Optical and Environmental Requirements for Display Applications

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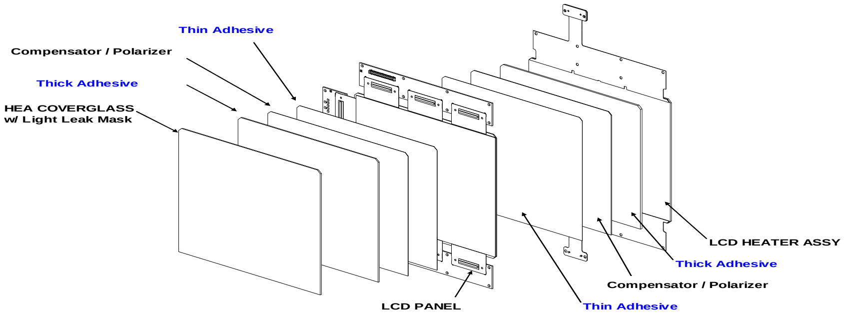
Abstract

Rockwell Collins has developed a robust, repeatable, low cost lamination process that utilizes a dry bond technology (using PSA) to directly couple substrates to display technology such as liquid crystal displays (LCD's) and organic light emitting diodes (OLED's). These substrates can serve as protective covers, reflection mitigation, heaters, filters, touch screens, environmental barriers, etc. This resultant assembly is very rugged; shock, impact, and vibration resistant, while maximizing optical performance. The optical requirements for these applications can be quite demanding, especially for cockpit applications. This paper will discuss the optical requirements used to qualify an adhesive for use in display applications. The optical requirements will include total specular reflectance for a full display stack, spectral specular reflectance by layer, diffuse reflectance, birefringence, and internal transmission. In addition, key environmental tests required for avionics display applications will be defined. This section will include thermal and humidity profiles, altitude, solar exposure, and boot-kick requirements.

Introduction

Rockwell Collins primarily provides aviation and information technology systems, solutions, and services to governmental agencies and aircraft manufacturers. Core product offerings include leading edge display technologies which are designed to withstand punishing climatic exposures. The current display technology that is being inserted into aviation and ground vehicle applications are Liquid Crystal Display's (LCD's). A significant amount of investment has been made by Rockwell Collins, Inc. to configure these rather delicate electronic devices such that they can survive harsh environments, while simultaneously improving optical performance. Most recently, the patented lamination and ruggedization technology developed for core LCD products has been offered to license into high volume commercial markets such as cell phones, TVs, laptops, tablets and e-readers. Key to penetrating these new high volume markets is the choice of adhesive used for the lamination which needs to be low cost and adaptable to high volume automation. This paper will delve into the key diagnostics that were used to characterize the adhesive being used for today's lower volume applications and should be considered as a starting point for new adhesives that would be applicable for high volume applications.

Typical Avionics Display Stackup

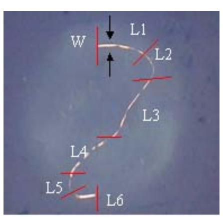


Optical Requirements

Defect Criteria

With any optical application it is important that the display be legible and free of defects within reason. Defects of a certain size can distort visual information which can lead to confusion and cause the display to be misinterpreted. This can have serious consequences when the display is used in life critical applications or when decisions must be made quickly. Ambient lighting conditions, display backlight luminance, and display size are all taken into account when considering appropriate criteria for a given application. Each customer may have their own specific version however; it is desirable for production (lamination assembly) to have one "common" criterion to use for all applications.

An example of common defect criteria for a 15-inch display is provided in Table 1 below. The maximum defect size allowed remains constant for all display sizes, while the quantity of allowed defects will change proportionately with display size. In order to properly interpret the criteria, the following formula should be noted.



$$\text{AD} = \text{Average Diameter} = \frac{1}{2}(Length + Width)$$

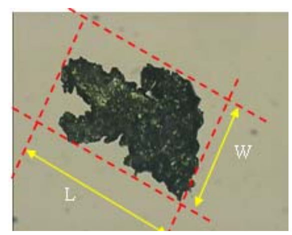
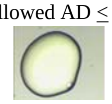
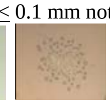
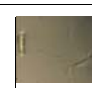


TABLE I
Component Defect Inspection Criteria for a 15" Display

Defect Type	Maximum Size (mm)	Minimum Separation Distance (mm)	Notes
Foreign Material	Width = 0.30 AD = 1.0	6.4	AD ≤ 0.1 mm not counted  
Bubble	AD = 0.40	6.4	No bubble patches allowed AD ≤ 0.1 mm not counted   
Adhesive Ding	Width = 0.30 AD = 1.0	6.4	AD ≤ 0.1 mm not counted 

Optical -General

In general, when a light ray impinges upon a surface the energy will be scattered into three classifications. These include: specular reflectance, diffuse reflectance, and haze. With LCD technology, the analyst need not worry about scattering for any surface behind the TFT substrate. This is due to the very low optical transmission inherent of the aperture for this device, therefore the contributions are negligible. Since haze is primarily a first surface contributor, it will not be specifically addressed in this paper. However, specular and diffuse reflectance, birefringence, and internal transmission are all discussed below because these are appropriate benchmarks for an optical adhesive assessment.

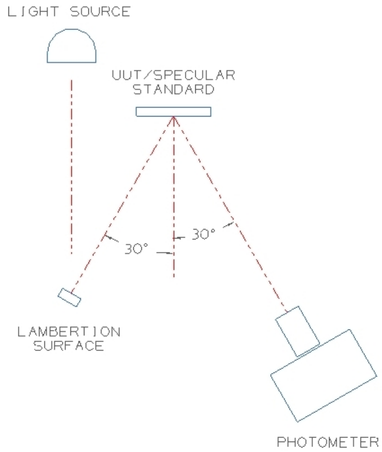
Total Specular Reflectance

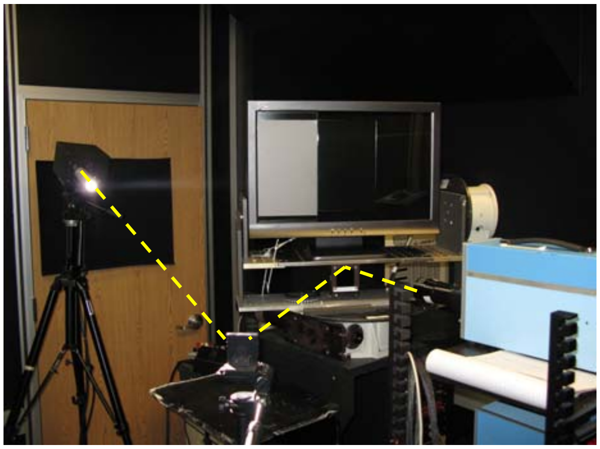
This is very important to achieve acceptable sunlight readability. Aircrews must be able to interpret the displays even when shafted sunlight is present in a cockpit. Every outdoor application is subject to reflectance problems and therefore, it is imperative that each material's refractive index be carefully considered during the design phase of a project. Internal air interfaces typically contribute 4% per surface which drives the need for lamination. Overall, the acceptable level of reflectance for an entire display stack should be < 0.5% @ 30 degree incidence.

Example of Shafted Sunlight in a cockpit with Laminated Display

Left: Anti-Reflective glass dry-bonded to 40" LCD TV in direct sunlight. Right: Sunlight readability example – Air gapped vs. Laminated.

Diagnostic Used





Schematic: Method of measuring specular reflectance. Photo: Specular reflectance test setup.

Calculation

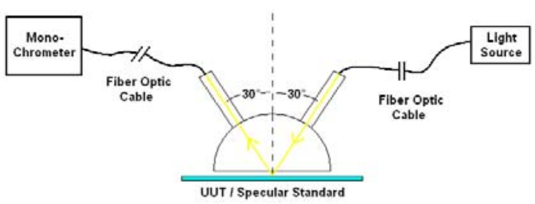
$$\text{Specular Reflectance} = \frac{L_{UUT}}{L_{Std}} * \rho * 100 \quad [\%]$$

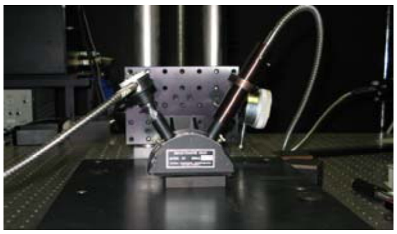
L_{UUT} = measured luminance of unit under test
L_{Std} = measured luminance of reflectance standard
ρ = reflectance of standard at angle (0.0438 @30°)

Spectral Specular Reflectance by layer

This is particularly useful for understanding the layer by layer contribution to the overall reflectance in complex optical designs with many layers. An acceptable level for a single layer of adhesive coupled to two substrates should not exceed 0.08%. Many times this is used simply for a unique material assessment, and other times, it is found beneficial in troubleshooting a reflectance issue.

Diagnostic Used





Schematic: Method of measuring spectral specular reflectance by layer. Photo: Spectral specular reflectance by layer test setup.

Calculation

$$\text{Photopic Reflectance} = \frac{\sum_{\lambda}\left(R(\lambda) * \bar{y}(\lambda) * D65(\lambda)\right)}{\sum_{\lambda}\left(\bar{y}(\lambda) * D65(\lambda)\right)} * 100 \quad [\%]$$

$R(\lambda)$ = measured reflectance over wavelength

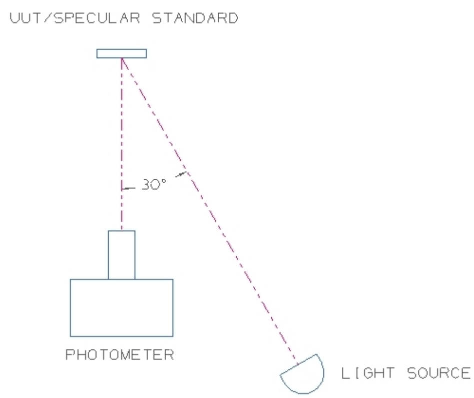
$\bar{y}(\lambda)$ = photopic curve

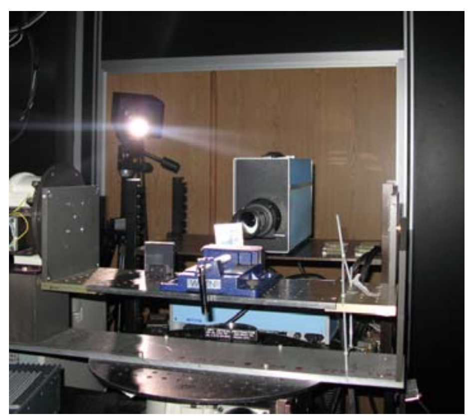
$D65(\lambda)$ = 6500K standard illuminant

Diffuse Reflectance

Similar to the case of specular reflectance, diffuse reflectance affects the legibility of the display. In this case however, it has to do with in-plane scattering of light which can cause significant loss of display contrast. A display with a significant amount of diffuse reflectance will appear “washed-out” and the image will be hard to interpret. Top level product values usually are specified to be <0.5% of which an adhesive bond-line should not contribute more than 0.02%.

Diagnostic Used





Schematic: Method of measuring diffuse reflectance. Photo: Diffuse reflectance test setup.

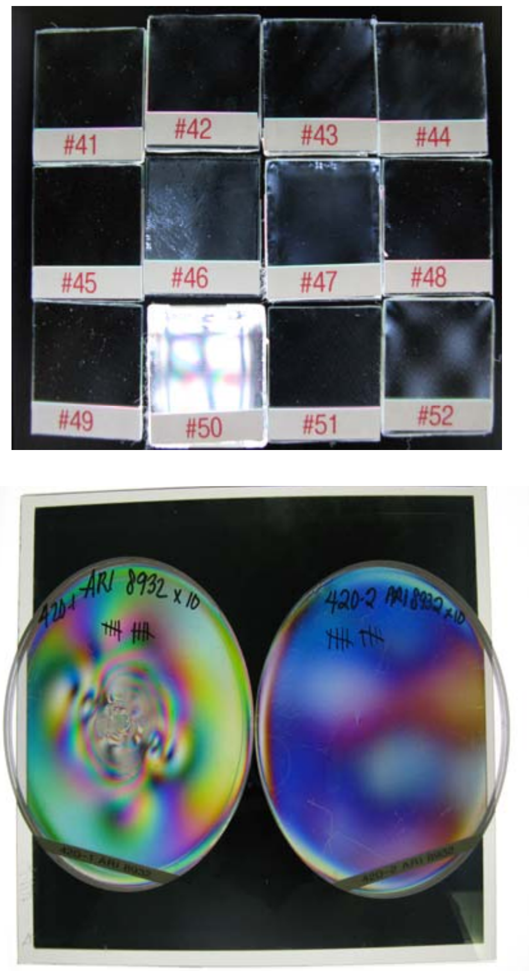
Calculation

$$\text{Diffuse Reflectance} = \frac{L_{UUT}}{L_{Std}} * 100 \quad [\%]$$

L_{UUT} = measured luminance of unit under test
L_{Std} = measured luminance of reflectance standard

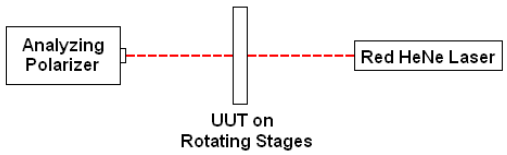
Birefringence

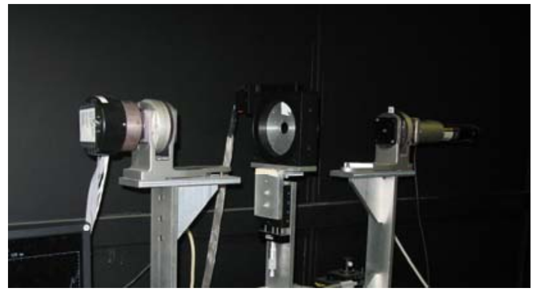
Birefringence is an important material characteristic to control for optimum display performance. Birefringence is essentially the decomposition of a light ray into two rays when it passes through a material. This affects display clarity while potentially disturbing polarization states and compensation effects. The adhesive must measure very low; less than 10nm is desirable. In some applications, a desirable and controlled state of birefringence is used to achieve a specific purpose; as is the case with contrast compensation films to increase an LCD’s viewing angle performance.



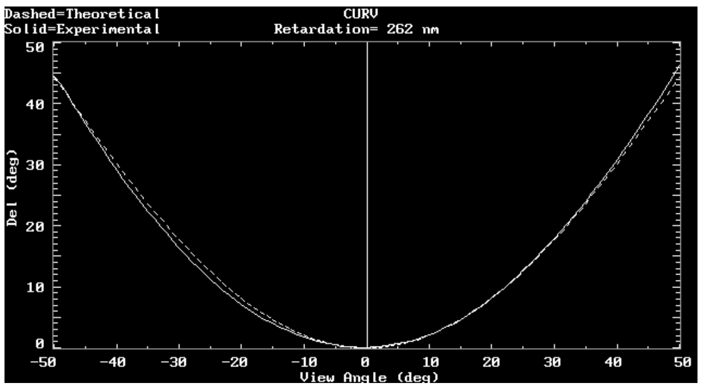
Examples of birefringent PSA candidates

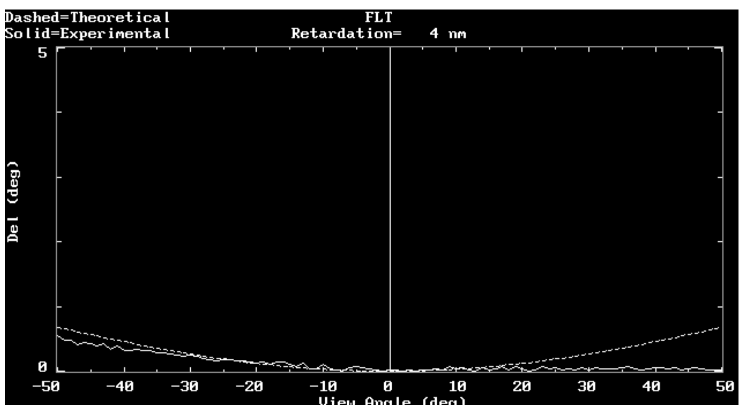
Diagnostic Used





Schematic: Method of measuring birefringence. Photo: Birefringence test setup.



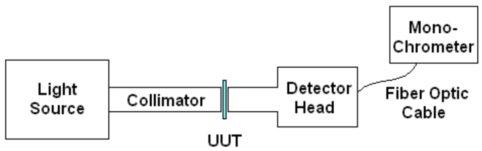


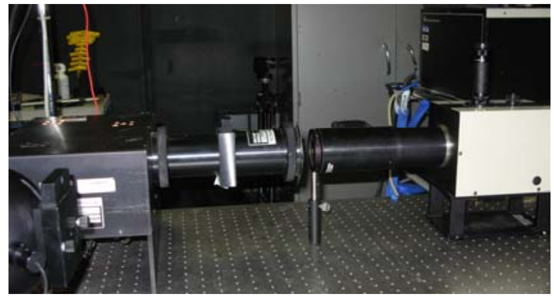
Example output plots from test software.
Top: High birefringence (262nm). Bottom: Acceptable birefringence (4nm)

Internal Transmission

It is desirable to select adhesive with high visible light transmission > 95%. Transmission losses lead to having to drive the backlight harder. This leads to an increase in operating power of the unit which in turn increases temperature, thereby affecting life. Optical transmission is intrinsically determined by the fundamental adhesive chemistry at the molecular level, and extrinsically influenced by refractive index. Any mismatch of refractive index at the bonded interface will increase specular reflectance; thereby reducing optical transmission.

Diagnostic Used





Schematic: Method of measuring internal transmittance. Photo: Internal transmittance test setup.

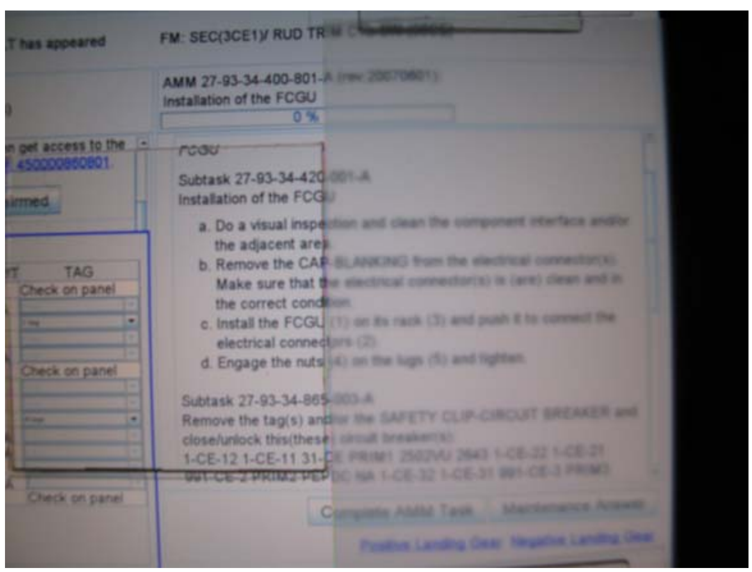
Calculation

$$\text{Photopic Transmittance} = \frac{\sum_{\lambda}\left(T(\lambda) * \bar{y}(\lambda)\right)}{\sum_{\lambda}\left(\bar{y}(\lambda)\right)} * 100 \quad [\%]$$

$T(\lambda)$ = measured transmittance over wavelength

$\bar{y}(\lambda)$ = photopic curve

Examples



Left: Sample with 98.5% internal transmission.
Right: Sample with 35.9% internal transmission.

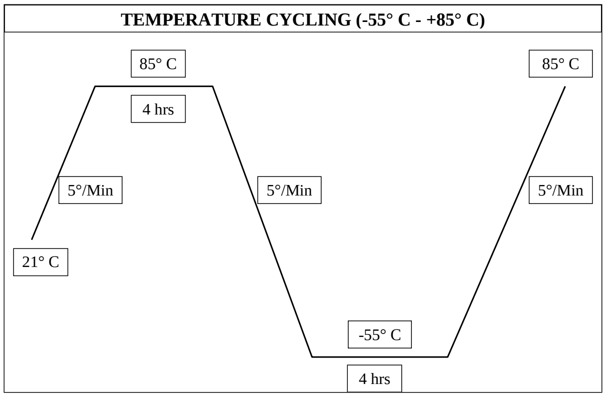
Environmental Requirements

Thermal Loading & Cycling

Given that these adhesive materials will be used both in aviation and ground vehicles, they must perform without significant degradation throughout a wide range of temperatures, time durations and ramp rates. A typical thermal soak test is -55°C for 48 hours followed by +85°C for an additional 48 hours. In many applications, thermal cycling is also required; a composite of worse case scenarios for many customer mandated profiles is shown below.

PSA candidates after thermal cycling.
Left: No yellowing (96.5% transmittance). Right: Yellowing (85.3% transmittance).

Diagnostic Used

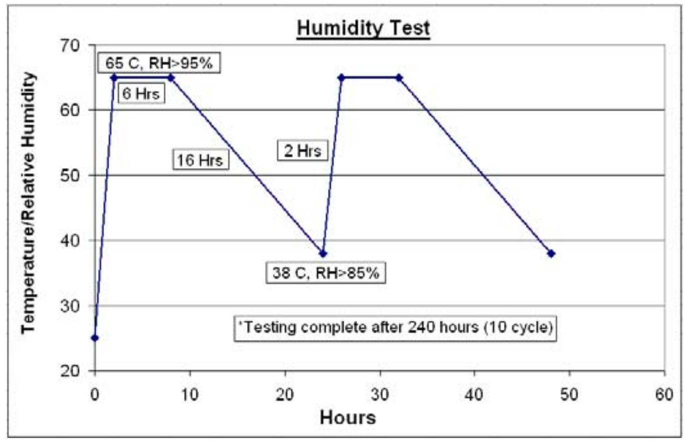


Left: Photo of thermal chamber. Right: Typical profile used to thermal cycling.

Humidity

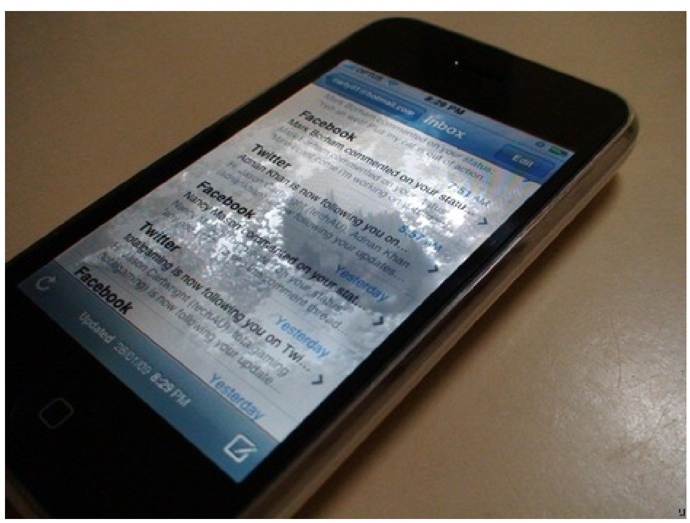
It is imperative to design robustness into the product with the expectation for both arctic and tropic climatic exposures since there is no way of knowing where equipment will be used. Both ground vehicles and aviation related equipment types are subject to this. Also, any electronic equipment that has an intended outdoor use will be subject to a harsh level of humidity and temperature. Immersion testing is usually NOT a concern for optical adhesives since those requirements typically drive the design to be totally sealed against any moisture intrusion. A typical humidity profile mandated by the Federal Aviation Administration is shown below.

Diagnostic Used



Left: Photo of humidity chamber. Right: Humidity cycle profile.

Example of Humidity Damage



Water damage behind cover glass of iPod.

Altitude

Exposure to altitude typical of aviation applications places the lamination adhesive in tension. Many optical adhesives that are soft enough and suitable for interfacing to an LCD have poor tensile properties and can lead to temporary or permanent de-lamination. Most requirements for commercial aircraft often require survivability to 35,000 feet; while the expectation for fighter aircraft is for full performance to 70,000 feet.

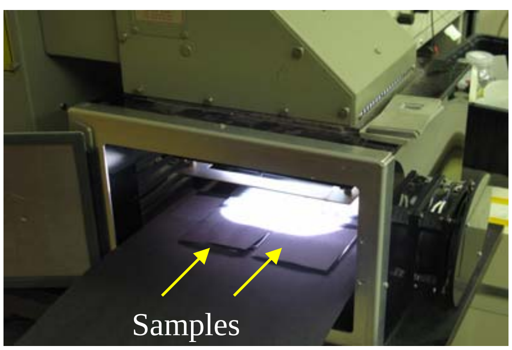
Diagnostic Used

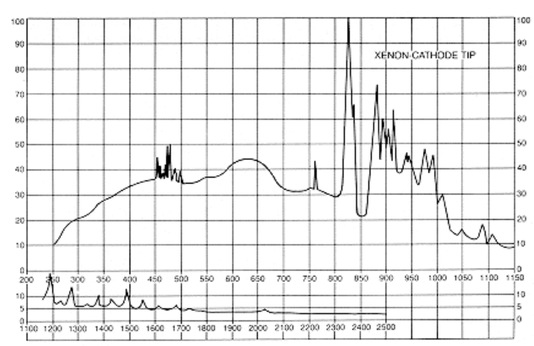
Photo of altitude chamber

Solar Exposure

Prolonged exposure to sunlight is a common occurrence in most display applications. Degradation of the adhesive in terms of discoloring, shrinking, and reversion are not permitted and are cause for dismissing the material as a candidate. Also, potential for photoluminescence should be considered. Since this can be a time dependent emission, careful and immediate testing is required after exposure.

Diagnostic Used: Xenon Compact Arc Lamp – 1000 hours direct exposure





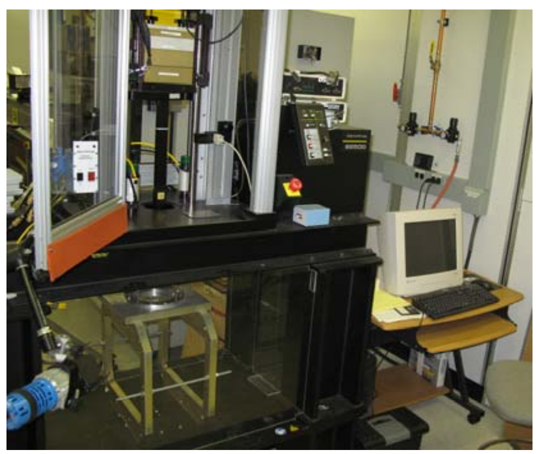
Left: Photo of solar simulator. Right: Spectral output of light source.

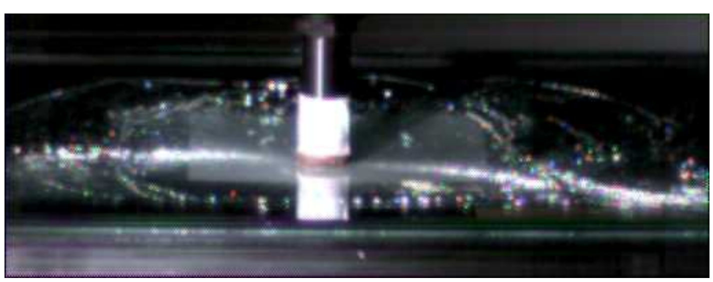
Boot-Kick

High impact resistance is a typical requirement for military ground vehicles. However, it is equally important for almost every application. Bare LCD's are very fragile to the touch and are easily damaged in vehicles where personnel are quickly entering or exiting a vehicle. This is also important for situations where incoming projectiles are possible, or in some cases the entire product such as a laptop display can be dropped on the ground. Many times, in order to ruggedize displays, a sacrificial shield is air-gapped in front of the display which introduces compromising optical effects. A more robust solution is to laminate the sacrificial substrate directly to the LCD. This approach offers a solution that is impact resistant while also significantly improving optical performance over the air-gapped design.

A generally accepted test requires a 45 lb mass striking the center of a display at 3.8 ft/s. The contact area at impact cannot exceed 0.5 in^2. The display is to be impacted six times without changing location of impact, followed by a close examination of the product.

Diagnostic Used





Upper Left & Right: Photos of impact tester. Lower: Snapshot showing impact of tup on touchscreen.

Conclusion

There are clearly many significant advantages for laminating Liquid Crystal Displays with enhancement and ruggedization components. The market for doing so is growing rapidly and new applications appear daily. In the high volume commercial markets optical clarity and high efficiency will drive new products that require either protective cover glass or touch screens to a bonding solution. New adhesives that are suitable for automated assembly processing and can meet robust environmental conditions are needed. This paper has outlined the typical optical and environmental requirements that are utilized when looking for new adhesive materials.

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