Fracture Behavior and Intrinsic Strength of FPD Substrates

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Abstract

The ultimate practical strength of an FPD depends largely upon the fracture behavior of its substrate. Commercial FPD substrates differ substantially in their response to localized stresses occurring in panel score and break processes, edge finishing and packaging. The scoring process, used as a reliable and inexpensive technique for the sizing of glass sheets, in particular, can have a substantial effect upon the strength of the final display. This paper will review the effect of glass composition on score behavior and its impact on AMLCD glass substrates.

Introduction

The choice of the substrate for flat panel displays directly impacts the strength of the final display. As FPD technology extends into new applications, the issue of display strength is becoming increasingly a priority. This paper will discuss intrinsic glass mechanical properties and behaviors in the display fabrication process that control display reliability.

In a previous paper by the authors[1] , a broad discussion was presented on intrinsic glass properties that can influence AMLCD robustness. The properties discussed included thermal expansion coefficient (its effect upon thermal shock resistance) mechanical properties that influence the functional strength of glass, and glass thermal properties that enabled the use of advanced display component technologies. It was asserted that low expansion, high strain point glasses with favorable deformation and fracture properties would optimize the mechanical reliability of AMLCDs.

Functional Strength of Glass

Failure of glass under load usually initiates at a pre-existing surface flaw; therefore, extrinsic factors such as the quantity and characteristics of surface flaws determine the functional strength of glass as much as intrinsic material properties.

Fracture toughness is the material property that is most commonly used to quantify the intrinsic strength of a material. When compared to the range of fracture toughness values for crystalline materials, glasses have a much more narrow range of fracture toughness values even across a broad very disparate compositional types than there is in crystalline materials. Almost all glasses have fracture toughness in the range of 0.6 to 0.8 Mpa.m$^{1/2}$. In actual experience, significant variation is seen in the mechanical robustness between glasses composition types even when differences in the extrinsic factors are removed. For example, differences between substrate glasses microscopic behavior in the score and break process are indeed determined strongly by composition factors and can make substantial impact on the robustness of the final display.

Score and Break Process

Typically, the AMLCD manufacturer processes multiple display units on a single substrate, separating the substrates into display cells by a score and break process as one of the final steps in panel manufacture. Therefore, the mechanical robustness of the display will be limited by the quality (size and density of flaws that can act as crack initiators) of the scored edge. Even if edge dressing (grinding) is performed on the final display, the resulting density and size of microcracks resulting from grinding has a similar effect.

In the scoring process, a score wheel is used to generate a median crack in the glass surface. While the scoring wheel only penetrates the glass surface to a depth of 2-5 μm, this median crack typically reaches a depth of 50-120 μm. The glass is separated by driving this median crack into the glass thickness by the application of stress.

How this glass responds to scoring within the first 2-5 μm influences the mechanical robustness properties of the final AMLCD assembly.

Glasses behave differently with respect to the scoring process. Critical parameters to control include geometry, size, and finish of the score wheel, scoring pressure and scoring technique. Typical conditions derived from historical experience with soda lime glass are inappropriate for high performance glasses used in AMLCDs. Operating outside of the optimum process window can lead to extensive damage of the glass, lowering its usable strength. In a previous paper a detailed discussion was presented on the process used for optimization of scoring conditions for the FPD substrates[2]. It was demonstrated that with any glass the scoring results are always a function of many parameters. Among the more important are wheel finish, diameter, tip angle and score load. An optimum process for one glass is not optimum for all others.

Experimental Method and Results

In the present study, two glasses were used that represent the two major types of glasses used in the AMLCD application. The first, Corning Code 1737, has properties optimized for second and third generation AMLCD processes and the trend towards larger, higher resolution displays. Code 1737, compared to code 7059 (the substrate standard with which first generation AMLCD processes were developed) engenders an increase of 70°C in thermal capability, lower thermal expansion by 1 PPM/°C and lower density. Glass A is an example of an intermediate temperature capability glass that followed the code 7059 standard of high thermal expansion and high density. The temperature capability of Glass A is approximately intermediate to that of code 7059 (593°C strain point) and code 1737.

Table 1: **Summary of Glass Porperties Composition Types for AMLCD**

Glass	Code 1737	Glass A
Density (g/cm^3)	2.545	2.752
Strain Pt. (°C)	666°C	635°C
C.T.E. (x10^{-7} /°C)	37.8	49
Composition Type	Alkaline Earth aluminosilicate	Alkaline Earth aluminosilicate

Samples of both substrate glasses were each scored with a 2.5 mm diameter, 130 degree polished wheel at score loads ranging from 1 kg to over 3 kg. By direct microscopic observation, the depth of the median cracks were measured. These data are shown in Figure 1. It can be observed that it takes slightly more score load to generate a median crack of given depth in Code 1737 than in glass A. This type of behavior may be incorrectly interpreted as Code 1737 having a "harder" surface.

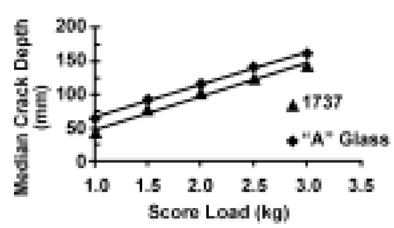

Figure 1 - Median crack depth versus glass composition

An unwanted secondary fracture morphology that occurs during the scribe process is the lateral crack. Lateral cracks occur in a direction approximately perpendicular to that of median ("good") crack. This was also measured for Code 1737 and glass A in the same score load regime. As seen in figure 2, substantially higher lateral crack growth occurs in glass A at lower score load than that in Code 1737.

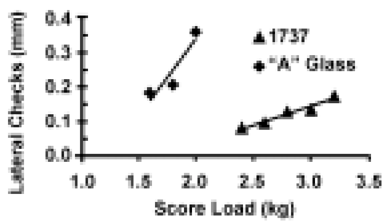

Figure 2 - Lateral crack depth versus glass composition

Supporting microscopic analysis was done that graphically illustrates the fundamental qualitative difference in how the two glasses fractured under the score load. The photos, figures 3 & 4, are 5000x SEM photo images of 1737 and A Glass, taken along the edge of a scored (2 kg load) and separated sheet. In glass A, substantial subsurface damage is generated during the score process, resulting in dramatic lateral cracking.

On a local scale 1737 plastically deforms under the intense contact stress of the score wheel. "A Glass" in turn experiences a more brittle local failure. This brittle failure is seen as the microcracks directly under the wheels contact.

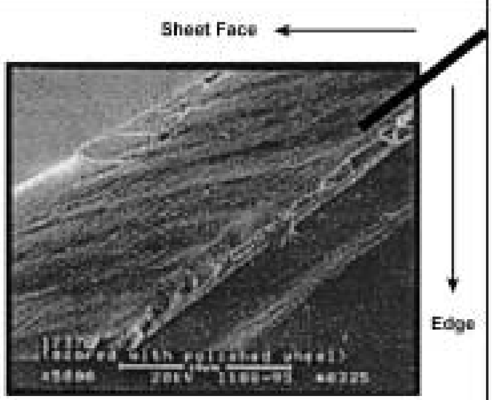

Figure 3 - SEM of 1737 scored edge

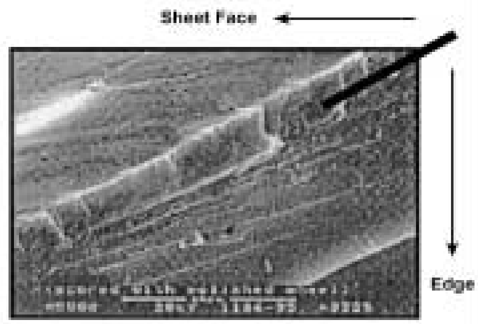

Figure 4 - SEM of "A Glass" scored edge

Impact Upon Panel Strength

This difference in subsurface damage is a direct consequence of the glass compositions and is the reason 1737 is resistant to lateral crack formation (Figure 3). These subsurface cracks in "A Glass" (Figure 4) are the defects from which lateral cracks initiate and why lateral cracks form at such low score loads. Once initiated the lateral crack penetrate deep into the glass body and become the edge failure origin.

Since edge failures dominate structural strength, a measure of residual edge strength is a direct measure of glass strength. Figures 5 is plot of edge strength in these glasses as a function of the scoring process. This data was generated from a Weibull analysis of a four point bend test. It is clear that the subsurface microcracks formed during the scoring of "A Glass" are the defects that lead to premature strength loss.

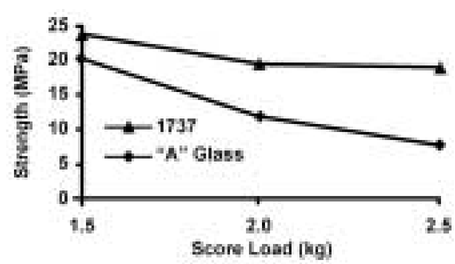

Figure 5 - Residual strengh of scored glass versus composition

Structural Interpretation of Substrate Behaviors

Differences between the response of different types of glass compositions under local load has been well documented in the literature[3,4]. At this early stage in the analysis of fracture behavior of AMLCD glass compositions, a detailed structural interpretation is premature. However, inspection of the glasses compositions suggests a qualitative explanation.

Code 1737 and glass A have similar compositions at first glance. They are both non-alkali boroalumino-silicates containing a mixture of alkaline earths (RO: MgO, CaO, SrO and BaO). In glass chemistry there are three types of behavior for glass constituents: network former, intermediate and network modifier. Glass formers are the "backbone" of glass structure, forming extended covalently bonded random networks that determines the glass's mechanical properties. Glass formers in AMLCD substrates are silicon and boron oxides. The alkaline earths act as modifiers in the AMLCD substrate glasses, breaking the metal-oxygen-metal bridges formed by the network formers, bonding more or less ionically in the glass structure. Aluminum oxide, an intermediate,has glass bonding behavior that is a combination of former and modifier behaviors, and can either become part of the network or enter the glass structure as a modifier.

Table 2: **Composition factors for Code 1737 and Glass A**

	Code 1737	Glass A
Total Network Former (Si+B)	75	71
Total Network Former (Si+B)	13	21
Ratio Former/Modifier	5.8	3.4

Table 11 lists the former and modifier content in mole % for the two glasses studied at present as well as the forrner/modifier ratio.

Note that glass A has a much lower former/modifier ratio, we have found that glasses that behave similarly to that of glass A in score behavior also have a low former/modifier ratio. A glass rich in modifier tends to be compact as the modifier ions can fill in "gaps" in the network, which tends to collapse the glass structure. (Note the higher density of A-glass compared to Code 1737). On the other hand, a glass relatively rich in formers tend to be more open. An open structure may tend to react to localized stress by densifying or plastic behavior, which is what is observed in the score behavior of Code 1737. The more dense and strongly modified glass is less capable of this type of response and the brittle failure is the dominant mode similar to that of glass A.

Moreover, we expect this type of composition factor to be operative in the other aspects of substrate robustness, such as long-term mechanical reliability. It has been found, indeed, that Code 1737 has substantial advantage in the area of fatigue resistance as well[5,6].

Conclusions

The quality of the as-scored edges found on AMLCD displays significantly influences the ultimate strength of the structural assembly. It is the nature of the substrate's mechanical response to scoring in the first few microns of surface layer that determines the quality of the as-scored edge. Glasses with high glass former/modifier ratio, such as Code 1737, have score process behavior that optimizes substrate and AMLCD panel mechanical strength.

Acknowledgments

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