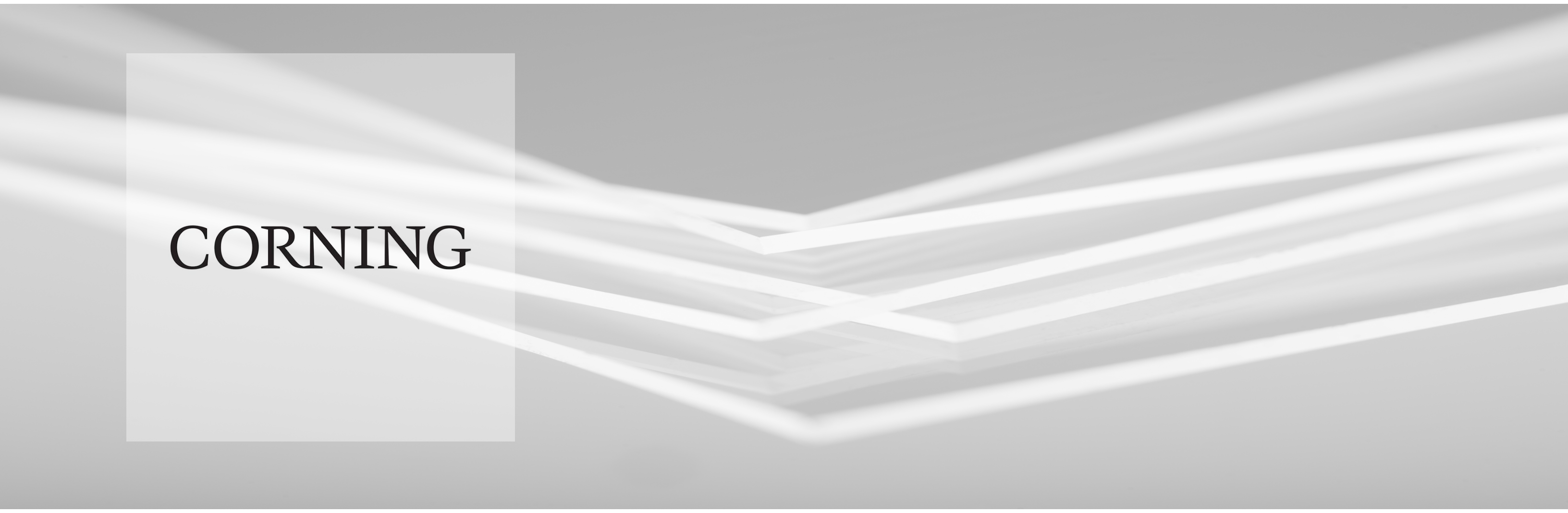
Strength Measurements of Thin AMLCD Panels



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Jamie T. Westbrook, John F. Bayne, Tim A. Roe, Jum S. Kim, Po-Hua Su*, Toshihiko Ono, and Suresh T. Gulati*****
Corning Incorporated, Corning, NY, USA

***Corning Display Technologies, Taiwan, Taichung, Taiwan R. O. C.**
****Corning Technology Center, Kakegawa, Shizuoka, Japan**
***** Research Fellow and Consultant**

Abstract
The biaxial strength using ring-on-ring (ROR) test and uniaxial strength using 4-point bend test (4PB) were measured for 13.3" panels with substrate thicknesses ranging from 0.25 mm to 0.5 mm. The effect of thinning process was quantified by these data along with identifying break sources using fractography. Strain gages were used to convert failure load to strength.

1. Objective and Background
Current trends in manufacturing AMLCD panels call for using thin substrates to minimize their weight. Such thinning may be accomplished either chemically or mechanically. The key objective of this paper is to characterize such panels with respect to their mechanical durability as follows:

i) measure surface strength using ROR test,
ii) measure edge strength using 4PB test,
iii) carry out break source analysis, and
iv) decipher bending vs. membrane stresses using strain gages.

2. Results
a) Ring on Ring Test

The popularity of this test, on samples which experience small deflections, stems from the facts that:

i) it stresses the panel surface in two directions simultaneously thereby sensitizing all flaws regardless of their orientation,
ii) it applies uniform biaxial stress in the region enclosed by the load ring,
iii) it minimizes failure initiation from the edges.

The panels measured 19 cm wide and 29.5 cm long. The TFT and CF thicknesses ranged from 0.25 mm/0.25 mm to 0.5 mm/0.5 mm. In view of low thicknesses and to minimize center deflection, we used 50.8 mm diameter load ring and 88.9 mm support ring with an overhang ranging from 30 mm to 100 mm. This choice of rings minimized buckling and eliminated failure initiation from the edges.

However, the high strength of relatively flaw-free surfaces resulted in large center deflection and introduced membrane esses in both radial and circumferential direction, notably in the region between load and support rings, thereby necessitating the use of strain gages on both the tension side (surface 4) and compression side (surface 1) as shown in Figure 1. Denoting the strains on these surfaces by ε1 and ε4, the biaxial stresses on these surfaces are given by:

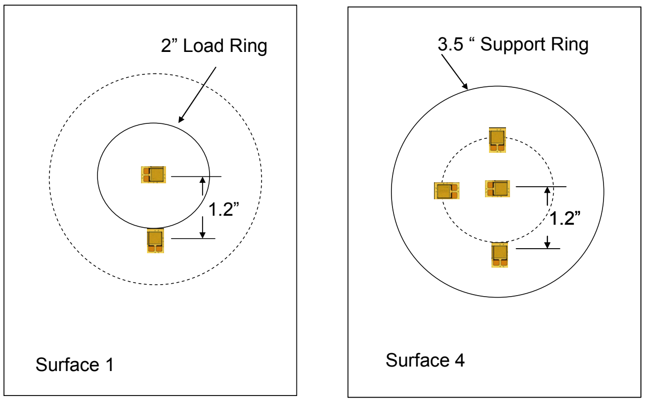

Figure 1. Strain gage locations for ROR test.

$$\sigma_{s1} = [E/(1-\nu)]\ \varepsilon_{s1} \qquad (1) \qquad \text{and}$$

$$\sigma_{s4} = [E/(1-\nu)]\ \varepsilon_{s4} \qquad (2)$$

where E and ν denote Young’s modulus and Poisson’s ratio of panel glass with values of 68.9 GPa and 0.23 respectively. However, the above stresses include both bending and membrane components, σ_b and σ_m, given by

$$\sigma_{s1} = \sigma_m - \sigma_b \qquad (3)$$

$$\sigma_{\sigma4} = \sigma_\mu + \sigma_\beta \qquad (4)$$

from which we obtain

$$\sigma_\beta = 0.5\ (\sigma_{\sigma4} - \sigma_{\sigma1}) \qquad (5)$$

$$\sigma_\mu = 0.5\ (\sigma_{\sigma4} + \sigma_{\sigma1}) \qquad (6)$$

The stresses given by eqns. 1 and 2 are those at the surface of strain gages. Since the latter have a finite thickness t_g which can not be neglected relative to panel thickness t, the true stress at the surfaces of glass panels are given by:

$$\sigma_{\sigma1} = [E/(1-\nu)]\ \{0.5\tau / (0.5\tau + \tau\gamma)\}\ \varepsilon_{\sigma4} \qquad (7)$$

$$\sigma_{\sigma4} = [E/(1-\nu)]\ \{0.5\tau / (0.5\tau + \tau\gamma)\}\ \varepsilon_{\sigma1} \qquad (8)$$

Figure 2 shows a plot of flexural/bending, membrane, and total stress inside the load ring on tensile surface 4 as function of failure load for 0.25 mm/0.25 mm panel. The stress based on linear theory [1] is also shown for comparison purposes. It is clear that:

i) linear theory overestimates the failure stress by orders of magnitude and hence is not applicable for thin panels,
ii) membrane stress is nearly as large as total stress implying that flexural/bending stress within the load ring region is negligible, and
iii) total stress inside the load ring is not the highest stress in the panel.

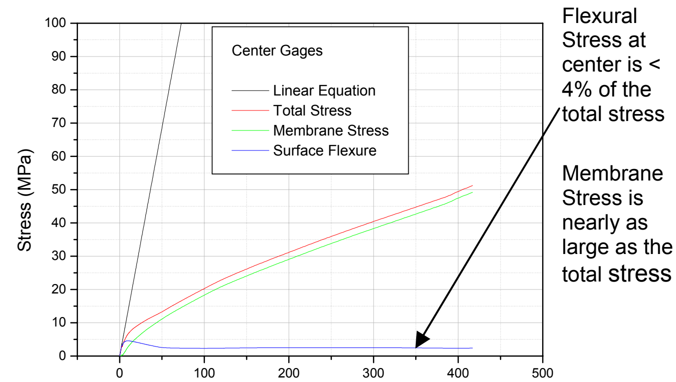

Figure 2. Flexural/bending, membrane, and total stress vs. applied load in ROR test: Comparison with linear theory.

The highest stress in thin panels occurs at much higher loads and just underneath the load ring as shown in Figure 3 for 0.5 mm/0.5 mm panel. Again, the stress at center of this panel is negligible compared to that underneath the load ring where flexural/bending stress has its maximum value. In short, stresses in thin panels are dominated by the membrane component both inside the load ring and between the load/support rings with high flexural/ bending stresses occurring under the load ring. Both the failure pattern and fracture origin for this panel are shown in Figure 4. The mist hackle on either side of fracture origin (wedge shape) shown in Figure 5 is indicative of panel bending over the load ring. The median ROR strength, based on measured values of mirror radii, is summarized in Table 1. The data in Table 1 show that, within the large scatter of strength values (low Weibull slope), polishing does not affect surface strength. Secondly, majority of the failures occur on surface 4 due to scratches, deep checks, fused glass, chatter checks and other types of contact damage.

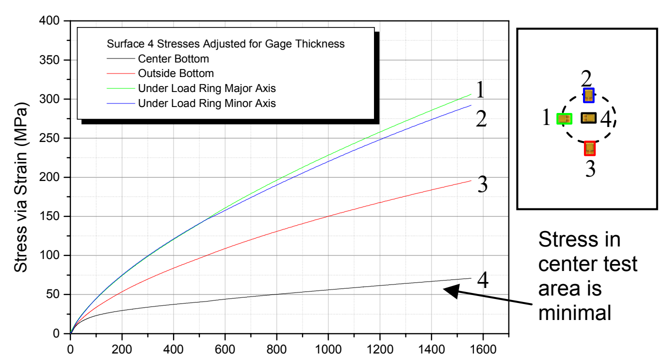

Figure 3. Strain gage based stresses vs. applied load in ROR test.

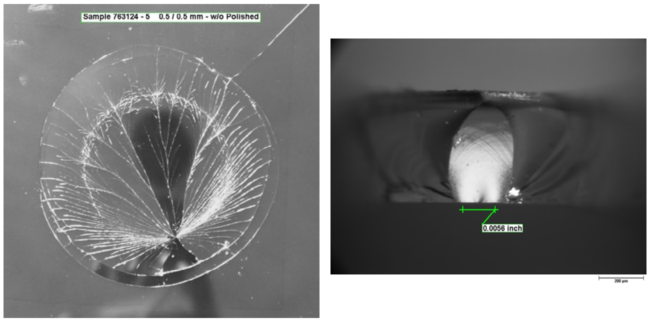

Figure 4. Failure pattern and fracture origin for 0.5 mm/0.5 mm panel.

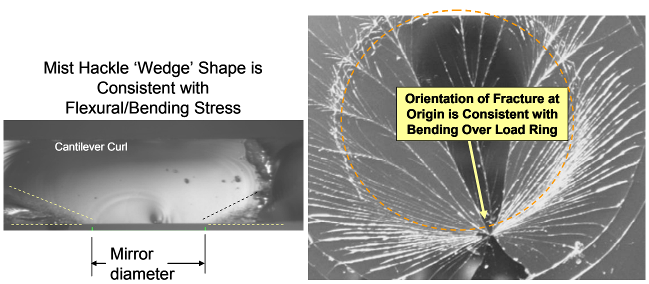

Figure 5. Failure pattern indicating panel bending over load ring.

Table 1. Summary of Median ROR Strength of Thin Panels

Thickness (mm)	N	Surface Finish	Median RoR Strength (MPa)	Weibull Slope (m)	Failure Surface
0.25/0.25	5	polished	208	3.0	1, 3, 4
0.25/0.25	5	not polished	132	6.4	4
0.3/0.3	6	polished	208	1.9	3, 4
0.3/0.3	6	not polished	178	3.3	4
0.5/0.5	5	not polished	193	2.5	4

b) 4-Point Bend Test

The 4-point bend test is a uniaxial test that stresses both the surface and edges of the panel. The failures, generally speaking, occur at the edges due to more severe flaws introduced during scoring and finishing, than those on thinned surfaces. It is therefore a good test for quantifying the strength of edges. Of course, fractography plays an important role in confirming the location of fracture origins and their analysis. Keeping in mind the size of thinned panels, we chose to use a support span of 254 mm and load span of 127 mm with short side of the panel as width of 4-point bend specimen. A schematic of this test is shown in Figure 6.

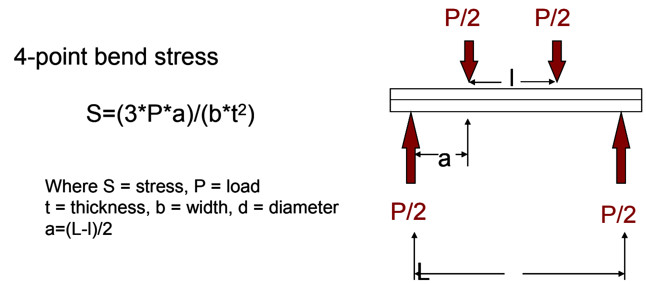

Figure 6. Schematic of four point bend test.

The failure stress σ_{4PB} is calculated from load P, specimen dimensions and moment arm a using eqn. 9 [2]:

$$\sigma_{4PB} = 3\,P\,a\,/\,(bt^2) \qquad (9)$$

where b and t denote width and thickness of panel respectively. We assumed panel thickness to be the sum of TFT and CF panels which would yield conservative strength values since both TFT and CF are not bonded rigidly. The moment arm a was 63.5 mm and panel width was 190 mm. The strength values for panels with different thicknesses are plotted in Figure 7 and ranged from 55 MPa to 78 MPa, lower value representing the edge strength of 0.5 mm/0.5 mm panel with no special edge finish.

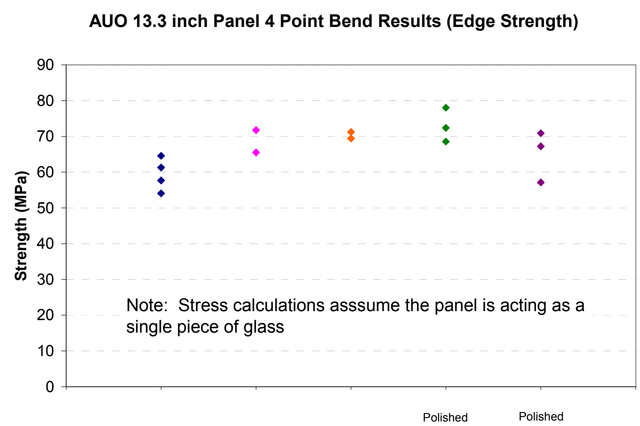

Figure 7. Four point bend strength data vs. panel thickness.

The failure origins were located on surface 4 (TFT side) and immediately below the loading bars. The typical fracture origins, shown in Figure 8, occur on the corner of the edges and are generally associated with the chamfering process.

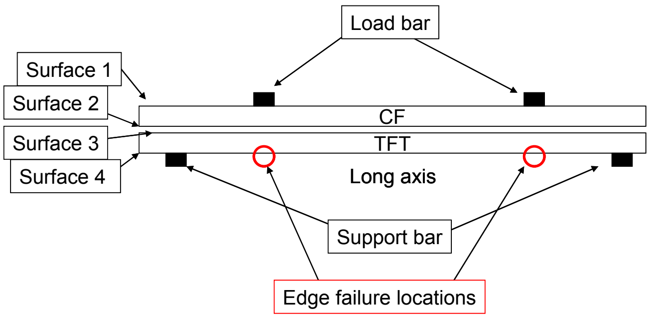

Figure 8. Schematic of failure origins in 4-point bend test during large deflection.

The mirror radius R_m, measured from these origins, was used to estimate failure stress using the well known equation [3]

$$\sigma_{4PB} = A / R_m^{0.5} \tag{10}$$

in which A is the mirror constant for glass with a value of 65 MPa $mm^{0.5}$. Figure 9 shows a Weibull plot of edge strength of panels, based on mirror radius, with different thicknesses. The mean strength of 0.25 mm/0.25 mm panel edge was 101 MPa, that of 0.3 mm/0.3 mm panel edge was 131 MPa and that of 0.5 mm/0.5 mm panel edge was 78 MPa. These values reflect the finish and quality of edges of these panels. Flaw types ranged from chips to scratches to contact damage. Failure stress based on eqn. 9 ranged from 44 MPa for 0.5 mm/0.5 mm panel to 113 MPa for 0.3 mm/0.3 mm panel and was lower than that given by mirror radius indicating that the effective thickness of panel is less than the sum of CF and TFT thicknesses. It is worth noting that the two lowest strength failures originated at surface flaws (not edge) indicating that surface damage also influences 4-point bend strength.

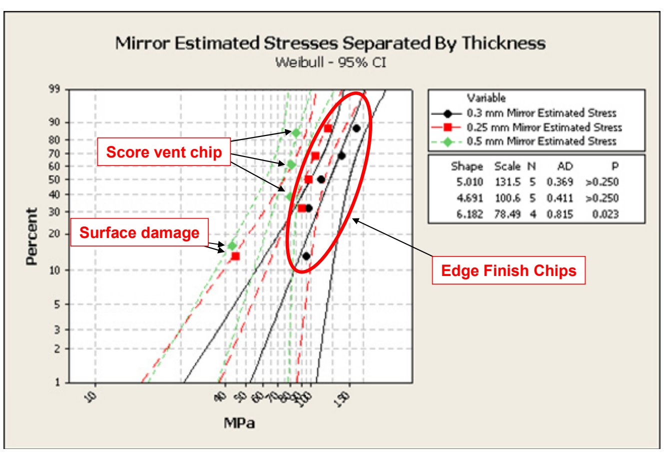

Figure 9. Weibull plot of edge strength of panels of different thicknesses based on mirror radius.

It is conjectured that location of failure origins immediately below the loading bar is indicative of high local stress as the panel bends around the loading bar.

3. Impact

The acid thinning process removes handling damage on surfaces 1 and 4 and can improve strength. It is critical to either protect them, or handle them, carefully immediately following the acid thinning process through and including the polarizer film application process to retain this newly acquired strength. This study indicates that panel strength, including that of its edges, can be measured using different tests. In view of large deformation during bending of thin panels, it is imperative to either use strain gages or resort to nonlinear theory for converting failure load to panel strength. This study also points out the importance of fractology for identifying and characterizing fracture origins. Such a study helps understand damage sources and modify post processing to minimize the deleterious effect of contact damage.

Surface strength of thinned panels can be as high as 200 MPa compared with 100 MPa for their edges. Hence, further improvement in edge quality and strength is possible by paying close attention to the scoring and finishing process [4].

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4. References

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