Stress relief

– New PC-Based Scanners Improve Quality and Productivity for Glass Fabricators

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Recent advances in computer technology have made new, easy to use PC-based measuring systems, formerly used only in float glass production, available to glass fabricators. Priced from under $25,000, they may be used to measure residual stress in heat-strengthened, tempered, and low-stress laminated glass, as well as roll-wave distortion in architectural glass. The systems may be configured either in off-line versions, on-line versions, or portable versions using a hand-held sensor (for automotive windshields). The instruments display and store actual stress or roll-wave data, which can then be used to optimize furnace parameters. No special operator skills are required.

THE BENEFITS OF AUTOMATIC MEASUREMENT

Dramatic design innovations in the glass industry have made the fabrication of architectural and automotive glass an increasingly complex and highly technical process. Among all of the variables affecting the quality and marketability of the product, controlling residual stress and roll wave distortion are among the most important.

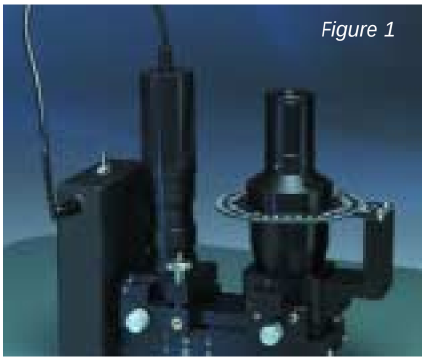
Up until recently, only large manufacturers of float glass could incorporate automatic stress scanners into their production line. These on-line systems, costing from $70,000 US to as much as $250,000 US, are too expensive for many small operators. More significantly, the speed of a tempering line has historically presented a problem in reliable data acquisition. New technology has managed not only to solve this problem, but has done so in a way that makes the equipment purchase cost-effective for virtually every fabricator.

BACKGROUND

Most fabricators, many of whom are required to test for stress in order to comply with industry standards or certification programs, now use manually operated instruments. While capable of producing reliable and repeatable measurements, these products are designed for off-line batch inspection by a specially trained operator in accordance with ASTM and equivalent standard methods. These instruments (Figure 1), manufactured and marketed by Strainoptic Technologies under the tradename GASP® (Grazing Angle Surface Polarimeter), are often used to measure surface stress in tempered glass to verify temper and to supplant destructive break-pattern testing.

Other instruments, designed to measure edge stress in automotive windshields, include the GES-100 (Figure 2), a hand-held device used to obtain quantitative stress measurements, and the VRP (Figure 3), a specially designed reflection-polarimeter that can be used to measure edge stress in the opaque painted or "frit" areas of automotive glass.

For measuring roll-wave distortion in architectural glass, some fabricators use a manual device that slides along the surface of the glass lite to ascertain its flatness. These roll-wave gauges are generally of a "flat-bottom" or "3-point contact" design. The flat-bottom gauge offered by Strainoptic Technologies (Figure 4), features a 12-inch (305mm) base and an analog dial gauge. The 3-point contact model (Figure 5), which features an adjustable length between contact points, has a digital readout and can be ordered with an LVDT sensor for



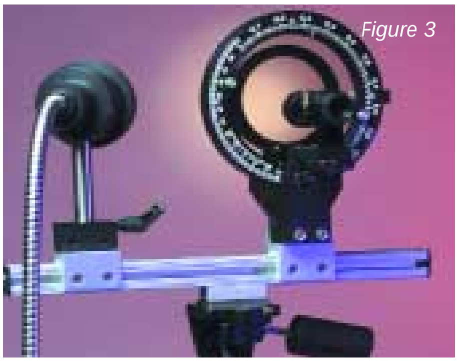


Figure 1. The GASP® Grazing Angle Surface Polarimeter used for manual, non-destructive measurement of surface stress in heat-strengthened and tempered glass. Figure 2. The GES-100 is used to manually measure edge stress. Figure 3. The VRP Visual Reflection Polarimeter is used to manually measure edge stress in the opaque "black band" area of automotive glass.

Figure 4. Flat-bottom roll wave gauge with analog dial readout.

Figure 5. Three-point roll wave gauge with digital readout

output to a PC or chart recorder. These instruments measure out-of-plane deformation (peak-to-valley depth), which must be converted to millidiopters using a standard equation to arrive at a true value for optical distortion.

While not particularly difficult to operate, manual instrumentation does require some training and a certain amount of skill to master. They cannot be adapted to on-line testing, and do not lend themselves to a regime that calls for 100% inspection. Automated systems, on the other hand, offer distinct benefits. These include:

- User-friendly, Windows-based operator interface with simple, menu-driven prompts. No special skills or knowledge required.
- Immediate, highly-accurate, and reproducible measurements of stress or retardation. No subjective interpretation of results.
- Speed of testing allows for 100% inspection, on-line or off-line
- Real time display and storage of measurement data and parameters for analysis and furnace optimization.
- Documentation of stress or roll-wave profiles for quality control
- Providing glass consumers with an assurance of consistent product quality
- Complete turnkey systems, priced from $20,000-$50,000 US

AUTOMATED EQUIPMENT FOR HEAT-STRENGTHENED AND TEMPERED GLASS

Most tempered glass produced today is not just ordinary flat glass. Some glass is more sophisticated, incorporating a large variety of coatings and/or laminations designed to change its radiant heat transfer characteristics, physical properties, or appearance of the glass. These complexities necessarily change the requirements of the tempering furnace, making parameter adjustments more critical. Optimizing these parameters is often a matter of trial and error and fabricators sometimes "over-temper" their glass to ensure acceptable break patterns and, in addition, run the risk of inducing unacceptable roll-wave distortion (see Tables I and II).

In the absence of real-time feedback, it is up to the operator to make the necessary adjustments to the furnace with each new batch, leaving problems to be discovered by the QC Department only after the entire batch is processed. A re-processing of the batch is then required, at a significant labor and energy cost to the producer, not to mention the additional expense of handling and re-inspection. Or worse, the glass is not properly tested, leaves the factory, and is installed even though it doesn't meet specifications.

Strainoptic Technologies has introduced a new, fully automatic, non-contact system for high-speed, on-line measurement of stress in tempered and heat-strengthened flat glass applications. Installed at the furnace exit (an off-line version is also available), the Series 1500-TG (Figure 6) senses and reports the temper for each lite of glass emerging from the furnace in real time and clearly displays the value on a computer monitor in numerical or graph form, eliminating guesswork and operator errors. Because the process is almost entirely automated, no special operator training or skills are required.

The system's proprietary software relies on edge stress data to verify that measured stress values fall within industry standards for tempered glass, thereby reducing the need for break-pattern testing and providing a more accurate and repeatable representation of stress levels. Edge stress reveals the strength and service performance of the product. Data acquired from each measurement is saved for documentation of quality. Batch ID numbers, lehr number, shift or other user-defined information may be stored.

Glass exiting the tempering furnace moves at a linear velocity ranging between 50 and 200 mm/sec. To obtain data at closely spaced points, with a spatial resolution of 0.1 mm, a very high data acquisition speed is needed. The 1500-TG system measures stress at a speed in excess of 2000 points/sec. The system yields more than enough data points to accurately establish the leading and trailing edge-stress, as well as the maximum average tensile stress in the near-edge region. Prices for the 1500-TG on-line package start at approximately $35,000US.

AUTOMATED EQUIPMENT FOR MEASURING STRESS IN AUTOMOTIVE GLASS

Strainoptic Technologies has introduced a portable PC-based stress scanner, the PES-100, that takes the guesswork out of edge stress measurement in automotive glass and has a base price under $30,000US, including the computer workstation. Based on the same proven technology used in our float glass scanners, this off-line instrument shares many of the same features as the 1500-TG.

To obtain an automatic measurement of stress in a particular sample, the operator simply passes a lightweight scanning probe along several small (typically 2 to 4 inch) segments of the edge being inspected (Figure 7). The software reports the maximum tensile and edge-compression stress values for each edge scan and also displays a graph of stress vs. position on the computer's monitor. The entire process takes only seconds to complete. In addition to point-to-point edge stress values, the software can also display maximum (peak) values for compressive and tensile stresses for any single edge scan or set of edge scans. The software allows stress values to be displayed in either psi or MPa units.

Additional features include fully automated system calibration, recognition and reporting of tensile vs. compressive stresses, and nearly maintenance-free operation. For fast "pass or fail" QC applications, the PES-100 offers an Inspection Mode in which the operator scans a pre-selected number of locations around the sample's perimeter. A table of maximum tension and compression readings for each scan is then displayed, and can be quickly compared to acceptable levels. The data is automatically filed, including sample ID number, lehr number, shift or other user-defined fields.

AUTOMATED EQUIPMENT FOR MEASURING ROLL-WAVE DISTORTION

Strainoptic Technologies has introduced a new, fully automated system for high-speed, on-line measurement of roll-wave optical distortion in tempered glass applications. Installed at the furnace exit, the LIN-2003 system (Figure 8) uses a unique, non-contact optical technology, combined with proprietary and user-friendly Windows-based software and a PC workstation, to provide fast, accurate and repeatable readings of roll wave distortion. Because the process is almost entirely automated, no special operator training or skills are required.

The LIN-2003 system is the only roll-wave measurement system on the market that measures optical distortion, unlike other products that rely solely on peak-to-valley depth and peak-to-peak distance, which are not true indicators of distortion. To arrive at a value for optical distortion using these instruments, the operator must take the deviation-from-flatness readings and employ a mathematical formula to convert them to optical distortion in millidiopters, a measurement called for in the latest GANA (Glass Association of North America) standards. Strainoptic's LIN-2003 system automatically and directly measures optical distortion in millidiopters, and displays it on a PC screen.

The ability to measure roll-wave distortion automatically and quantitatively offers glass fabricators the following benefits:

Table 1: Residual Stress Specifications Summary

Tested Glass	Surface Compression (psi)	Edge Compression (psi)
Annealed	< 600	300 - 900
Heat-strengthened	3500 – 7500	3500 - 7500
Fully tempered	> 10,000	> 9700
Safety*	15000 – 20000	15000-20000

* Experimentally established correlation

These surface and edge stress levels are not explicitly stated in the European Norms prEN1863, part 1 and part 2, and prEN 12120, part 1 and part 2, where the strength in bending is specified, and use of GASP for measuring surface compression (that correlates to strength) is suggested. Since the surface compression increases the strength, the European standards are nearly identical to ASTM C1048-97b. A summary of the European requirements is shown in Table 2.

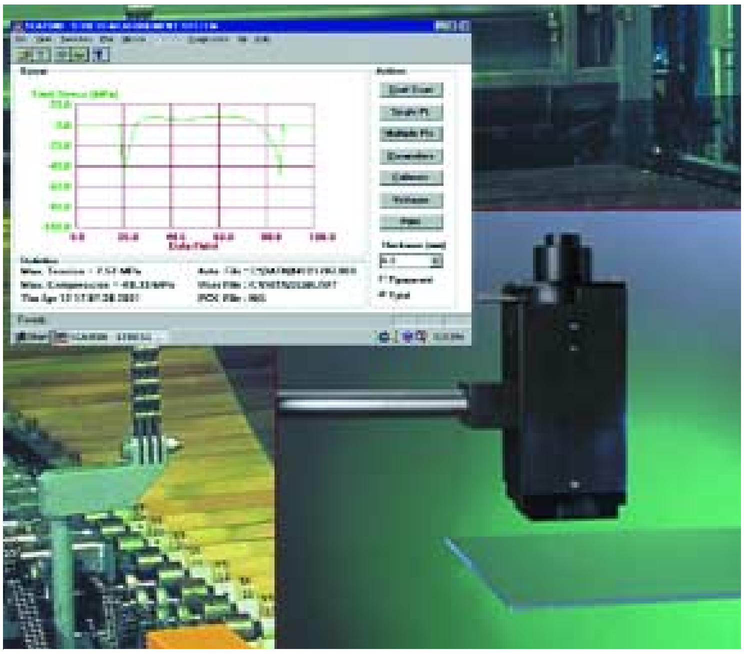


Figure 6. The Model 1500-TG is a PC- based system that offers fully automated, on-line edge-stress measurements of heat-treated glass. (Furnace photo courtesy of Tamglass Ltd. Oy)

- Assured optical quality for architects and end-users
- High reproducibility
- Better control of furnace temperature and other operating parameters

	Heat Strengthened	Tempered
Fragmentation Test **Test Frequency**	Mandatory 1 test/10,000 units (or m^2)	Mandatory 1 test/10,000 units (or m^2)
Mechanical Prop. **Strength** **Test (destructive)** **Residual Stress (NDT)*** **Test Frequency**	Mandatory 70 MPa (10,000 psi) 4-point bending (MOR), GASP for correlation GASP, manufacturer specs. 1 test/batch	Mandatory 100 MPa (14,500 psi) 4-point bending (MOR), GASP for correlation GASP, manufacturer specs. 1 test/batch
Flatness (local bow)	0.3 mm/300 mm (130 mdpt)	0.5 mm/300 mm (220 mdpt)

*Residual Stress Value established by correlation

Table 3, Automotive Laminated Glass

	Maximum Tensile Average**			Edge Compression**		
Thickness	Single lite		Laminated	Single lite		Laminated
Mm	nm	MPa	nm (Typical Industry Practice)	nm	MPa	nm
1.8	36.9	7.6	40	-50	-10.3	-100
2.1	43.1	7.6	50	-65	-11.4	-130
2.3	47.2	7.6	60	-75	-12.0	-150
2.6	53.4	7.6	70	-80	-11.4	-160
3.2	65.7	7.6	100	-100	-11.5	-200

**Measured Using GES-100, ASTM C1279

Product specifications published by automotive industries define an additional test parameter: the maximum average tensile stress occurring near the edges. In automotive glass, edge stress testing has higher emphasis, justified by the frequency of installation and service failures. This table shows typical windshield glass inspection limits.

- Improved productivity, with less waste and lower energy costs
- Optimal furnace and roller maintenance
- Avoidance of excessively high surface stress
- QC Documentation for factory and trade certification programs
- Compatibility with statistical control and factory automation programs

The LIN-2003 system is calibrated using a traceable standard and measures optical distortion levels from 0 to 500 mdpt, with a resolution of 1 mdpt. A specially designed optical sensor and high-speed data acquisition allows for continuous measurements at normal furnace speeds. The flatness of each lite is monitored as it emerges from the furnace and distortion values are displayed on a PC monitor in graphical and numeric formats.

Pre-set limit values alert the operator to any unacceptable roll-wave distortion. Measurement data, including peak values, may be identified by batch or shift number, furnace ID, etc. and stored for later retrieval and analysis.

The on-line sensor head is mounted on a lightweight rail, and easily moved from one furnace lane to another. For 100% inspection, additional sensors can be installed over multiple lanes. The system can also be configured as a portable installation for use with more than one furnace, and a table-mounted version is available for performing off-line inspections. The LIN-2003 Roll-Wave Measurement System may be incorporated with the 1500-TG Stress Scanner to provide one integrated package for total on-line measurement of residual stress and roll-wave distortion. The basic LIN-2003 on-line system is priced under $25,000US.

SUMMARY

As glass manufacturers respond to the growing demands of architects, consumers, and standards organizations worldwide for tighter control of residual stress and roll-wave distortion, a new generation of PC-based automated systems offer a cost-effective solution. Automating the measurement of edge stress in glass improves quality and productivity by eliminating operator error, providing documentation for quality control, optimizing furnace parameters, and reducing waste and rework. It also provides an assurance to the glass customer of consistent product quality. On-line systems contribute even more to profitability by making continuous measurements and 100% inspection possible, and integrating with existing factory automation schemes. ■

Figure 7. The PES-100 is a portable, PC-based system that uses a handheld sensor to measure edge stress in heat-treated glass. Figure 8. The LIN-2003 is the only roll-wave measurement product on the market that reads optical distortion directly in millidiopters, a unit of measurement called for by GANA (Glass Association of North America) in its latest recommendations.


Figure 7

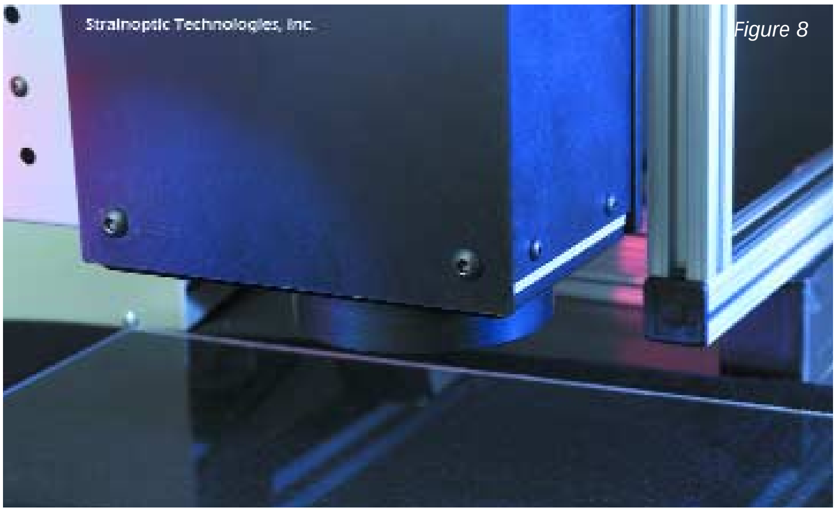


Figure 8