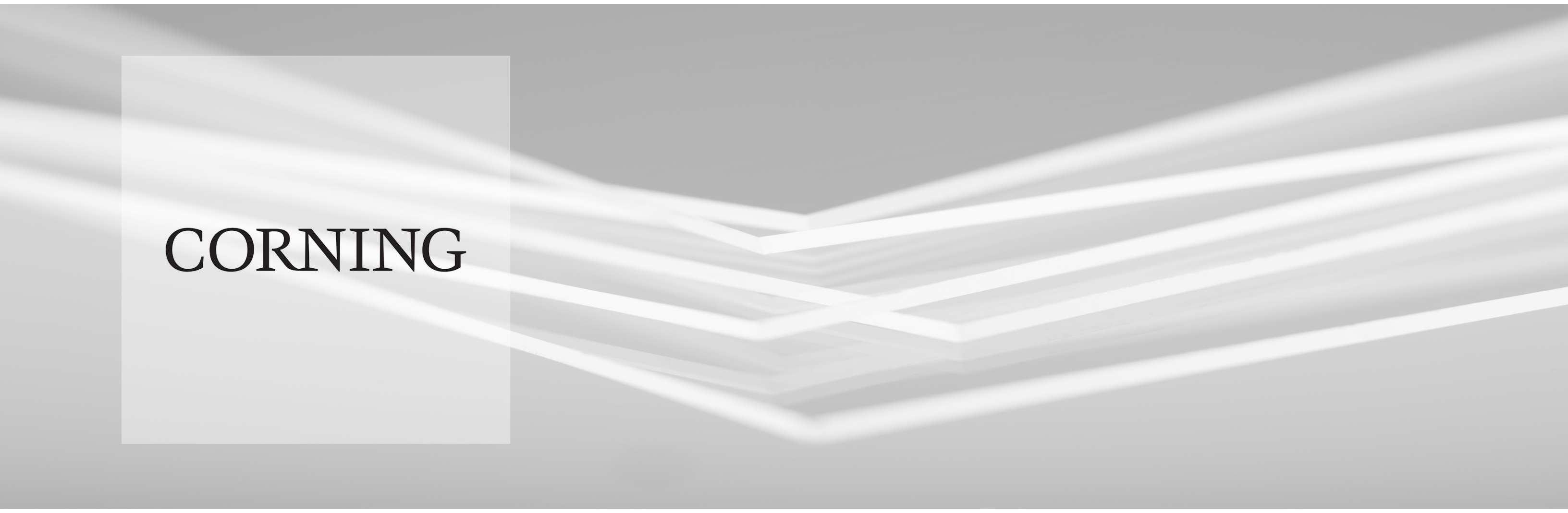
Improved Methodology for Testing Edge Strength for Ultra Thin Panels



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Abstract

Traditional testing methodologies (four point bend and three point bend) have limited effectiveness as panel thicknesses decrease due to a variety of interconnected factors. This limited effectiveness impacts the ability to make reliability predictions based on edge strength measurements. This paper provides an improved methodology for testing the edge strength of ultra-thin panels for reliability predictions through a system of rollers strategically placed only at the edge of the glass panel.

1. Introduction

New opportunities for glass display panels exist in a number of fields that require demonstration of high mechanical reliability, such as auto interior displays for infotainment units. However, the traditional testing that is done on glass panels breaks down when it used on ultra-thin panels (<0.3 mm), and the results must be used for reliability predictions. This study examines the breakdown of the traditional testing methods, and presents an improved edge strength testing methodology for these panels.

2. Traditional Testing Breakdowns

Traditional four point flexure testing of glass is detailed in ASTM C158 [1]. This testing methodology was developed for thicker glass plates, but was modified to ASTM C1161-13 for thinner glass [2], although it has been successfully modified to be used for thinner glass plate as well. It has also been used to evaluate the edge strength of display panels, with a high amount of success. For traditional ASTM four point flexure testing, the failure stress is given by

$$\sigma_f = \frac{3P(L-a)}{2bt^2} \quad (1)$$

where P is the applied force, L is the outer support span length, a is the inner loading span length, b is the width and t is the glass thickness. However, the ASTM standard breaks down significantly for testing large portions of the edge for ultra-thin glass plates and displays (<0.3 mm total thickness). There are a significant amount of factors that affect the accuracy, and these factors are often interconnected. A critical assumption in using the equations in the ASTM standard is that the deflection is small compared to the thickness, with the generally assumed rule of a maximum where P is the applied force, L is the outer support span length, a is the inner loading span length, b is the width and t is the glass thickness. deflection of 0.5t being allowed. This is to reduce effects from contact point tangency shifts (slip) and friction. To reduce deflection, the loading and support spans can be reduced. However, when the spans are decreased, new problems arise, such as contact stresses. US Army Laboratory Report MTL TR 87-35 details the percent error associated with minor deviations from the ASTM standard [3]. However, tablet sized display panels deviate even more significantly from the ASTM standard, and are not easily predicted from either the ASTM standard or the MTL TR adjustments.

This study evaluated the deviations for specific loading and support spans, with two different rod diameters for a 0.2 mm thick sheet of glass. The strain is measured directly through strain gauges placed in the middle of the loading span in the center of the sheet and near the edge. Figure 1a shows that the stress initially agrees well with the ASTM standard, however, very limited amounts of stress are able to be generated despite deflection of approximately 50 mm (maximum allowable in the specific four point bend fixture) for large spans. When the spans are reduced (Figure 1b), stress is generated more quickly, but it starts to deviate from the ASTM prediction due to contact point tangency shift. The stress starts to increase more quickly than the ASTM prediction at approximately 50 MPa. To reduce the noticed slip, one would decrease the loading and support spans. However, doing so would cause crushing of the glass, as the rods would overlap. This problem can be solved by reducing the rod diameter, as seen in Figure 1c. However, we are still not able to generate sufficient stress for typical edge strengths of 80-250 MPa (dependent on edge finishing treatement). We can try to again move the support and loading rods closer, but run into new non-linearities. These non-linearities are likely in part due to the strain gauge size relative to the stressed area and in part due slip and friction.

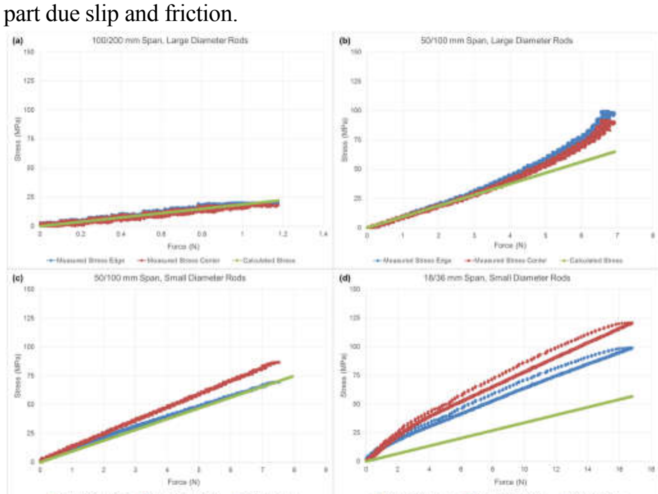

Figure 1. Stress vs force for a variety of given configurations: a) large rods, 100/200 mm test span, b) large rods, 50/100 mm test span, c) small rods, 50/100 mm test span, d) small rods, 18/36 mm test span. Al show an inability to generate sufficient stress before a 50 mm deflection.

Another factor that must be considered during testing of ultra-thin glass panels is sub-critical crack growth, or fatigue. Fatigue is the stable crack growth of silica based materials in the presence of humidity under an applied stress (static or cyclic). Fatigue happens during traditional ASTM standard testing, which is why traditional testing is typically recommended to be a consistent test time, so comparisons between configurations can made. It has been generally shown that typical strength reductions during short (<10 s) test times is approximately 30%. Because fatigue is a time dependent phenomena, there will be a loading rate dependency, with longer test times causing more complications with using strength measurements for reliability predictions.

To reduce both the large deflection and the long test times, spans need to be placed exceedingly close. However, doing so reduces the effective area tested. This has two implications for reliability predictions. The first is that the test methodology will test the center of a glass panel and assumes that the defects are consistent on the entire panel, which is not always a good assumption due to process changes near the start and end of the glass panel. A second consideration is that an area correction factor must be applied to estimate the reliability of the entire edge when only a small fraction is tested, as shown below"

$$F(\sigma_f) = 1 - \exp\Big[-\frac{A}{A_0}\Big(\frac{\sigma}{\sigma_0} \tag{2}$$

where F is the failure probability, A is the area of the object of reliability concern, A_0 is the measured area, σ is the measured strength and σ_0 and m are Weibull fit parameters used to predict reliability. When the test area is small compared to the designed stressed area, many more panels must be tested to generate accurate reliability predictions, as shown in Figure 2. The plot shows measured strength data on a small test area, as for an optimized four point flexure test for ultra-thin panels. The bold line shows the reliability curve for the full panel edge length (assuming a 5:1 test area to panel edge length ratio). As can be seen, the unreliability is higher for the same stress, requiring more data for accurate predictions in the desired reliability range. A test methodology that minimizes deflection, reduces test time and tests a large area are highly desired for reliability predictions.

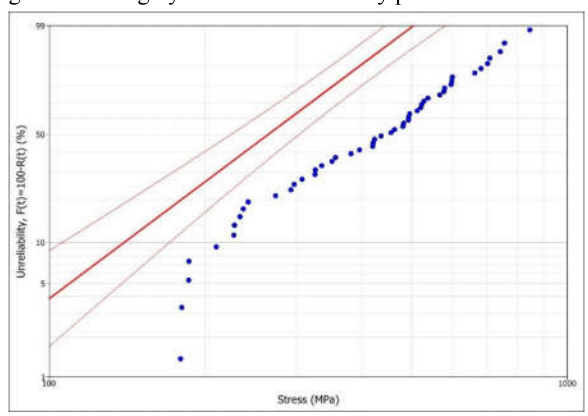

Figure 2. Weibull plot for a simulated measured data set (blue dots) with Weibull prediction curve after an area correction factor (red line). Lighter red lines indicate reliability bounds for the Weibull prediction.

3. Improved Edge Strength Methodology - Edge Strength Measurement System (ESMS)

As previously mentioned, four point bending, which is the current paradigm for measuring ultra-thin monolithic glass sheets and/or panel type geometries, suffers from several shortcomings. From a fundamental standpoint, non-linearity in the stress vs. force/ displacement relationship stemming from geometrical constraints make the acquisition of data within the required stress range difficult or nearly impossible. From a more practical perspective, each sample measurement provides a singe data point, because the panel breaks in such a way to prevent further testing. Because of this, compiling a statistically significant body of quality data can be a resource intensive activity, while simultaneously consuming an undesirable amount of potentially sellable product.

Here we presents newly developed alternative methodology that helps alleviate many of these concerns.

Conceptually, the ESMS is an out of plane horizontal bending test that relies on urethane coated ball bearing assemblies to impart stress to the localized area at the panel/glass edge, as opposed to the loading beams using in classical three or four point bending methods. Two assemblies are typically used for testing, where one imparts tensile stress to the top (or A side) edge and the other imparts the same stress to the bottom (or B side) edge. The upper roller fixtures are attached to linear stages with high resolution absolute encoders for precise control of position, whereas the bottom rollers are driven by pneumatic cylinders to the precise position of the down-facing (B side) glass surface. Figures 3a-c show the ESMS roller platform design concept with components labeled accordingly.

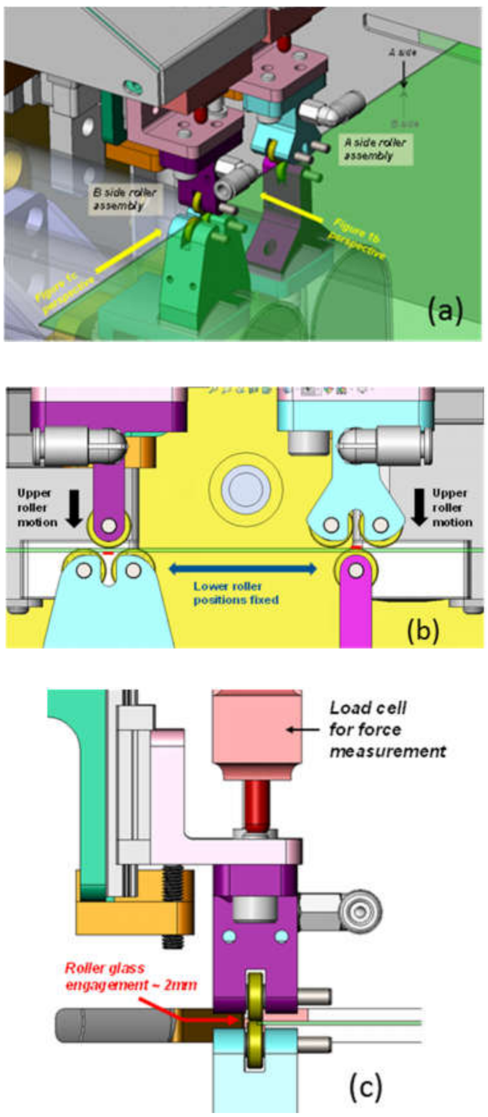

Figure 3. (a) Isometric depiction of the ESMS roller heads engaged with a sheet of glass. A side and B sides are labeled accordingly with visual aid markers for parts b and c. (b) Rollers engaged with the glass from normal perspective. Roller motion profiles and positions are indicated. Red lines indicate regions of tensile stress application. (c) Tangential view of roller engagement. The out-most 2mm of the edge are engaged with the roller surfaces.

The ESMS can be operated using two separate modes. "Static" mode involves moving the roller assemblies to a specified region of the edge and displacing the upper rollers into the glass until one side fails. This mode includes suspensions, as the side that did not fail is included as a "pass" in the statistical analysis of the whole data set. The system detects the crack based on a proprietary signal filtering algorithm and the rollers retract and move to a new region of the edge to repeat the test. In "dynamic" mode, the rollers are driven along the entire length of the edge under a specified applied force, while recording the average applied stress and whether or not the glass broke over programmed increments. By measuring several sheets in order of increasing (or decreasing) stress, a strength distribution can be derived. The resulting method(s) are effectually hybrid types of proof testing that provide high throughput quantitative strength information for increased quality control as well as near-immediate finishing process feedback, while avoiding any adverse effects in turnaround time. Finite Element Modeling (FEM) using the Ansys® simulation software package has been used to demonstrate how ESMS technology can overcome some of the fundamental limitations seen for more classical bending approaches during application to ultrathin panel glass. Because of the highly localized force application inherent to ESMS geometry, high levels of stress can be achieved for low levels of glass and/or roller displacement, thereby eliminating any of the aforementioned non-linear effects seen for 3 or 4 point bending. The results of FE simulations for 0.1mm x 0.1mm glass (Corning EAGLE XG®) stacks with a thin, low modulus intermediate layer meant to simulate a liquid crystal structure effectively demonstrate these advantages (Figures 4a-c).

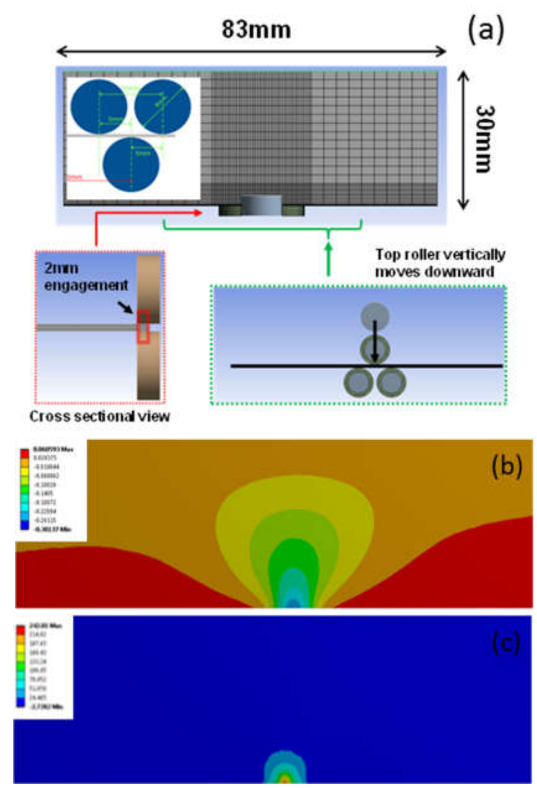

Figure 4. (a) Geometry used for FEM analysis. Compliant (durometer ~ 70 shore) polyurethane compound. Diagram showing roller dimensions is flipped relative to other drawings. (b) Panel displacement of the surrounding measurement region (~-30µm displacement in immediate tensile zone). (b)Stress field corresponding to displacement in 2b (maximum stress ~ 240MPa).

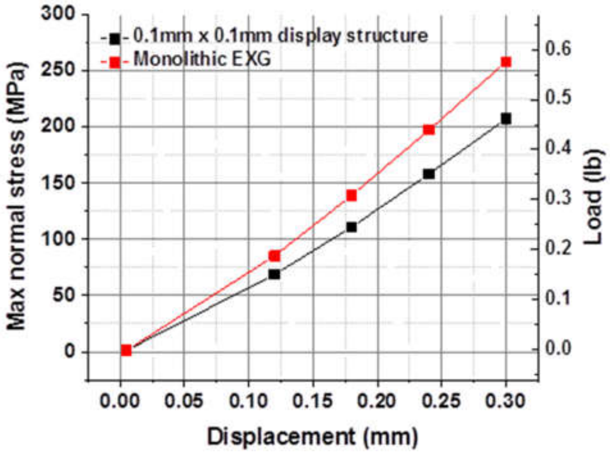

Figure 5. Stress and force vs. displacement curves for ESMS measurement simulations using FEM.

4. Summary

Traditional edge strength testing methodology breaks down for ultra-thin glass panels, particularly when this data is being used to demonstrate reliability for a particular application. While four point flexure tests can be adapted to minimize effects such as slip, friction and sub-critical crack growth, it can create additional issues such as contact stresses. Further, the testing modification requires that the loading span is very small, which causes concerns for reliability predictions due to potential non-uniformity of defects along the entire edge, and a size scaling factor. The ESMS system avoids those major pitfalls by allowing for a very small test span that can be applied to almost the entirety of the edge. This provides a significant benefit to make accurate reliability predictions needed for new display applications, such as auto interiors.

5. References

[1] C158-17. Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature. ASTM International, 2017.

[2] C1161-13. Standard Test Methods for Strength of Glass by Flexure (Determination of Modulus of Rupture). ASTM International, 2013.

[3] F. Baratta, W. Matthews, G. Quinn. Errors Associated with Flexure Testing of Brittle Materials. Army Materials Laboratory Report MTL TR 87-35, 1987.

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