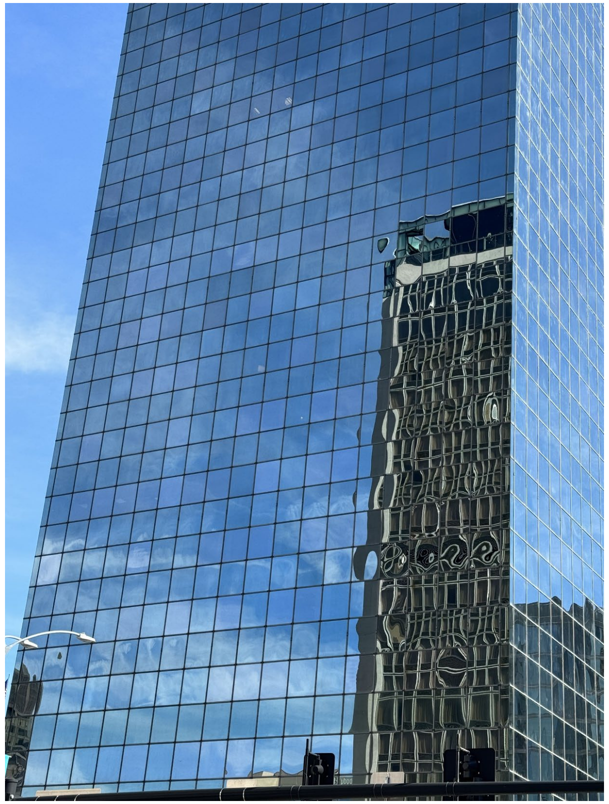
Coating Information is either:

- Entered Manually
- Supplied from an ERP system
- Detected with online coating sensor

Glass Distortion

Real-World Examples

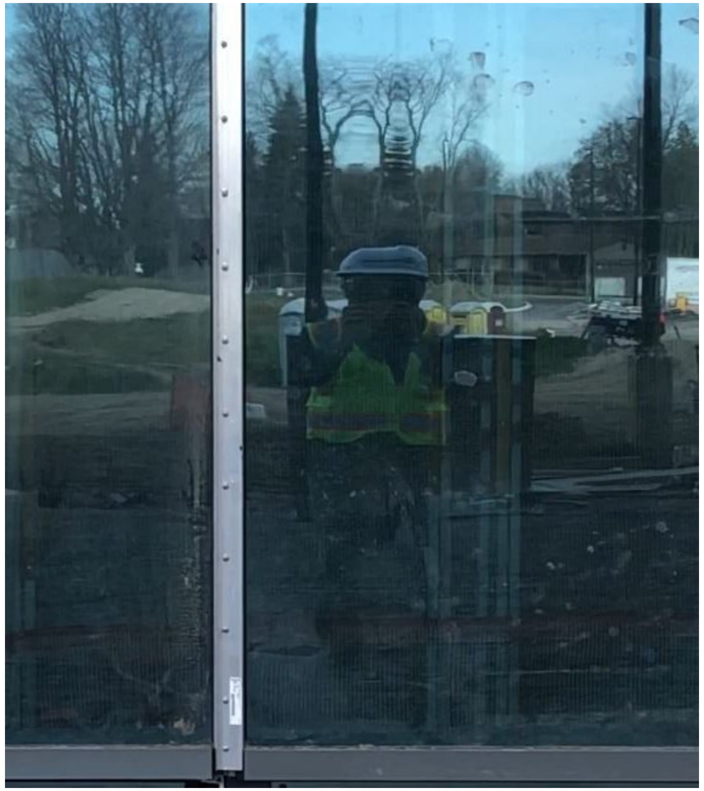
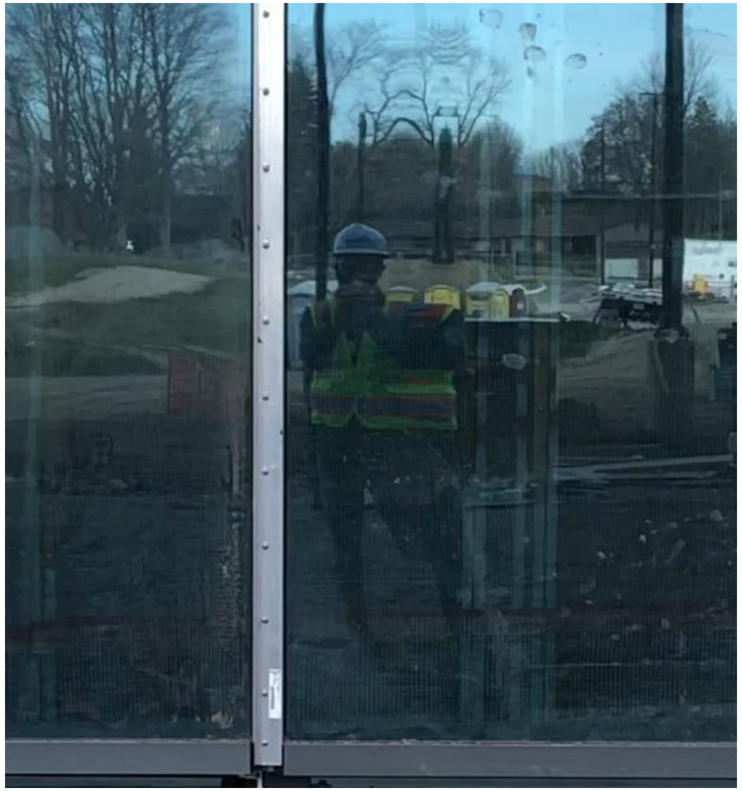
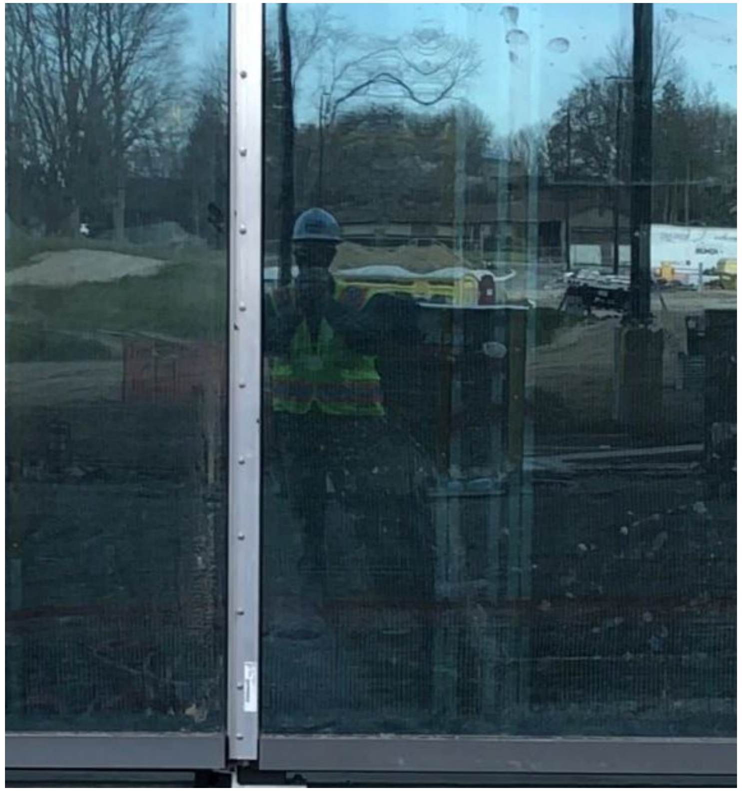




Images courtesy of Aaron Rosen @ RosenBEC

Case Study

Reported Problem at the Project Site

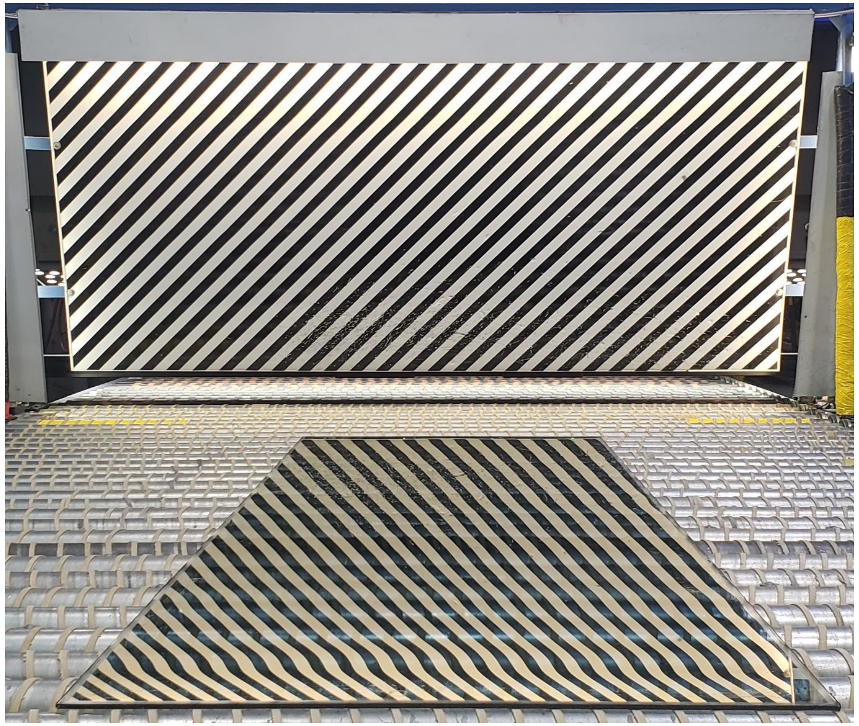




Images courtesy of Aaron Rosen @ RosenBEC

Forensic Investigation

Representative Zebra Board Visual Evaluation

Baseline control sample for Group 2

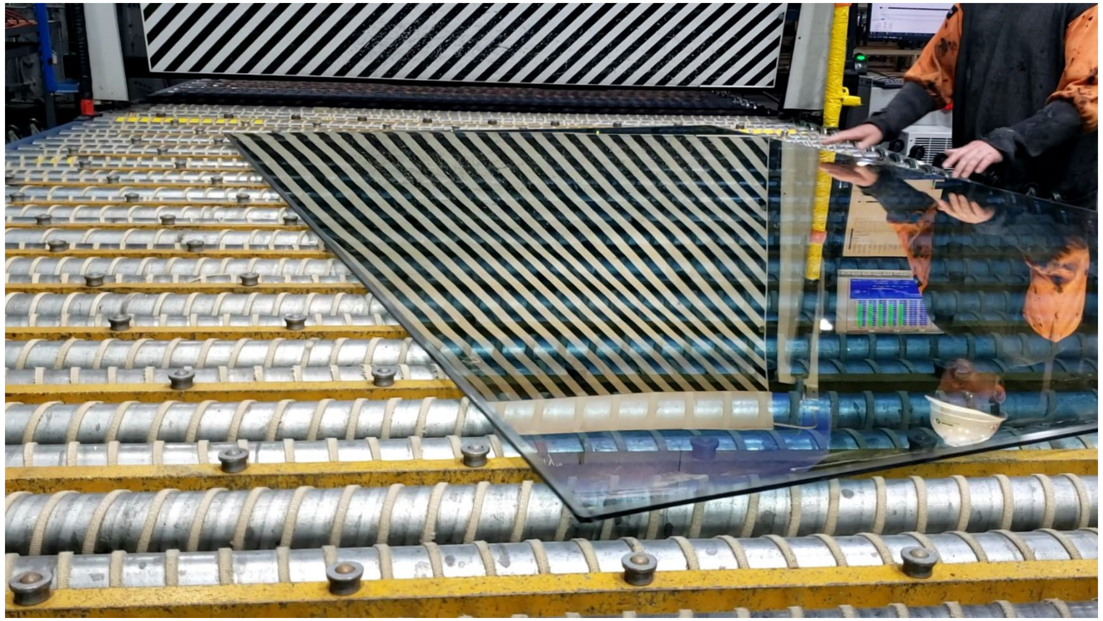


Project glass sample 2A

Images courtesy of Aaron Rosen @ RosenBEC

Forensic Investigation

Representative Zebra Board Visual Evaluation (Rotating Glass 90°)

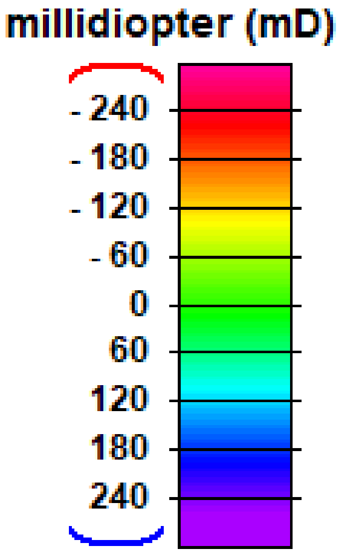


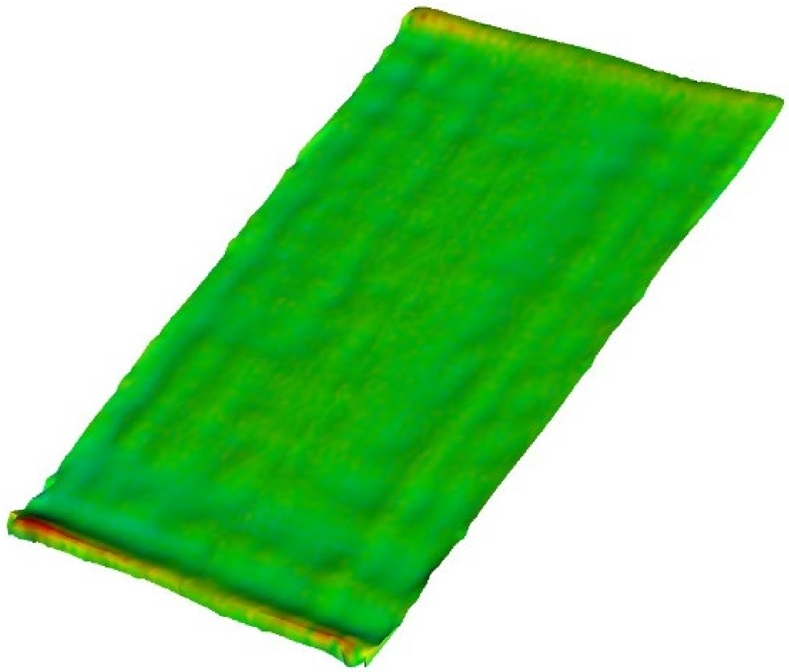
Project glass sample 4A

Images courtesy of Aaron Rosen @ RosenBEC

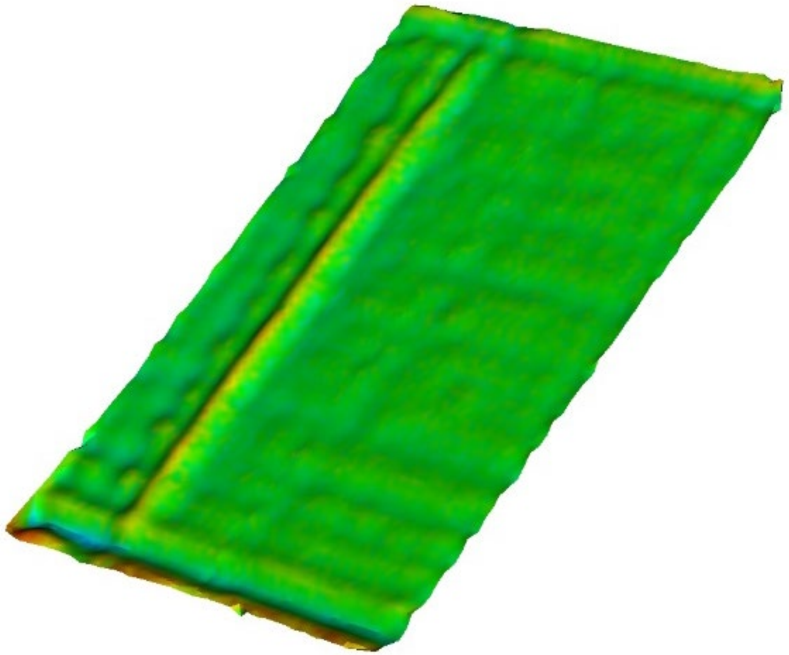
Forensic Investigation

Representative Electronic 3D Glass Scans





Baseline control sample for Group 1

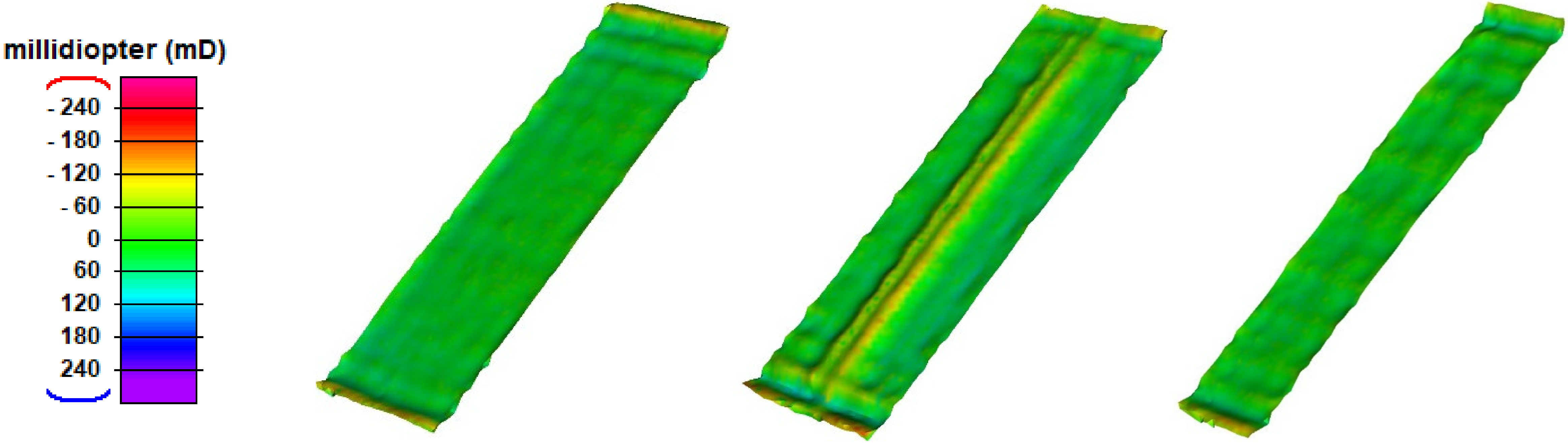


Project glass sample 1A

Images courtesy of Aaron Rosen @ RosenBEC

Forensic Investigation

Representative Electronic 3D Glass Scans



Baseline control sample for Group 2

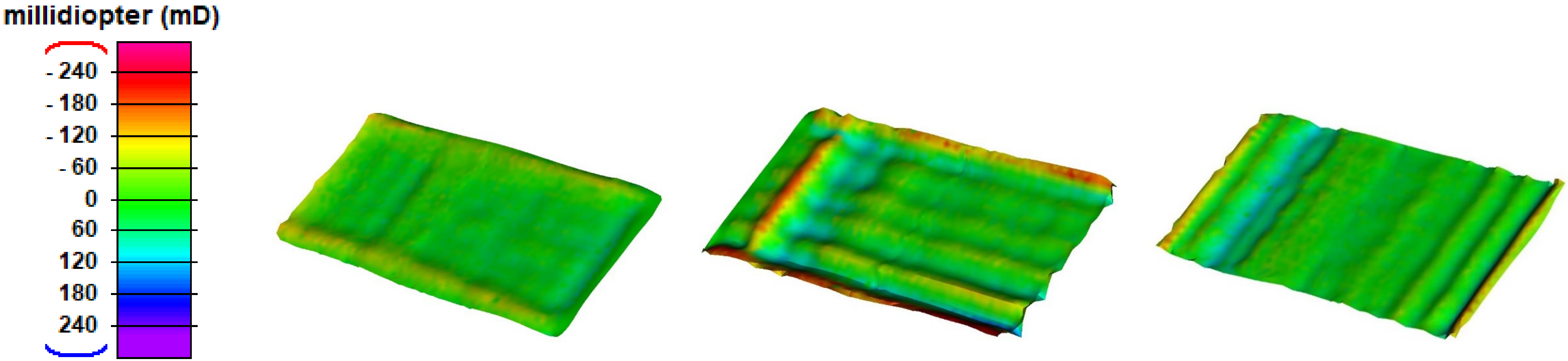
Project glass sample 2A

Project glass sample 2B

Images courtesy of Aaron Rosen @ RosenBEC

Forensic Investigation

Representative Electronic 3D Glass Scans



Baseline control sample for Group 3 *Project glass sample 3A* *Project glass sample 3B*

Images courtesy of Aaron Rosen @ RosenBEC

Top Takeaways

1. Without a technology to measure and quantify distortion in glass, the only other options are subjective (zebra boards) or too manual to provide a true measurement of the entire surface area (3-point gauge, Flat-bottom gauge, Feeler gauge).

2. Peak-to-Valley measurements do not measure what the eye sees which is why millidiopters is a better way to measure optical distortion.

3. With the advancements in furnace technology, simply looking for only roller wave and edge kink is not enough. Multiple other types of distortion need to be inspected: cross conveyor (center kink), bi-stability, picture framing, and pocket distortion.

4. Quality Control Test Limits may require constant adjustment depending on the mix of products, customers and applications which only automated inspection systems can handle.

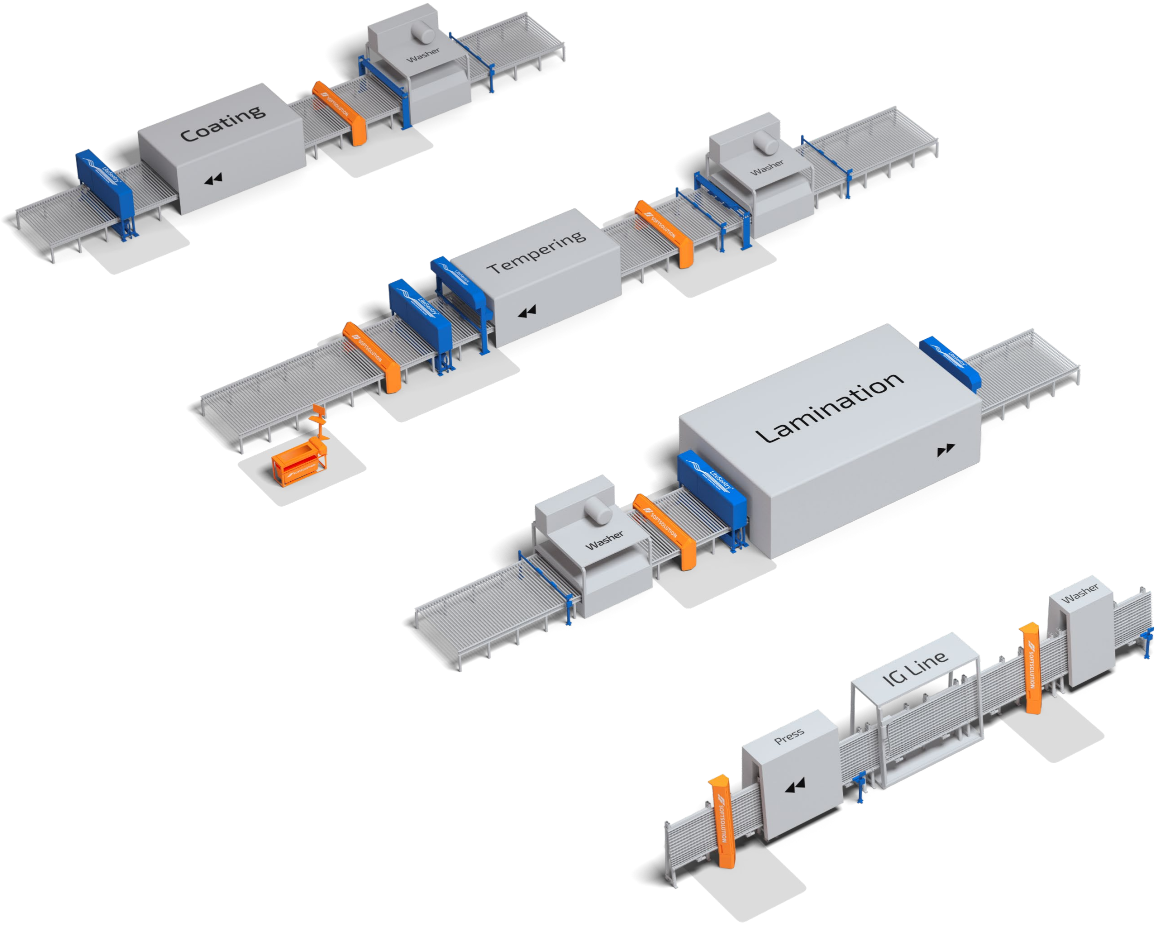
5. Distorted glass can cause major issues in IG units, laminated units, VIG, and more.

We are LiteSentry-Softsolution-Strainoptics…WHERE ULTIMATE INSPECTION TECHNOLOGY IS BORN

NATIONAL GLASS ASSOCIATION with GANA

COME SPEAK WITH US TO HEAR MORE ABOUT OUR WIDE RANGE OF INSPECTION AND METROLOGY EQUIPMENT:

- LineScanner – Inline Quality Inspection (Surface and Dimension)
- Osprey 10 Complete – Distortion and Anisotropy Inspection
- Owl 5 – Automated Recipe Selection and Fault Detection System
- White Haze Scanner – Heat Stain Inspection
- Load Validator – Geometry and Load Fault Detection
- Hawk – Brightfield/Darkfield Inspection
- VirtualDigitizing – Digitizing Customer Templates
- CulletScanner – Digitize Daily Break Tests
- TS4000 – Glass Coating and Thickness Sensor
- BowScanner – Inline Bow Measurement



GlassQuality.com

THANK YOU!!

Questions?

GlassQuality.com