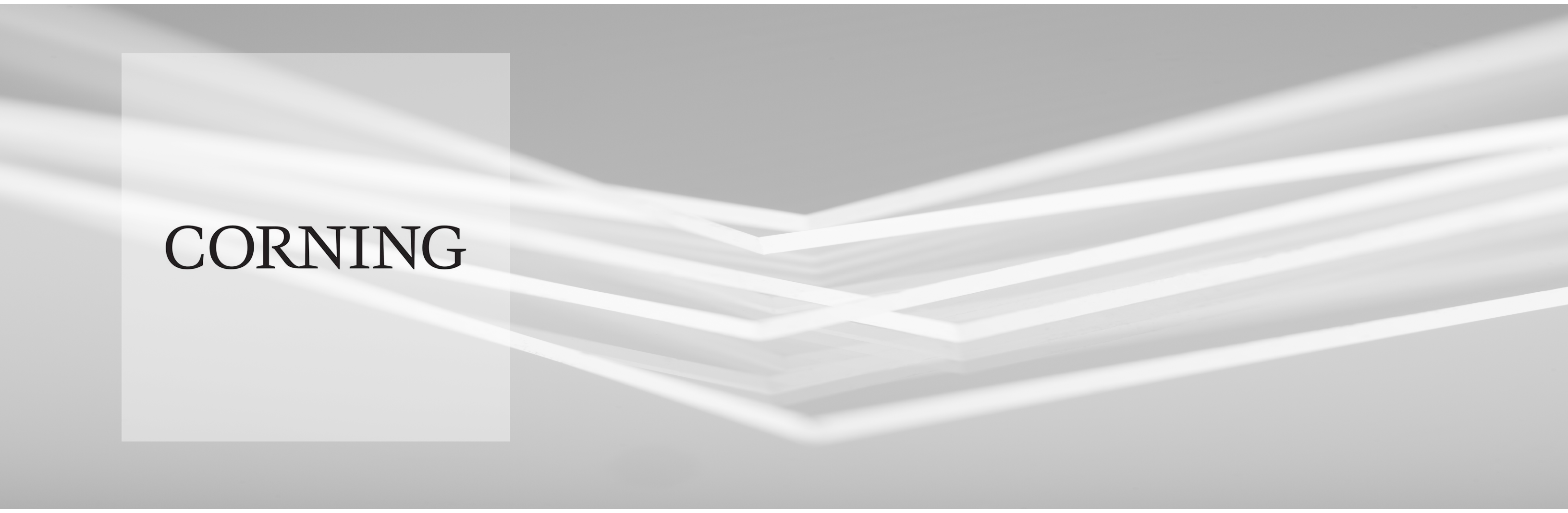
Edge Strength Measurement of Ultra-Thin LCD Panels



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Abstract

The feasibility of using Corning's edge strength measurement system (ESMS) for ultra-thin LCD panels has been demonstrated. Panels were used to validate the load-to-stress correlation: digital image correlation, finite element analysis and mirror radius measurement all showed good agreement, supporting the robustness of the strength measurement. The edge strength of panels was measured by both static and dynamic ESMS. Test results revealed that dynamic ESMS is advantaged over static in better capturing the relevant flaw population owing to its larger test area. Accurate edge strength measurement via ESMS coupled with selective fracture analysis on the weakest flaws will assist in improving the edge strength of ultra-thin LCD panels.

1. Introduction

Display panels with a fixed bending curvature can provide an ergonomic user experience to the car interior design. Owing to its low cost, brightness and low energy consumption [1], liquid crystal displays (LCDs) will play a key role in this space. However, such displays may have higher reliability challenges than their flat counterparts dye ti the in-built bend stress. Such requirements include being robust under season temperature cycling, having minimal light leakage [2], having no mechanical failures [3], etc. Among the many requirements, mechanical failure of glass is one of the key areas of concern since the panel must survive a constant tensile stress which induces sub-critical crack growth, also known as fatigue, over a lifetime of years at very low failure rates. Designing and manufacturing such panels with high mechanical reliability is challenging and could require a combination of proof/strength test and process control [4].

Typically, the most severe flaws on a panel are introduced at the edge during the singulation process. These are the flaws that are most likely to lead to delayed failure due to fatigue. Therefore, to predict the bending capability, one must assess the edge strength of the panel. However, testing ultra-thin glass/panels under 0.3 mm becomes difficult with conventional test methods due to large deflections and delamination [5, 6]. Last year, we introduced the edge strength measurement system (ESMS) as a potential tool for ultra-thin glass/panel edge strength measurement [5]. The main advantage of ESMS over conventional tests is a controlled stress field that can be applied to the entire edge. In this paper, ultra-thin panels were tested on the ESMS to demonstrate its feasibility. Results showed that the panel strength can be accurately measured in a predictable and repeatable way.

2. Edge Strength Measurement System

The ESMS is an out of plane horizontal bending test that relies on urethane coated ball bearing roller assemblies to impart stress to the localized area at the panel/glass edge, as opposed to the loading beams used in classical three or four-point bending methods [5]. Figure 1 shows a schematic of the ESMS rollers engaged to a sample's edge and it's two modes of testing: Static and dynamic. Static testing refers to engaging the ESMS rollers at a fixed location on the panel edge and applying increasing load until failure. Several locations on the edge are tested, while the failure load, thickness and off-apex failure locations are measured to calculate the failure stress. Dynamic testing refers to having the rollers apply a constant load, but rolling them across the entire edge at the same time. If the sample survives the applied load/stress, a higher stress is applied until a break occurs (stepped-stress testing). If there are testable edges remaining, the test is continued. The number of breaks at each step stress is counted to calculate the probability of failure.

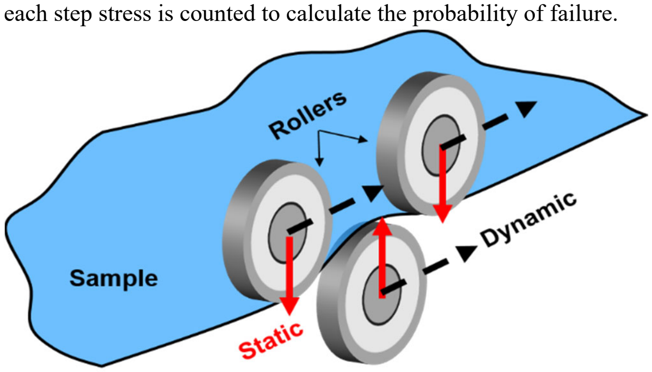


Figure 1. Schematic of the ESMS rollers engaged to a sample's edge and it's two modes of testing: Static and dynamic.

The ESMS has a non-constant stress field over its test area since it has a roller configuration similar to a three-point bend test. Therefore, to apply Weibull statistics whose derivation is based on a constant stress field [7], it utilizes a custom statistical approach that allows for better predictions down to low failure rates from smaller number of failures even with non-constant stress fields. After a strength distribution is obtained, one may do area-correction to the strength distribution according to the equation below:

$$\frac{\sigma_1}{\sigma_2} = \left(\frac{L_2}{L_1}\right)^{1/m}$$

Here, σ is the edge strength, L is the test area/length, m is the Weibull modulus and subscripts 1 and 2 represent tests with two different test areas/lengths. In this way, the small tested area can be extrapolated to discuss the reliability of a larger area, like the panel edge length.

3. Panel Samples

Two batches of ultra-thin panels with the same design but separated using different score wheels were tested. All panels consisted of a laminated CF and TFT glass without polarizers. It was assumed that the panel's failure behaves similar to a monolithic glass as a well-bonded panel [8].

4. Load-To-Stress Correlation

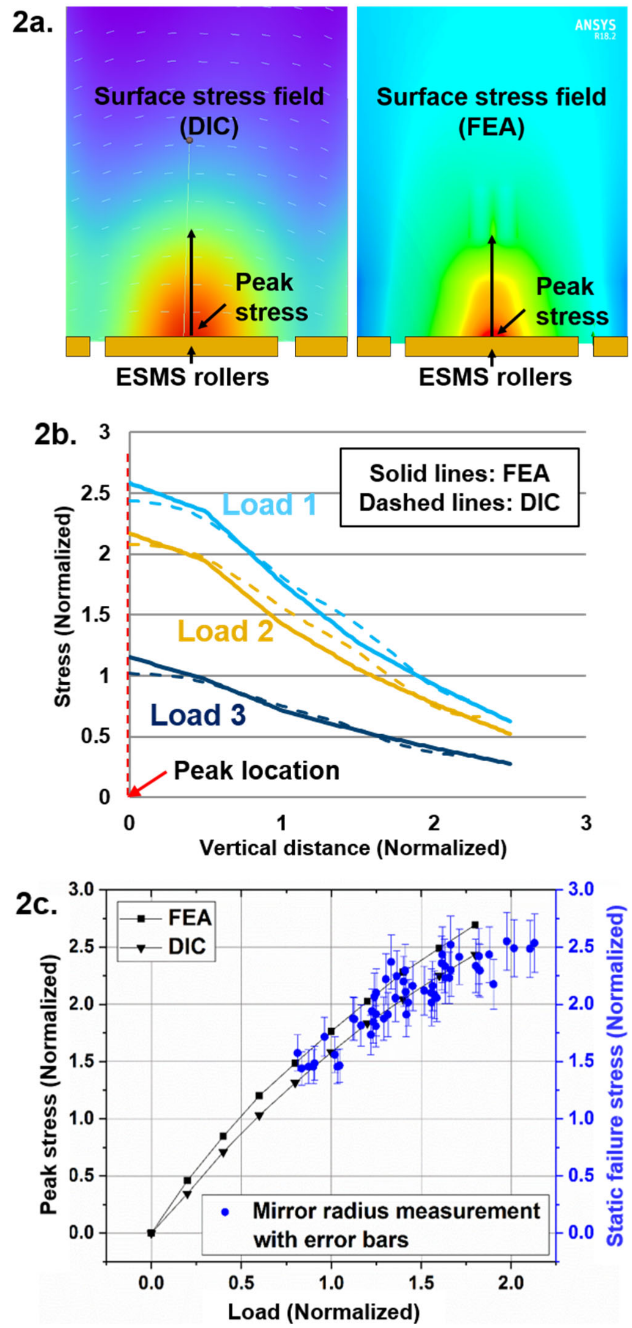


Figure 2. (a) Maximum principle stress distribution on the panel's top surface measured by DIC (left) and FEA (right) at a given load, (b) maximum principal stress along the vertical line (shown in Figure 2a) from the loading point obtained from DIC and FEA at various loads and (c) the load-to-peak stress correlation obtained from DIC, FEA and mirror radius measurement at the loading point on the sample edge.

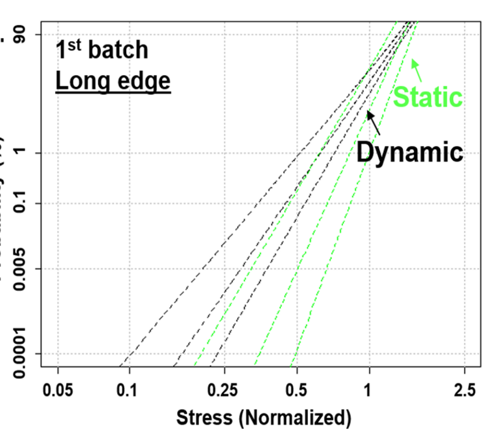
To obtain the failure stress from the measured load, the load-to-stress correlation was determined by three methods: Digital image correlation (DIC), Finite element analysis (FEA) and Mirror radius measurement. DIC is a full field optical measurements technique that measures surface deformations thereby strains, by tracking the random speckles coated on the specimen surface. Stresses under plain stress condition are evaluated from the measured strain fields using the elastic properties of the glass. FEA modeling was done using the panel design parameters and compared with DIC results. Both DIC and FEA was done on a static ESMS setup with the assumption that the load-to-stress correlation in dynamic condition is the same as that in static condition. Mirror radius measurements [9] were performed on panels tested on static ESMS to obtain the estimated failure stress, which was then used to further validate the load-to-stress correlation.

Figure 2a shows the maximum principal stress distribution on the panel's top surface (tension side) measured by DIC (left) and calculated by FEA (right) at a given load. Figure 2b shows the comparison of max. principal stress along the vertical line (shown in Figure 2a) from the loading point obtained from DIC and FEA at various loads. DIC and FEA results show good agreement within ±10%. The peak stress is experienced at the loading point on the edge and thereafter it decreases as it gets farther away from the edge. The load-to-peak stress correlation obtained from DIC, FEA and mirror radius measurement at the loading point on the sample edge is shown in Figure 2c. Results obtained from all three methods showed good agreement, where the failure load was clearly correlated to the estimated failure stress from the mirror radius measurement. The noise in the mirror measurement data is easily explained by the precision of mirror stress measurements (approx. 20%) and variation in edge quality of the panel samples.

5. Panel Test Results

Figure 3 shows the Weibull slopes with 90% confidence intervals of the two panel batches tested on static and dynamic ESMS – Figures 3a and 3b show the results for the 1st and 2nd batches, respectively. The long edge was tested and used as the area correction factor assuming the panel would be bent along the long edge. Twenty and thirty panels respectively were tested on the static and dynamic tests. For static ESMS, 4 locations along the long edge were tested, which equated to a test area of approximately 4 mm. For dynamic ESMS, 170 mm of the long edge was tested. Thus, the difference in test areas between static and dynamic ESMS at a given edge was 1:42. For both batches, dynamic test results had a lower Weibull slope than static, implying that it captured a greater fraction of the weaker flaw populations, which are important to reliability predictions. For both static and dynamic tests, the 1st batch had a higher strength than the 2nd batch.

3a.



3b.

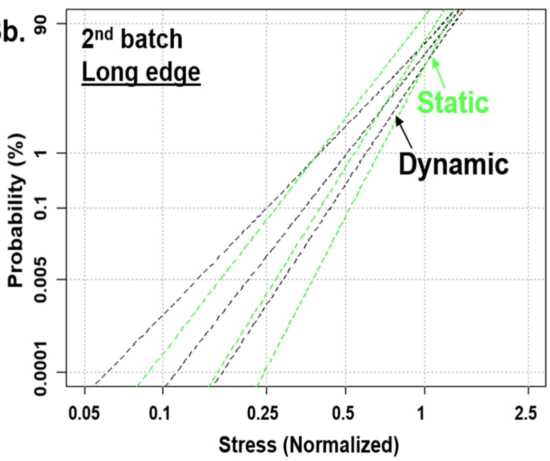


Figure 3. Weibull plots of the two panel batches tested on static and dynamic ESMS: (a) 1st batch (b) 2nd batch.

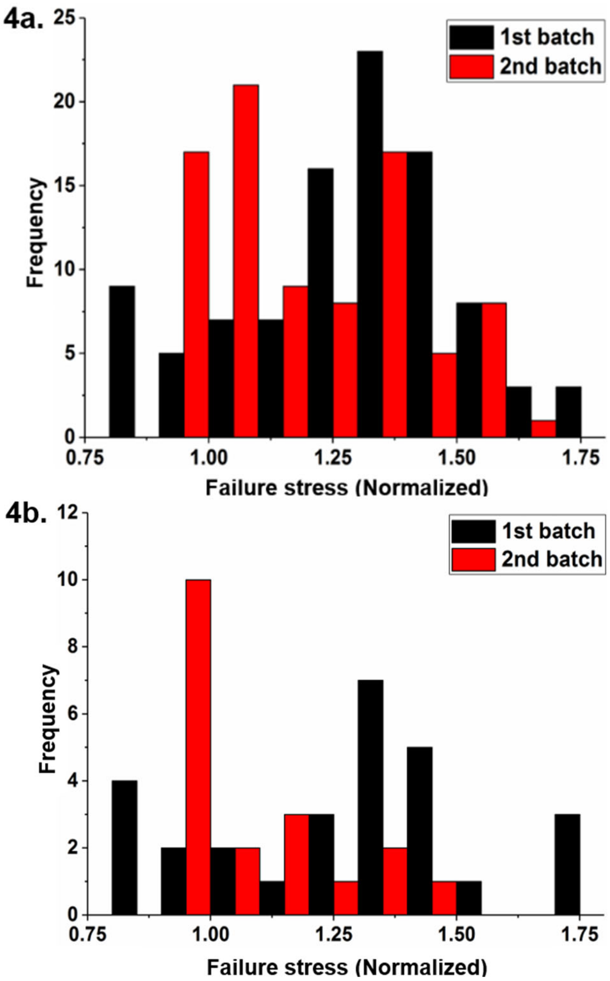


Figure 4. Failure stress distribution and their frequency of panel batches tested on dynamic ESMS: (a) All failures and (b) score and break damage induced failures only.

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The failure mode of the panel is usually multi-mode depending on the test type and panel design. To understand the failure modes of the panels tested on ESMS, fracture analysis was done. Failure mode analysis results showed that (1) most of failures happened at the edge under tension, (2) a few of the samples failed from near-edge surface damage and (3) no primary failures from the sealant or breaks outside of the test area were observed. Since all failures occurred on the intended surface/edge, it implied that ESMS could replicate edge failure modes during bending.

Figure 4a shows the failure stress distribution and their frequency of the panel batches tested on dynamic ESMS. The two batches had different failure stress distributions, where the 2nd batch had a higher frequency of lower stress failures. Fracture analysis was done on the tested samples to understand the failure origin and sources of strength difference. Analysis results showed that for both batches, the primary damage source was coming from the score and break process, where a low frequency of near-edge surface failures (handling/shipping) was also found. Figure 4b shows the failure stress distribution of panels that were analyzed to have been broken due to the score and break process. The relatively high frequency of low stress failures in the 2nd batch implies that the main source of lower edge strength was due to the difference in the singulation process/score-wheel.

6. Conclusion

The feasibility of using ESMS for ultra-thin LCD panel edge strength measurement has been demonstrated on thin panels. We have shown good correlation of ESMS to two other, well accepted methods (DIC and mirror measurements). Although static ESMS captured the relative difference in strengths between batches, dynamic ESMS is a more comprehensive approach since it tests the whole edge and better captures the flaw population. Dynamic ESMS accurately measured different strength regimes and determined differences between sample sets. When coupled with fractography, ESMS can be a useful tool in assessing and improving strength limiting flaws, enabling higher panel mechanical reliability. The benefits of dynamic ESMS as an edge strength measurement tool can be summarized as following:

1. Dynamic ESMS can test a large fraction of the edge which is important for knowing the weakest flaws;
2. Static and dynamic ESMS can measure a wide range of flaws;
3. Static and dynamic ESMS can test both panels and monoliths.

7. Acknowledgment

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