NATIONAL GLASS ASSOCIATION with GANA

Glass Technical Paper **FB04-03 (2021)**

Design Considerations for Laminated Glazing Applications

Modern architectural designs often require glazing materials that provide enhanced levels of security and safety performance properties. These properties include resistance to ballistics, blast, hurricane/cyclic wind pressures and physical attack. Applications may also require desirable properties such as sound reduction, fade resistance, and solar & thermal control. Laminated glazing materials (see Figure 1 and Figure 4) consist of multiple plies of glass, interlayers, resins and/or plastic glazing materials (such as polycarbonate sheet or acrylic), which are often complex in nature. They are designed to provide specified levels of performance.

Design professionals and building owners should be aware of the following considerations when selecting and specifying laminated glazing constructions:

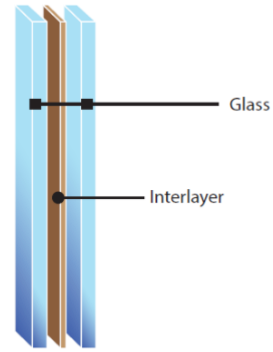

Figure 1: Basic laminated glass

Aesthetic Color

Commercial clear float glass is nearly colorless, however, a green or blue-green tint, which is faint in thin glass may become noticeable in glazing applications where the glass thickness exceeds 3/8” (10 mm). Laminated glazing materials, utilized for their impact resistance to ballistics, blast and physical attack and for additional applications such as zoo exhibits and large aquariums, incorporate numerous plies of transparent glazing materials. In these applications, the thickness of the glass portion of the laminate often results in a more apparent degree of green. In some instances, the green tint is not as pronounced, as it can be disguised by the blue color of the water or the color of painted walls in an aquarium. The green tint also may not be as apparent in certain constructions such as glass-clad polycarbonate laminates that contain more polycarbonate than glass.

However, in certain applications, the green tint may be regarded as aesthetically displeasing to a designer and owner. For those projects that require the highest level of color clarity, low-iron float glass should be considered (see Figure 2). Low-iron float glass may also assist the designer in providing a closer color match to a less thick glass that is in proximity to the laminated glazing.

Figure 2: Comparison of clear float glass and low iron glass

Many laminated glazing components are designed to block ultraviolet light (energy wavelengths from 280nm - 380nm); however, these components may also block a portion of the visible light spectrum (wavelengths from 380nm – 420 nm) with a result that there may be a slight yellow appearance. This yellow appearance may become noticeable when these materials are used in thicker or a greater number of multiple layers. In addition, yellowness can vary by interlayer type and manufacturer. This color should be considered in conjunction with color imparted by the glass itself.

There are also design considerations, which must be taken into account when a low-e or reflective coating is used in the construction of a laminate. When the coating, applied to the glass substrate, is placed in contact with the interlayer, the refractive index of the coating is changed and may result in a perceived color shift. This means that a coating in an IG unit may appear a different color than the same coating in a laminate.

Optical Distortion

<u>Heat-Treated Glass</u>

Images viewed in reflection from and by transmission through laminated glazing materials may be distorted (see Figure 3). Both reflected and transmitted optical distortion may result from heat-treatment of glass, thickness variability of the materials used, mechanical stresses applied by the framing system and changes in exterior wind pressure and interior building pressure.

Laminated glazing materials may incorporate multiple plies of heat-treated (e.g. heat-strengthened, tempered) glass in order to achieve high levels of resistance to thermally and mechanically applied loads. Bow (warp), roll wave distortion and picture frame distortion are inherent characteristics of heat-treated glass. While fabricators take steps to minimize these conditions, they cannot be eliminated. All of these characteristics are accentuated by the use of reflective coatings and tinted glass substrates.

Since transmitted distortion is dependent on the overall thickness variability, it tends to be exaggerated by multiple plies of glass and other components, i.e., lens effect. The thickness variations of the individual plies are additive. Laminated constructions incorporating annealed glass typically exhibit less reflective and transmitted optical distortion. Distortion in all glazing materials may occur as a result of glazing system wind load pressures. Refer to ASTM C1172 *Standard Specification for Laminated Architectural Flat Glass* for allowable process blemishes, length and width tolerances, and maximum allowable overall bow.

Figure 3: Example of distortion

The visibility of reflective distortion is greatly affected by surrounding conditions and glazing orientation. If the reflected image is a uniform blue sky, the reflective image that appears in the laminated product may appear without distortion. If the same laminate is reflecting multiple gridlines from an adjacent building, the reflection may appear distorted. Roll wave distortion may be more visible by reflectance and transmittance when the direction of the wave pattern is glazed parallel to the jamb or vertical dimension of a window or door. In this application, images of lineal objects (such as building walls, utility and flag poles) and moving objects (such as cars and aircraft) become more visible as the viewing angle changes. In order to decrease the visibility of roll wave distortion in heat-treated laminates, fabricators commonly recommend, and design professionals specify, that the wave direction (wave's peak) be glazed parallel to the sill of a window or door whenever possible. It is recommended that the manufacturer be notified in writing of these instructions prior to the onset of glass fabrication. Heat-treated glass fabrication equipment limitations may not allow roll wave orientation to the sill when the width dimension of a lite of glass exceeds the width of the heat-treating oven.

Multiple-Ply Laminates

Multiple-ply glazing materials (see Figure 4) that include non–glass components such as interlayer films and/or plastics sheet products such as polycarbonate, acrylic sheet or polyethylene terephthalate (PET), may also be a source of unwanted optical distortion. Special consideration should be given to these types of laminates.

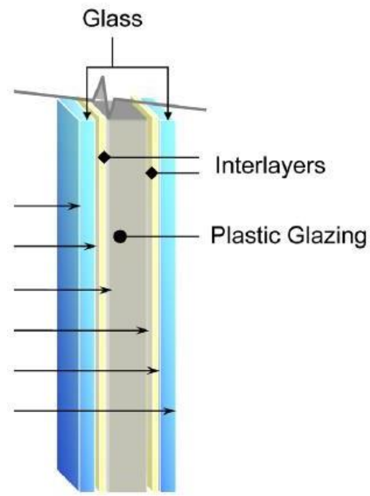

Figure 4: Example of multiple-ply laminate

Both glass (as previously described) and non-glass components may have thickness or flatness variability that creates lens or other visible effects, which may cause distortion of images when viewed through the glazing material. The magnitude and spacing of this variability are both important factors when trying to assess the suitability of a multiple-ply laminate for a given application as a precise alignment of the components containing this variability is not possible. This distortion is greatly affected by viewing angle, and vertical lens lines are generally more objectionable.

High performance plastic sheet used in multiple-ply laminates are most often either polycarbonate or acrylic sheet.

Acrylic sheet materials are produced by several processes, which exhibit varying degrees of distortion and thickness variations. Polycarbonate sheet is produced by an extrusion process, and therefore exhibits die lines (ripple direction) on both coated and uncoated polycarbonate, which may produce an objectionable distorted image. This distortion can be minimized by placing the ripple direction horizontal to the plane (when feasible). While plastic sheet manufacturers take steps to minimize these conditions, they cannot be eliminated.

Designers are recommended to further consider other conditions, such as:

- Thermal expansion/contraction properties and changes in humidity, which may cause the plastic glazing material or the interlayer to bow and/or warp
- Adequate space within framing systems to reduce perimeter issues due to edge pinch
- Localized areas of distortion resulting from small particulate inclusions (fish-eyes) on coated plastic sheet materials
- As more individual plastic layers are utilized in the laminate, distortion may become more pronounced.

Multiple-Ply Laminates incorporating both glass and polycarbonate components and their appropriate interlayer(s) are further described within ASTM C1349 *Standard Specification for Architectural Flat Glass Clad Polycarbonate*, and its Appendixes. Additional reference to the plastic sheet components and these types of laminates can also be found within the *GANA Glazing Manual* and the *GANA Laminated Glazing Reference Manual*. Refer to ASTM D4802 *Standard Specification for Poly (Methyl Methacrylate) Acrylic Plastic Sheet* for the methods by which acrylic plastic sheet is produced and other specifications.

Iridescence

When viewing laminated glazing constructions, under certain conditions, a pattern of iridescent spots or darkish shadows may become visible (see Figure 5). This is commonly referred to as the strain pattern/anisotropy of the heat-treated glass and is related to

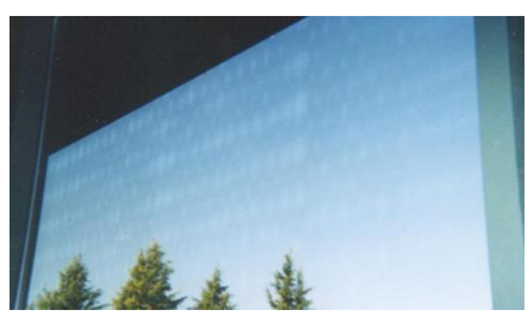

Figure 5: Example of iridescence

the stresses introduced in the cooling process of the glass fabrication. While not normally visible, the strain pattern may become more evident by reflectance and in transmittance when viewing the glazing material at severe angles or under polarized light conditions. The potential of the iridescence becoming more pronounced is enhanced as the thickness of the laminated glazing material increases. The strain pattern is inherent in those heat-treated components and is not a result of discoloration or non-uniformity.

Temperature Performance

Laminated glass may be used in applications where the laminate could be exposed to high and low temperatures. Examples are spandrel, tinted, southern-facing elevations, coatings, and non-conditioned space behind the glass. The performance of the interlayers at different temperatures varies by interlayer type. Consult the interlayer manufacturer for specific interlayer temperature limits.

Laminated glass, when properly laminated, will pass the Bake Test for 16 hours at 212°F (100 °C) in accordance with ASTM C1914 *Standard Test Method for Bake and Boil Testing of Laminated Glass*. Performance will vary with time and temperature above this limit and the laminate may visually show bubbles and/or slight yellowing, typically at or near the edge. Consult the interlayer manufacturer for specific interlayer temperature limits.

The glass strength charts presented in ASTM E1300 *Standard Practice for Determining Load Resistance of Glass in Buildings* assume an interlayer temperature of 122°F (50°C) when calculating the short duration load resistance and the center of glass (COG) deflection for laminates exposed to the specified wind loads. The shear relaxation modulus of interlayers changes with temperature and duration of load.

For more information on laminated glass and temperature capabilities and performance, refer to the NGA Laminated Glazing Reference Manual and consult with the interlayer manufacturer or supplier.

Product Awareness

As the design thickness of multiple plies of heat-treated glass and/or glass and plastic material increases to meet application requirements, the potential for distortion of images viewed through the glazing also increases. The bonding of multiple surfaces accentuates distortion as a result of the inherent variations in flatness of the component materials. Design professionals and building owners must be particularly aware of these characteristics in applications that involve viewing moving objects through the glass.

It is essential that design professionals consult with fabricators and suppliers in the early stages of design and engineering, given the sophisticated nature of laminated glazing materials required for optimum performance in safety, security, hazard resistant and sound reduction applications. Awareness of the laminated glazing product construction and inherent characteristics of the laminated glazing can dramatically affect the design application. Design professionals and building owners are strongly encouraged to utilize full-size mockups for evaluating the appearance of the glazing system under the specific project conditions, lighting conditions, and surrounding landscape. Utilization of a mockup is an inexpensive and reasonable process to ensure the product(s) and project design(s) meet a client’s expectations.

References

- ASTM C1172 Standard Specification for Laminated Architectural Flat Glass
- ASTM C1349 *Standard Specification for Architectural Flat Glass Clad Polycarbonate*- www.astm.org
- GANA Glazing Manual- https://www.glass.org/resources/publications/manuals
- GANA Laminated Glazing Reference Manual- https://www.glass.org/resources/publications/manuals
- ASTM D4802 *Standard Specification for Poly (Methyl Methacrylate) Acrylic Plastic Sheet*

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