Lamination 101: Class in Session

by Carol Vargas

Whether you're just getting into the industry or have been in the field for years, following is a refresher/reminder of laminated glass codes, tests and current standards: Perfect timing before entering the hurricane season.

From about the time the first window was broken, glass manufacturers have looked for ways to improve the properties of this useful but brittle material. Of key concern was, and is, how to make glass stronger and more versatile. One way to achieve this is to laminate two or more pieces of glass together with a bonding interlayer. The multi-layer system provides impact resistance and versatility, and if the glass is broken, the bonding layer holds the resultant shards together. The interlayer can also be designed to resist puncture or penetration upon impact. Glass lamination thus makes for a more valuable product for window and door manufacturers, designers and architects. Laminated glass can provide hurricane resistance, safety, security, noise reduction and other benefits that make its additional processing and costs well worth it. What follows is a brief description of how glass is laminated, the benefits that it can provide, and how those benefits are measured for certain applications.

Technology

There are several methods by which two or more layers of glass can be bonded together. The traditional method is through the use of a film such as PVB (polyvinyl butyral). PVB film has been used to laminate glass since the 1930s, and new types of laminating films such as thermoplastic ionoplasts have been developed recently to provide improved performance for certain applications. The film is placed between the glass, the air is removed from between the film and the glass by a vacuum, and heat and pressure is used to bond the layers together. This process generally takes place in an autoclave. Glass laminates can also be made with several film interlayers, such as a combination of polycarbonate and polyurethane, where the polyurethane provides the adhesive layer that bonds the polycarbonate to two outside lites of glass. These laminates are generally made by the same process as single interlayer PVB, through the heat, pressure, and vacuum of an autoclave. Another method of glass lamination is through the use of a liquid system. This method does not require an autoclave and typically represents a much lower investment for the laminator. The liquid is pumped between the glass layers, where a double-sided tape provides the dam to hold the liquid in and establish the interlayer thickness. Upon controlled exposure to heat or light, a chemical reaction occurs that allows the liquid to form a solid polymer that bonds with the glass. Whatever the technology used, the laminated glass must remain completely bonded together, must not noticeably discolor or weather over time, and must be shown to meet the testing standard requirements for its particular application.

Table 1. Important Hurricane Resistance Standards and Tests

Organization	Code
ASTM International	E1886-97 Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Storm Shutters Impacted by Missiles and Exposed to Cyclic Pressure Differentials E1996-02 Standard Specification for Performance of Exterior Windows, Glazed Curtain Walls, Doors, and Storm Shutters Impacted by Windborne Debris in Hurricanes
AAMA	506-00 Voluntary Specifications for Hurricane Impact and Cycle Testing of Fenestration Products
Texas Department of Insurance	TDI-98 Impact Protective Systems for Windborne Debris
International Building Code	Section 1609.1.5
Florida Building Code	TAS 201, 202, 203: impact testing, static air pressure, and cyclic wind pressure loading test

Hurricane Resistance

In 1992, Hurricane Andrew, a Category 4 storm packing maximum wind gusts in excess of 170 miles per hour, made a direct hit on the heavily populated south Florida coast near the city of Miami. The damage was more than $30 billion in terms of property losses. Thousands of homes were destroyed. As a response, a new building code for Miami-Dade established tougher specifications to make homes and buildings more hurricane-proof. Similar codes extend to other coastal areas prone to high winds from hurricanes, since nearly one third of new home construction in the United States is within a coastal region or windborne area. 2004 provided another reminder of the danger of hurricanes, with an unprecedented four major Category 2 or higher storms: Charley, Frances, Ivan and Jeanne—all striking the state of Florida and other South-eastern states in less than a two month period. Since windows are an important part of a building's envelope and a potential weak spot during a hurricane, an important focus of hurricane codes is increasing the strength and fortification of the fenestration system. Laminated glass provides an excellent way to improve window hurricane resistance.

During a strong hurricane, high winds flow over a building and create a pressure differential, similar to what lifts the wings of an airplane. High winds from a hurricane are also subject to shifts and changes in intensity over a period that can be several hours. If the building's envelope, including windows and doors, is not secure, this cycling pressure and suction can lift a roof right off of the building, leading to its destruction. Standard single layer glass windows can be shattered by windborne debris, leading to potential failure of the building envelope. One way to protect windows is to install hurricane shutters, though this can be time-consuming and quite literally leave homeowners in the dark when they return after the hurricane. High-performance laminated glass provides an option that can give a building round-the-clock protection without the need for the owners, along with hundreds of their neighbors, to run to the hardware store for plywood and nails.

Figure 1: In the small missile impact test, the glazing system must survive impact without tears or holes larger than specified, after which it is then subjected to 9000 cycles of positive and negative windload pressure.


Figure 1


Figure 2

Figure 2: In the large missile impact test, structural glazing systems below 30 feet are tested with two impacts by a nine-pound, eight foot 2-by-4 timber, fired at a speed of 50 feet per second.

There are two main tests that are part of most hurricane resistance testing protocols, including the Miami-Dade protocol. These are the impact test and the cyclic loading test. For high wind velocity zones, structural glazing systems below 30 feet are tested with two impacts by a nine-pound, eight foot 2-by-4 timber, fired at a speed of 50 feet per second, as shown in Figure 1. This is the large missile impact test. Structural glazing above 30 feet is hit three times by ten steel ball bearings, each weighing two grams. This is the small missile impact test. The glazing system must survive impact without tears or holes larger than specified, after which it is then subjected to 9000 cycles of positive and negative windload pressure, as shown in Figure 2. The glazing system cannot have large rips (more than 5 inches) or tears or pull out of the frame in such a way as to sacrifice the integrity of the building

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Table 2. Safety Testing and Standards

Organization	Test Method	Test Type
ANSI	Z97.1 Safety Performance Specifications and Methods of Tests for Safety Glazing Materials used in Buildings	Pendulum falling bag test, 100 lb. filled with lead shot
Consumer Product Safety Commission	CPSC 16 CFR 1201	Pendulum falling bag test, 100 lb. filled with lead shot, different drop heights depending on the category

envelope. For building code approval, these tests are performed at independent certified testing laboratories.

Safety and Security

Just as laminated glass can help protect the building envelope in a hurricane, it can also provide protection against theft, bullets, bomb blast and from other flying objects. Laminated glass, because it helps keep broken glass shards together, reduces the chances of glass shards cutting or piercing a person impacting the window or door. Safety glass laminates are also used in automotive applications to reduce injury from broken glass and to keep occupants from being thrown outside of the vehicle. Security glass laminates can be used in storefronts, jewelry cases, detention systems, commercial buildings, government buildings and residential homes to protect against forced entry. The level of safety or security desired will determine the need for single- or multiple-interlayer systems and the type of laminate needed. For safety applications where one is only looking for protection for a human body impacting the glass, or for minimal or low level security applications where one is only looking for basic protection against "smash and grab" type theft, a single interlayer laminate may be sufficient. For other applications, such as bullet resistance and resistance to more severe cases of forced entry, multiple layers of all-glass or glass-clad polycarbonate may be necessary. Table 2 and Table 3 list some of the most common safety and security tests.

Table 4. Acoustic Test Methods and Standards

Organization	Test Method
ASTM International	E 413 Classification for Rating Sound Insulation (STC) E 1332 Standard Classification for Determination of Outdoor-Indoor Transmission Class (OITC) E 90 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions E 1408-91 (1995)e1 Standard Test Method for Laboratory Measurement of the Sound Transmission Loss of Door Panels and Door Systems E 1425-91 (1999) Standard Practice for Determining the Acoustical Performance of Exterior Windows and Doors
International Standard (ISO)	R140-3 Laboratory Measurements of Airborne Sound Insulation of Building Elements (Rw)
AAMA	1801-97 Voluntary Specification for the Acoustical Rating of Windows, Doors, and Glazed Wall Sections

Table 3. Security Testing and Standards

Organization	Test Method	Test Type
ASTM	F1233-98 Standard Test Method for Security Glazing	Resistance to ballistic impact, blunt tool impacts, sharp tool impacts, thermal stress, and chemical deterioration
Underwriters Laboratory	UL 972	Burglary Resistant Glazing Material: Ball Drop with 5 lb. steel ball
H.P. White Laboratory	TP-500.03	Ballistics and forced entry testing, similar to ASTM test above
National Institute of Justice	NIJ STD-0108.01	Ballistics test
Underwriters Laboratories	UL 752	Ballistics and forced entry testing, similar to ASTM test above

Bomb-Blast Protection

In an era of heightened danger from terrorist attack, laminated glass is often the preferred glazing solution for protection against bomb blast. Combined with structural designs to keep the glass attached to the frame and wall system, laminated glass helps keep broken shards together in a blast event, thus reducing the risk of injury and better absorbing the blast force. ASTM F1642 (Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings) and GSA-TS01-2003 describe protocols for performing tests on glazing systems to evaluate their performance under blast loads. The window system is subjected to an airblast load from an explosive charge or shock tube to produce the desired pressure and impulse and the desired pressure-

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time waveform characteristics. The performance and the related hazard levels are categorized based on the condition of the window and the "post-test location of fragments and debris relative to the original (pre-test) location of the window." If the glazing does not break and there is no visible damage to the glazing or frame, it is rated a 1, or "safe" protection level, with no hazard. If there is cracking of the glazing, then it is rated from 2-4, a "very high" to "medium" protection level, depending on the size of dust or fragments and their location relative to the original window position. Catastrophic window system failure, or when fragments impact a witness panel 10 feet away at a height greater than 2 feet, would be rated a 5, a "low" protection level. The use of laminated glass in the window system can improve the performance rating and greatly reduce the hazard.

Acoustics

Windows are one way through which sound can enter a building, so in areas where noise control is necessary, laminated glass can provide some assistance. Laminate interlayers can provide sound damping properties that can make sounds from outside less audible to those inside a building. Some types of interlayers are designed specifically for acoustic performance, and are used in applications such as hotels in downtown areas or homes located near busy roads or airports.

Acoustic performance of laminated glass is determined by looking at the sound transmission loss across an isolated test specimen. To make comparisons among different materials, a single number rating that expresses the performance over the given sound level measurement range is preferred. The acoustic performance of laminated glass is most often expressed with one of two single numbers that have roughly equal values, though they are calculated slightly differently. The Sound Transmission Class (STC) system is a part of ASTM E 413 "Classification for Rating Sound Insulation" and corresponds to the sound transmission loss for a "standard household noise" spectrum. The ISO Weighted Sound Reduction Index (Rw) is used in ISO R140-3, and is roughly the same as the STC rating, though the measurement range and calculation method are slightly different. Another more recent classification system is described in ASTM E 1332, and uses the "Outdoor-Indoor Transmission Class" (OITC) rating. This was developed to put more emphasis on low frequency incident sounds. Test methods related to acoustic performance are shown in Table 4.

Design

Besides having utilitarian uses for wind protection, safety, security and acoustic performance, laminated glass can be used to add beauty to architectural elements. Architects and artists can use glass lamination to add decorative elements such as colored or textured glass with added safety performance and strength. Figure 3 shows a decorative bar made with laminated textured glass. The interlayer itself can also be colored, and some artists and designers incorporate different decorative materials into the interlayers themselves. Bent glass can also be laminated, providing additional design possibilities.

Figure 3: Laminate with textured glass, such as that shown here, can add a decorative element to any application.

Summary

Laminated glass provides a diverse array of performance benefits. Its strength and impact resistance can protect lives and property from windborne debris, bomb blasts, ballistics, etc., while still allowing a clear view to the outside world when danger is not present. Laminated glass can reduce injury that can occur when a human body impacts a window or door. It can reduce noise entering a building, and allow for the use of new decorative elements in architecture and design. For nearly all of these benefits, new standards and tests exist to properly measure, compare, and evaluate laminated glass performance. Glass manufacturers, product designers, engineers, architects, artists and others will continue to play roles in utilizing and improving glass lamination, and it will continue to be an increasingly important part of window and door design. ■

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