Automated Measurement of Edge Stress in Automotive Glass

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Keywords

1 = Measuring stress 2 = Edge stress 3 = Automotive Glass 4 = Quality control

Abstract

Automotive glass is subjected to a complex set of stresses resulting from bending, heating and laminating processes. Tensile stresses develop near glass edges. If not controlled, these tensile stresses can result in delayed fracture and service failures. Windshields are also known to fail as a result of insufficient edge compression.

To assure quality and avoid service failures, thorough Quality Control procedures are implemented in producing automotive glass. Automotive glass manufacturers measure compressive and tensile stresses at numerous points around the periphery using manual Edge Stress meters. Visual readout however is time consuming and requires operators. Since the measured retardation in laminated windshields is low, repeatability of visual inspection is not satisfactory.

A new system was developed which automatically measures edge stress using a lightweight, portable, PC-based probe. This new system eliminates operator error and features data storage for review and documentation.

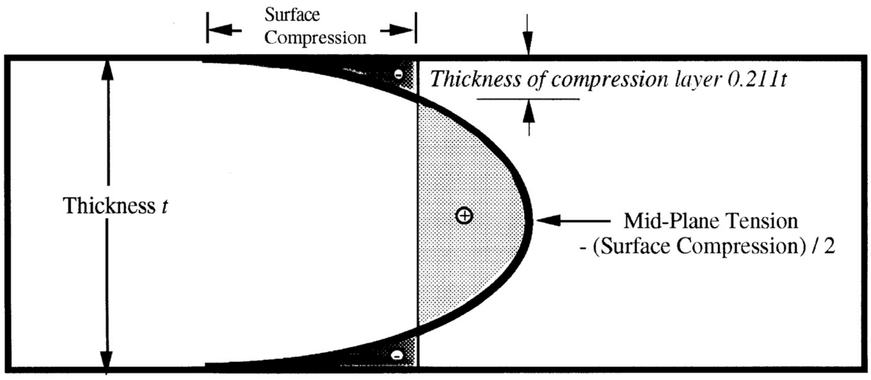


Figure 1.
Stress distribution in thickness of tempered and annealed glass

Figure 2.
Surface and mid-layer stress near edges

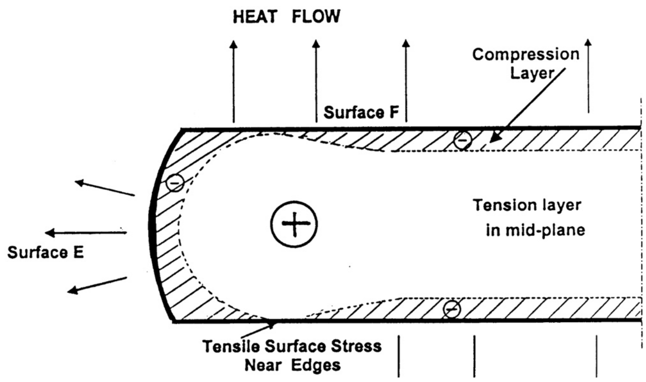
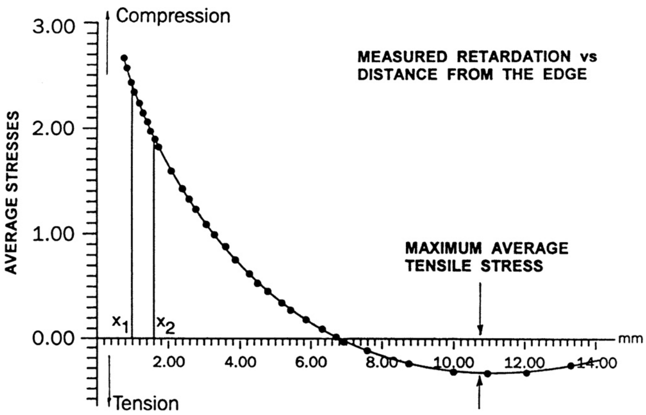


Figure 3.
Membrane stress vs. distance from edge



Introduction

In tempered glass, the objective of the process is to develop a protecting layer of surface and edge compression. In bent and laminated products, surface compression is also present, although to a much lesser degree, and bending stresses are considerably higher. At some distance from the edge, well-known parabolic stress distribution develops as illustrated in figure 1 below.

The stress distribution near glass edges is considerably more complex than shown in Figure 1. In addition to the surface cooling, the heat dissipates also along the edges, creating edge compression on the surface E shown in figure 2 and a substantial increase of the mid-plane tensile stress, balancing the edge compression.

Analysis of the stresses that develop in tempering, bending and lamination were reported by Dr. S. T. Gulati [1] who strongly recommended stress measuring as a systematic and necessary part of quality control to eliminate potential of delayed fractures. Surface stresses are related to the temperature gradient that results from cooling. Surface stresses are also related to bending in bent and laminated glass [1]. As shown in figure 2, the edge surface of a glass "E" will develop surface compression comparable in size [2] to the surface (F) stress, assuming the cooling rate and the heat flow are approximately the same.

Compression forces on surfaces E and F are balanced by tensions in the mid-plane. Under certain conditions, whenever bending introduces additional surface tension (figure 2), the tensile region reaches the glass surface.

Measuring the average membrane stress in transmitted light yields the results shown in figure 3, indicating a peak average tensile stress at a small distance from the edge (typically 12-25 mm). A large positive tensile average is an indication of an undesirable edge cooling rate and a potential bending problem. Dr. S. T. Gulati [1] indicated that a membrane tensile stress of 1000 psi (7 MPa) could lead to a delayed crack growth.

Figure 4.
Glass Edge Stress Meter

Measuring Edge and Membrane Stress

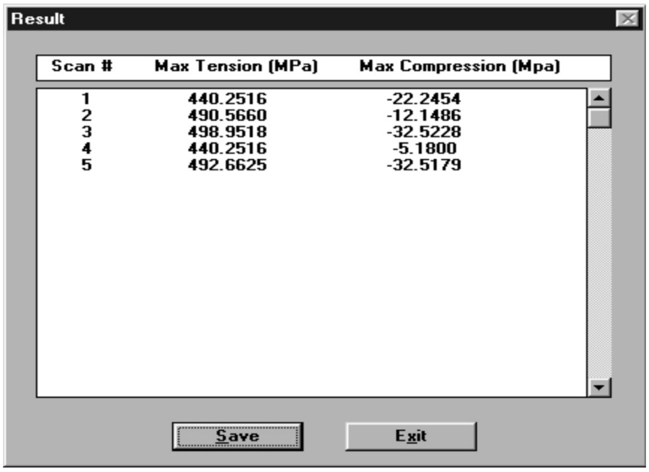
Transmitted light reveals edge-compression and tensile membrane imbalance with photoelastic test methods. Compensators (ASTM test method C1279) [3] provided stress resolution of 0.3 MPa in 3 to 4 mm glass. The ASTM test procedure includes an extrapolation method that is recommended whenever the ground edge finish depth exceeds 0.25 mm. This procedure is time consuming and requires a very highly trained operator. For this reason, it is not extensively used in the automotive industry. Instead, the edge stress is customarily measured at the end of the ground finish and an additive empirical constant is used to account for the fact that the stresses at the extreme edge are higher. Visual measurements are extensively practiced for inspection of automotive glass (see figure 4).

New Method

To eliminate subjectivity and low sensitivity of visual stress measurements, a new PC-based, Portable Edge Scanner (PES-100) was developed. This instrument was designed to scan a short line perpendicular to the edge at any desired number of locations. The measuring of stresses is accomplished using SCA method [4] with several changes needed to increase the speed of data acquisition, increase the sensitivity, to permit accurate measurements of small tensile membrane stress in laminated glass and increase the range to permit measuring of edge stress in tempered glass. The speed of data acquisition of the portable probe is 1000 points/sec. A scan along a 50 mm segment takes 2 to 3 seconds.

Upon completion of the desired number of scans, a table of results, shown in figure 5 below is generated and a data file saved, providing fully documented inspection. Figure 6 shows an operator using the PES-100 inspecting a windshield placed on a rotary fixture.

Figure 5.
Tabular presentation of measurements after completion of scans on 5-points on the perimeter of a windshield



Result

Scan #	Max Tension (MPa)	Max Compression (Mpa)
1	440.2516	-22.2454
2	490.5660	-12.1486
3	498.9518	-32.5228
4	440.2516	-5.1800
5	492.6625	-32.5179

Save   Exit

Software

In developing this new system, particular attention was devoted to obtain valid edge-stress measurements. In automotive glass, the depth d of the finish is not standardized and in industrial practice, it ranges from 0.5 to 2 mm. Considering the steep stress gradient near the edge, illustrated in figure 3 above, the results are meaningless unless the location of the edge is defined. The ASTM method C1279 specifies a linear extrapolation based on measurements obtained at x_1 and x_2. In industry, it is a common practice to measure at the end of ground finish. Figure 7 below shows experimental results obtained using PES, illustrating the data-cropping and selection of extrapolation region.

The newly developed software permits:

- implementation of ASTM linear extrapolation.
- measuring at point P.
- implementation of an algorithm, Stress = Stress (P) + Constant

The software is editable along the users choice of parameters and extrapolation methods that are in agreement with his requirements.

Summary

A new, portable edge measuring system was developed. The system is PC-based, fully-automated, permitting operator independent data acquisition, yielding accurate edge-compression and near-edge tensile average measurements.

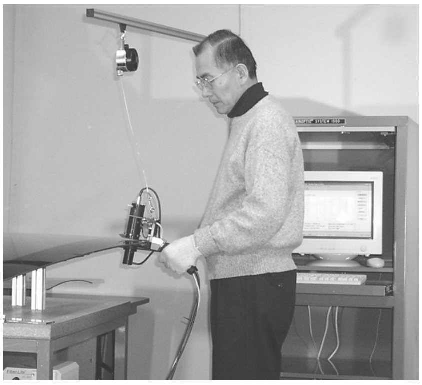


Figure 6.
PES-100 PC-based portable edge scanner

References

[1] Gulati, S.T., et al., "Delayed Cracking in Automotive Windshields," Materials Science Forum Vols. 210-213, Transtec Publications, pp. 415-424, Switzerland, 1966.

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[3] ASTM C1279, "Standard Test Method for Non-Destructive Photoelastic Measurement of Edge and Surface Stresses in Annealed, Heat-Strengthened and Fully Tempered Flat Glass," ASTM, Conshohocken, PA, 2000.

[4] Redner, A.S., "Photoelastic Measurements by Means of Computer-Assisted Spectral contents Analysis," Experimental Mechanics 25(2), pp. 148-153, June 1985.

Figure 7.
PES-100 graph