# Behavior of OLED Panel under 4 Points Bending Test

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## Abstract

*Four-point-bending (4PB) test is a common method to evaluate the strength of a panel. In this paper, we discussed the behavior of organic light emitted display (OLED) during bending. We found most of OLED panels show a unique fracture mode that fracture originates from the sealing material frit, which is different from the glue used in LCD panels. This study verified this phenomenon through experiment and simulation.*

Keywords: *OLED (organic light emitted display), 4PB (4 points bending), FEA (finite element analysis), fracture analysis, frit.*

## 1. Introduction

The structure of OLED panel is comprised of cover glass and TFT glass. TFT glass is used to deposition OLED material. These two glass substrates are sealed by frit through laser sealing to effectively prevent the moisture and oxygen invasion (Fig. 1). By 4PB test, the strength of the panel is obtained through fracture load. When defects exist, the fracture load is decreased, and so is the fracture strength. The tested specimens are inspected for fracture origin by the patterns appearing on the surface of cross-section under optical microscope. LCD panel has been widely used for display. The fracture mode of LCD panel usually breaks from tension surface of glass substrate between two loading rods, that's why the 4PB test is using to test the quality of cutting. However, the fracture of OLED panel originates from frit but glass substrate.

Finite element analysis is a foundation of solid geometry model created to predict the performance and feasibility of the display products. Simulation results are also taken into account to verify the fracture value and fracture origin. In order to quickly obtain the results, we choose the numerical analysis methods.


Figure1. Illustration of OLED panel with frit sealed

## 2. Experiment

Eagle XG glass is used in this study which is manufactured by Corning Inc. Test setup of 4PB is shown in Fig.2. Panel size is 57 mm wide x 100 mm long. Thickness is 0.3mm for TFT glass and 0.5mm for cover glass. The glass substrate are sealed by frit of 5~10um high. The rod diameter is 4mm, and the span of the load rods and support rods is 45mm and 90mm, respectively. The procedure of the test is described in the following. The load span depress slowly until panel is broken under excessive deformation. The output data is read from load cell about force and displacement when panel broken.

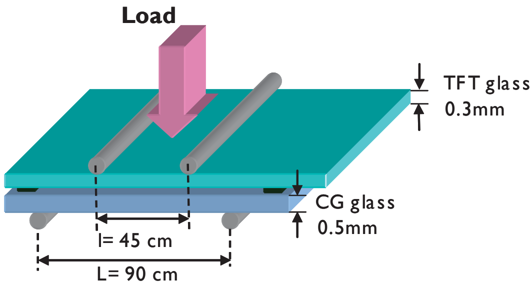


Figure2. Schematic of four-point bending test

## 3. Fracture mechanics

According to fracture mechanics in brittle material, when the crack reaches a certain critical length, it can propagate catastrophically through the structure, even though the gross stress is much less than that would normally cause failure in a tensile specimen [1]. The fracture implies the crack exists in the structure that contains defects, using the eq.1 gets cracks open by low stress when crack size is large. $\sigma_f$ is failure stress, Y is shape factor, c is crack size, and $K_{IC}$ is fracture toughness.

$$\sigma_f = \frac{1}{Y}\frac{K_{IC}}{\sqrt{c}} \tag{1}$$

The literature treats three types of cracks, mode Ⅰ, Ⅱ, and Ⅲ (Fig.3), Mode Ⅰ is a normal-opening mode, while mode Ⅱ and Ⅲ are shear sliding mode. Most of fracture types are mode Ⅰ. In order to know the fracture strength, the fracture cause in 4PB test must be found.

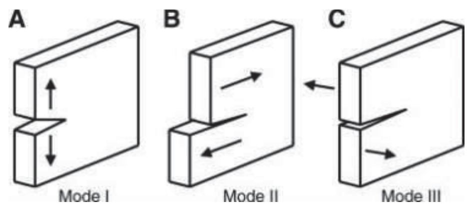


Figure3. Fracture mode.[2]

To obtain correct stress value, facture analysis is performed through cross-section inspection. Using the empirical eq.2, failure stress ($\sigma$) can be calculated where A indicates mirror constant and Rm mirror radius. Before the failure stress is obtained, the fracture origin should be found. Observe the wallner line is a key point to find the fracture origin as illustrated Fig.4. [3] The crack runs from left to right, wallner lines are the key in determining the direction of crack propagation.

$$\sigma = \frac{A}{\sqrt{R_m}} \qquad A = 65.4MPa\sqrt{mm} \qquad (2)$$

After the direction of crack is determined, the mist and mirror region is soon discovered. Mist marking on the surface of an accelerating crack close to its effective terminal velocity, observable first as a misty appearance and with increasing velocity revealing a fibrous texture, elongated in the direction of cracking. And mirror region is a smooth region surrounding and centered on the fracture origin [3]. Rm is a distance between fracture origin and mist. Fig.5 is an example for finding fracture origin.

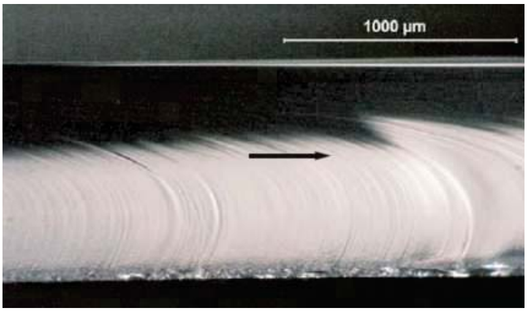


Figure4. Illustration of wallner line

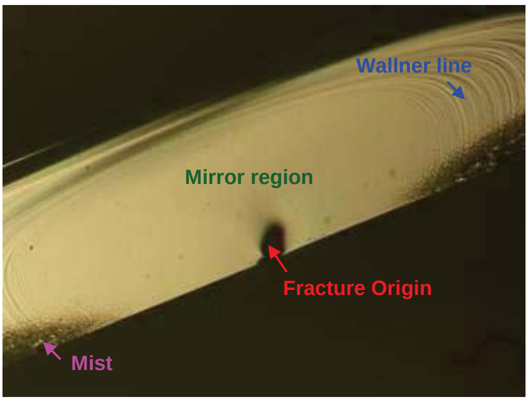


Figure5. Fracture analysis :

mist, mirror region, and Rm

## 4. Simulation

The software, Abaqus, is used to simulate the strength of the OLED panel. Max. principle stress is extracted as an index to evaluate panel strength. The model is shown in Fig.6. The mesh size is 1 mm and the element type is C3D10M. The upper rod applies a downward force while the lower rods are fixed. The quasi-static analysis model is used to simulate a steady state.

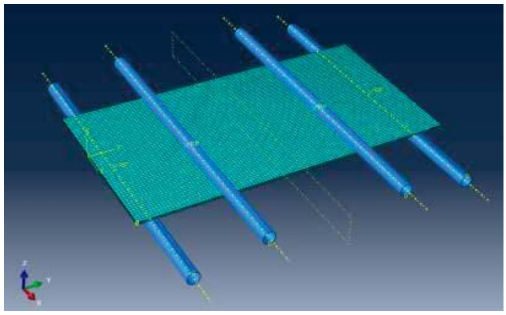

Figure6. The analysis model of 4pb

## 5. Results

### 5.1 Strength of experimental panel

The experimental results of 8pcs specimens are recorded in Table 1, and three fracture types are concluded as Fig.7: (1) surface damage 1pcs, (2) edge damage 1 pc and (3) frit fracture 6pcs. Type 1 of surface damage relates to manufacturing process and type 2 of edge damage relates to cutting process. Type 3 exhibits a new fracture pattern which was not observed in LCD before. Most of the fractures are frit fracture, and there are many parallel like cracks on glass substrate and frit. Moreover, near the sealing site on short edge, the fracture line is curved instead of a straight line that is due to the frit encapsulation. With such fracture type, it is assumed the result was caused by shear stress creation, because of large deflection during 4PB test.

Table1. The experimental results of 4 point bending

| Sample No. | Pattern Type |
|---|---|
| (1) | 3 |
| (2) | 1 |
| (3) | 3 |
| (4) | 2 |
| (5) | 3 |
| (6) | 3 |
| (7) | 3 |
| (8) | 3 |

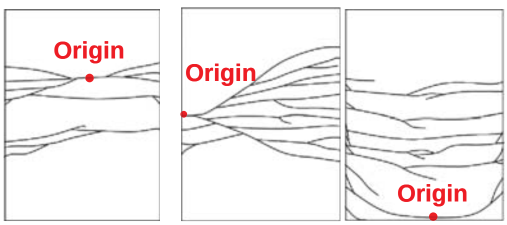


Figure7. Fracture type : (1) surface damage, (2) edge damage, (3) frit fracture

## 5.2 Fracture analysis

The fracture origins of test specimens were also examined by mirror radius Rm. Using eq. 2, fracture origin and fracture stress can be calculated. However, Rm value can't be determined in our experiment due to the mist is not found. Therefore Rm value is larger than 1 mm that almost can't find on optical microscope, so the fracture stress is small even smaller than 65.4MPa from eq.2. For the experiment of OLED panel, fractures often occurred on frit as Fig.8 (sample 7). When CG side is faced downward, many horizontal cracks can be observed on CG glass. The fracture origin on frit occurred along the edge of the frit, and propagated into the glass, which causes glass breakage immediately.

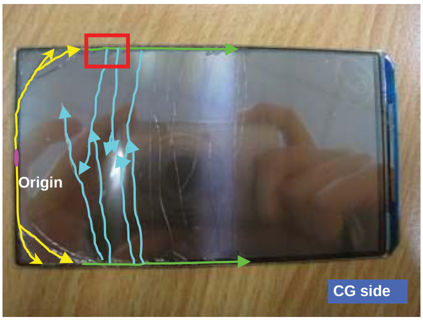


Figure8. Fracture mode occur on frit site

The fracture origin is observed on frit at left side from the crack of glass because the later crack does not cross the earlier crack. There are many cracks on frit observed by using optical microscope, and the cracks propagate into TFT glass by removing the crack frit (Fig. 9). The phenomena show the frit is the fracture origin. From fracture analysis, we observe the initial fracture from frit in the cross-section view of panel (Fig. 10). In Summary, the results indicate frit is the weakest area of OLED panel structure.

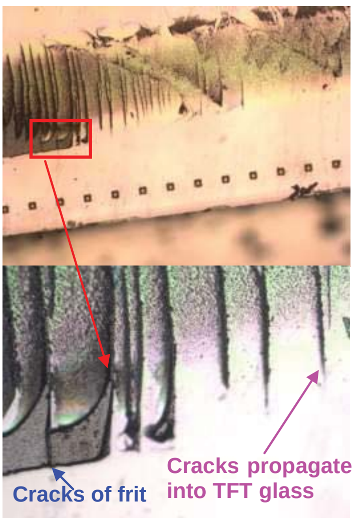


Figure9. The cracks of frit

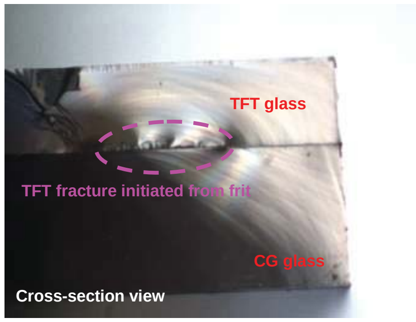


Figure10. fracture origin on frit

## 5.3 Simulation analysis results

The stress distribution of OLED panel for 4PB simulation is illustrated in Fig11. The frit is highly stressed, maximum stress is located inside frit. The direction of the maximum principle stress at frit is illustrated in Fig12. There are six stress concentrated locations from which fracture origins initiate due to the brittle characteristic of frit. The simulation result is the same as the experiment result that frit is fracture origin. The maximum stress location of structure is easily broken. The stress of short edge is higher than the stress of long edge in six stress concentrated locations. Because the stress direction of short edge is near shear direction, the same as the experiment results that fracture type cause by shear stress. Therefore, using the sealing material, frit, is easily high stress of structure.

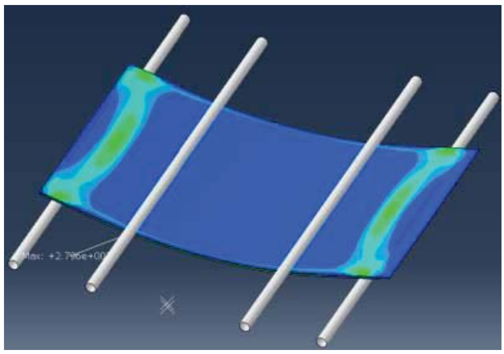

Figure11. The stress distribution of 4PB OLED panel.

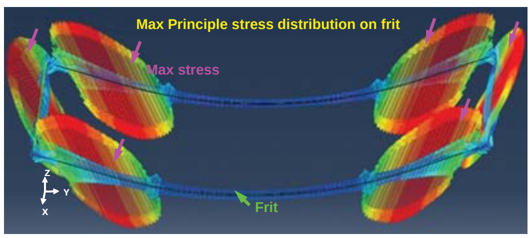


Figure12. Max. principle stress direction of frit.

## 6. Conclusion

There's a unique behavior of OLED panel that fracture originates from frit during 4PB tests. Unlike LCD panel, the sealing material, frit, is hard and brittle which easily causes stress concentration, and easily becomes a fracture origin. The analysis data indicates the sealing material's stress of OLED panel is high stress during 4PB test. The simulation data are verified by experiment data and confirms the validity.

## 7. References

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