Bomb Blast Resistant Glazing: Testing and Standards

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ABSTRACT

This presentation will focus on industry test methods and standards used to evaluate the performance of security glazing or glazing systems. Specific standards include two ASTM standards: ASTM F 1642 (airblast loadings), ASTM F 1233 (ballistics and physical attack); as well as the UL standards for burglary resistant glazing and bullet resistant glazing. These standards enable building owners and designers to better understand the performance of security glazing as a means of reducing the risk of personal injury and physical damage to a facility.

The U.S. State Department is engaged in an active embassy construction program that specifies the blast performance of security windows. Although the State Department requirements are substantially higher than other federal agencies, both General Services Administration (GSA) and Department of Defense (DoD) have adopted requirements for blast resistant glazing. An increasing number of commercial projects in major metropolitan areas are also incorporating requirements for blast resistant glazing.

In addition to increased security concerns, government agencies and private clients are also seeking enhanced energy performance. As this trend continues to develop, blast resistant glazing will need to deliver both security and energy performance.

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INTRODUCTION

As a means of keeping people and property safe, security glazing is used in a variety of building types, and can offer a range of protection features. Because these features vary from intrusion and bullet resistance to bomb blast and hurricane resistance, security glazing is a catchall phrase that can define a multitude of solutions. From a product development standpoint, security-glazing options have expanded over the years to include laminated glazing materials, applied films, and blast curtains and shades. In order to specify the appropriate security glazing solution, it is necessary to make assumptions about the level of performance required to resist the anticipated threat.

Test methods and specifications have been developed to address many threat scenarios, and software programs can speed up the process of selecting the proper type and thickness of security glazing. Three government agencies have taken the lead on testing and specifications for security glazing—General Services Administration (GSA), Department of State (DOS), and Department of Defense (DoD). Courthouse, embassy, and military housing projects sponsored by these agencies have afforded designers practical experience in the use of security glazing.

However, security is not the sole concern of these agencies. Other considerations do affect the use of security glazing in buildings. Minimum energy performance is specified in the building codes, as well as in the commercial energy standard ASHRAE 90.1. This often leads to the use of high performance glass and coatings to help minimize solar heat gain and reduce U values.

SECURITY GLAZING DESIGNED TO RESIST BOMBS

The first test method to be developed in the area of bomb blast was ASTM F 1642, Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings, published in 1996. The test method applied to glazing or glazing systems and provided a means of establishing the airblast resistance capacity of these materials through arena or shock tube testing. Following testing, a specimen was deemed to have failed if an opening was created in the glazing through which airblast pressure could pass or if spall from the specimen penetrated an aluminum foil witness panel placed twelve inches behind the test specimen.[1]

Ten years later, the American Architectural Manufacturers Association published their standard AAMA 510-06 Voluntary Guide Specification for Blast Hazard Mitigation for Fenestration Systems. This standard expands the industry's understanding of blast hazards by establishing system performance classifications. It creates categories of systems with standard test sizes, enabling manufacturers to test systems and evaluate and compare performance.

[1] ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

The guide specification requires testing that includes peak positive pressure, equivalent triangular load duration or impulse, and performance condition, also called the hazard level. This information often comes from the blast consultant working on the project.[2]

In 2006, ISO published two bomb blast standards--ISO 16933 (arena blast) and ISO 16934 (shock tube). Both standards present levels of classifying specific types of blast events in terms of measured blast pressures and impulses.

TABLE 1: ISO 16933—Vehicle Bombs[3]

Mean peak air blast pressure kPa	Mean positive phase impulse kPa-ms
30	180
50	250
80	380
140	600
250	850
450	1200
800	1600

[2]American Architectural Manufacturers Association, 1827 Walden Office Square, Schaumburg, IL 60173.

[3]ISO 16933 Glass in building—Explosion resistant security glazing—Test and classification for arena airblast loading, International Organization for Standardization, Geneva, Switzerland.

TABLE 2: ISO 16933 —Hand-carried Satchel Bombs[3]

Mean peak air blast pressure kPa	Mean positive phase impulse kPa-ms
70	150
110	200
250	300
800	500
700	700
1600	1000
2800	1500

TABLE 3: ISO 16934-- Explosion Resistant Glazing[4]

Minimum values	
Peak pressure P_C kPa	Impulse I_C kPa-ms
30	170
50	370
70	550
100	900
150	1500
200	2200

[4] ISO 16934 Glass in building—Explosion resistant security glazing—Test and classification by shock tube loading, International Organization for Standardization, Geneva, Switzerland.

GOVERNMENT STANDARDS

The government began to take an active role in developing test methods and specifications following the 1995 Oklahoma City bombing of the Alfred P. Murrah Federal Building. In response to the bombings that killed 168 people and injured many more, the President directed the Department of Justice (DOJ) to assess the vulnerability of federal facilities. DOJ recommendations included the creation of the Interagency Security Committee (ISC), a permanent body that would continue to address government-wide security concerns, classification of buildings into five levels in order to evaluate security requirements, and the review, establishment, and implementation of uniform construction standards related to security considerations.

GSA was the first to develop its GSA Criteria, a performance-based standard for security glazing. The goal of the GSA standard was to mitigate the consequences of an explosion, paying special detail to protecting personnel and the public from the hazards of flying glass. In 2001, the ISC Security Design Criteria was signed by 26 federal agencies. It was based largely on the work of GSA, and like the GSA Criteria, applied to new construction.

Flying glass is a major source of injury and/or death in an explosive attack. To prevent injury and loss of life during an explosive event, the first step is to ensure that the window system design is balanced. The glazing, frames, and anchorage must all be able to survive the blast loading in order for the overall system to provide adequate protection. If any one part of the system fails, then the entire system fails. Similarly, the supporting wall must be able to handle the loads imparted into it by the window system. If the window system has a higher capacity than the supporting wall, when the wall fails the entire window system may be blown into the facility.

GSA has developed a method of evaluating the protection offered by various window configurations. The performance conditions are characterized based on glass breakage within a ten-foot box. The GSA/ISC protection levels for glazing response to blast range from 1 (Safe Protection Level, No Hazard Level) to 5 (Low Protection, High Hazard Level). Glazing response varies based on the type of glass or system installed in the opening.

TABLE 4: GSA/ISC PROTECTION LEVELS[5]

Condition	Protection Level	Hazard Level	Description of Glazing Response
1	Safe	None	Glass does not break
2	Very High	None	Glass cracks but retained in frame
3 a	High	Very low	Glass cracks. Fragments land on floor no further than 3.3 feet.
3 b	High	Low	Glass cracks. Fragments land on floor no further than 10 feet.
4	Medium	Medium	Glass cracks. Fragments land on floor no further than 10 or height no greater than 2 feet above floor at witness 20 feet away.
5	Low	High	Glass cracks and catastrophic failure.

GSA notes that annealed glass is the most hazardous glass type for blast resistant performance. With an ultimate design stress of 4000 psi, annealed glass breaks into irregularly shaped pieces that can be propelled at high speeds and are capable of producing serious bodily injuries and even death. Heat strengthened glass has an ultimate design stress of 3500 to 7500 psi. Although it has a higher strength than annealed glass, it, too, breaks into longer shards of glass. Thermally tempered glass has an ultimate stress of greater than 10,000 psi. When it breaks, it breaks into small cube-shaped fragments that are the least hazardous.

Security window film in 4, 6, 7, or 11 mils applied to the interior glazing surface can also reduce explosive event hazards. The film can either be applied to the vision surface only, edge-to-edge (where the film extends into the window frame), wet-glazed (where the film is adhere to the window frame with silicone), or mechanically attached (where the film is screwed to the window frame with mechanical batten).

Blast curtains and shields can be used to mitigate the hazards from flying glass. They do not stop the window from breaking, but they are designed to catch and trap the glass shards before they can be propelled into the room.

Laminated glass, two plies of glass bonded together by an interlayer, can be engineered to provide very high levels of protection at blast pressure/impulse levels far greater than blast curtains and/or films. When laminated glass breaks, glass shards remain adhered to the interlayer, significantly reducing the risks associated with flying or falling glass.

[5] GSA-TSO1-2003—US General Services Administration Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings

Security measures comprise the core of the State Department master construction plan for U.S. embassies around the world. While hardening the windows, walls, and roof of these structures is a top priority, these buildings still attempt to achieve a sense of openness. State Department blast standards for embassies are higher than those of GSA, and in some embassy locations forced entry and ballistics protection are required.

SECURITY GLAZING DESIGNED TO RESIST PHYSICAL ATTACK

There are several tests that have been used to evaluate the ability of glazing to resist physical attack. The ASTM test F 1233, Standard Test Method for Security Glazing Materials and Systems, modeled on the H.P. White Laboratories test procedure HPW-TP-0500 Transparent Materials for Use in Forced Entry or Containment Barriers, includes blunt impacts from a sledge hammer, pipe, and ram; sharp impacts from a chisel/hammer, angle iron/sledge, pipe, fire axe, and wood maul; thermal attack from a fire extinguisher, propane burner, and acetylene torch, and chemical attack from gasoline, windshield washing fluid and acetone. The test can be preceded by three bullet shots. Another approach to physical attack testing is covered in ASTM F 1915, Standard Test Methods for Glazing for Detention Facilities, which presents specific security grades based on time and a sequence of blunt and sharp impacts generated mechanically in a test laboratory environment.

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TABLE 5: ASTM F1233 IMPACT SEQUENCES[6]

Impact type	Level 1	Level 2	Level 3	Level 4	Level 5
Blunt Impacts Sledge Hammer (25)		5	10,16	19,22,27	30,33,36,39
4 inch dia. Pipe/Sledge (25)			9	18	29
Ram (10)	N/A		8	17	28
Ball Peen Hammer (10)	1	2			
Sharp Tools Ripping Bar (10)		7	12	23	
Chisel/Hammer (25)	N/A	N/A	13	25	35,40
Angel Iron/Sledge (25)	N/A	N/A	15	N/A	N/A
1 ½ inches dia. Pipe/Sledge (25)	N/A	3	N/A	N/A	N/A
Fire Axe (25)	N/A	N/A	N/A	24	32,38
Wood Spliting Maul ((25)	N/A	N/A	N/A	21	34,41
Thermal Stress (minutes) CO2 Extinguisher (1)	N/A	4	N/A	N/A	N/A
Propane Torch (5)	N/A	6	11	20	31
Chemical Deterioration (Amount) Gasoline (1/2 pt)	N/A	N/A	14	N/A	N/A
Acetone (1/2 pt)	N/A	N/A	N/A	26	37

SECURITY GLAZING DESIGN TO RESIST BULLETS

The principal tests for assessing ballistics resistance are Underwriters' Laboratories (UL) 752 Standard for Bullet Resisting Equipment and NIJ 0108.01 Ballistic Resistant Protective Materials. Both standards specify rating levels, ammunition, grain, velocity, and number of shots. Bullet resistant laminates are typically designed to resist bullet penetration and flying glass fragments (spall). Laminate construction can be all-glass, glass-clad polycarbonate, or laminated polycarbonate.

[6] ASTM F1233-98 (Reapproved 2004) Standard Test Method for Security Glazing Materials and Systems, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

TABLE 6: UL 752 REQUIREMENTS[7]

Rating	Ammunition	Grain	Min. Velocity fps	Max. Velocity fps	Number of shots
Level 1	9mm Full Metal Copper Jacket with Lead Core	124	1175	1293	3
Level 2	.357 Magnum Jacketed lead Soft Point	158	1250	1375	3
Level 3	.44 Magnum Lead Semi-Wadcutter Gas Checked	240	1350	1485	3
Level 4	.30 Caliber Rifle Lead Core Soft Point	180	2450	2794	1
Level 5	7.62mm Rifle Lead Core Full Metal Copper Jacket, Military Ball	150	2750	3025	1
Level 6	9mm Full Metal copper Jacket with Lead core	124	1400	1540	5
Level 7	5.56mm Rifle Full Metal Copper Jacket with Lead Core	55	3080	3388	5
Level 8	7.62mm Rifle Lead Core full Metal Copper Jacket, Military Ball	150	2750	3025	5

[7] Underwriters' Laboratories (UL) Standard 752, Standard for Bullet Resisting Equipment, 333 Pfingsten Road, Northbook, IL60062.

SECURITY GLAZING DESIGNED TO RESIST VANDALISM

The most commonly used test method to determine the suitability of glazing for burglary resistance is Underwriters' Laboratories Test UL 972 Standard for Safety for Burglary Resistant Glazing Material. There are several parts to the UL test. In the basic test, a five-pound steel ball is dropped at a distance of 10 feet onto glass. The procedure requires multiple drops of the steel ball onto the same glazing specimen without penetration of the specimen. The complete test calls for the ball drop procedure to be conducted on specimens at various temperatures in an outdoor and indoor environment. There is also a high-energy impact test where the steel ball is dropped from a vertical height of 40 feet.

SUSTAINABILITY/ENERGY CODES

The Department of Energy (DOE) has proposed new, more stringent, requirements for energy efficient glazing. Programs like LEED®, Leadership in Energy and Environmental Design of the U.S. Green Building Council, call for energy performance beyond industry standards. To meet these requirements, solar control coatings such as Low-E's or Hybrid Low-E coatings can be incorporated into the glass make-ups to reduce solar heat gain and improve occupant comfort.

Some recently completed projects are outlined as case studies to illustrate that designers and developers are able to achieve the security levels required without surrendering aesthetic form or function. In addition to the case studies, several recent U.S. Embassy facilities have been built around the world incorporating stiff ionoplast interlayers in the glass laminates for extremely high security levels as well as solar control coatings to provide better energy performance. Some notable examples are the embassies in Kabul Afghanistan, Algiers, Algeria, and Managua, Nicaragua.

PHOTO CAPTION: WILKIE D. FERGUSON, JR. UNITED STATES COURTHOUSE

The Wilkie D. Ferguson, Jr. United States Courthouse in Miami, FL, posed a challenge for designers in order to meet the GSA Federal Courthouse security standards for blast resistance, as well as DOE requirements for energy efficiency, and Miami's rigorous building code for hurricane resistance. In addition, the building's design focused on natural daylight and beautiful views. The 578,000 square-foot space spans two city blocks and is one of the nation's largest federal courthouses. The approximately 200,000 square feet of exterior glass in 18 different configurations ranging from skylights to vertical wall facades features low-E insulating laminated glass. Architects Arquitectonica International Corporation and Hellmuth, Obata + Kassabaum chose combinations of glass substrates with low-E coating to allow high visible light transmission and limited solar heat gain. Both PVB and ionoplast interlayers were used for impact protection.

CONCLUSIONS

Security glazing enables a building to be both attractive and functional without jeopardizing the safety of occupants. Security glazing products fit into categories of performance that range from low level security, such as storefronts requiring smash and grab protection, to high levels of security, requiring both forced entry and ballistics protection. The proper choice of security glazing is dependent on understanding the desired level of performance.

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ASTM, ISO, and government standards are available to aid in the selection process. In 2008, large commercial projects incorporating security glazing are under construction in major markets from New York to Los Angeles. The architectural specifications for these projects have called out test methods and specifications to identify the proper performance of the glazing material. As security becomes more of a priority in building design, coupled with more stringent energy requirements, glazing systems will continue to offer both benefits.

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