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CMU Elastomers and Window Safety Films: Dual-Use Retrofit Technologies for Airblast and Wind-load Protection

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Abstract

Fragmentation failure of unreinforced masonry and glazing systems are among the leading causes of injury and death during terrorist and storm events. As a result, concrete masonry unit (CMU) elastomers and window safety films have gained popularity as cost-effective alternatives to conventional reinforcement and high-strength or laminated glass, especially for building retrofits. Elastomeric spray-on coatings have shown to greatly improve tensile strength of infill masonry walls exposed to blast loads. Various combinations of wet glazed films and mechanical attachment systems, including those satisfying ASTM F1642 for glazing systems subject to airblast loadings, have been shown to meet windload and debris impact standards, including ASTM E1996 standards adopted by the International Building Code (IBC). Both technology concepts allow non-ductile wall and glazing assemblies to deform rather than fail in a sudden and catastrophic manner under non-point load wind overpressure, point load projectile impact, and positive and negative phase airblast loading. In addition, both technologies require little or no impact to existing building components and minimal loss of space use during retrofit.

Keywords

Airblast loading, cyclic wind loading, impact resistance, International Building Code (IBC)

1. Introduction

As the most vulnerable components in the building envelope, unreinforced masonry and glazing systems have not only proven to be the leading cause of injury and death in terrorist attacks, these systems have also been the primary failure mechanism for structures exposed to wind loads and projectiles during major weather events. An unprecedented hurricane season in 2004 saw four major hurricanes with sustained winds ranging from 105-145mph at landfall, impact 60 of 67 counties in Florida within a span of six weeks. These storms left more than 3,000 people dead, including 152 in the U.S., making 2004 the deadliest hurricane season since 1969 when a category 5 hurricane named Camille devastated coastal Louisiana. The 2004 hurricanes also caused over $US 42B in damage, more than any other hurricane season or natural disaster in U.S. history (Explores!, 2004).

In spite of the increasing threat of both natural and human-caused hazards, the capital required for replacing conventional glass with high-strength or laminated glass is often prohibitive, as is retrofitting unreinforced masonry. As a result, safety films and spray on elastomers have been developed to incorporate as much of the existing envelope into the retrofit as possible to minimize costs as well as reduce loss of space use during the retrofit. The following paper presents research into such "dual use" technologies and the potential for developing cost effective all-hazard mitigation.

2. Window Safety Films

Window safety film can be used to increase the failure strength of existing commercial glazing assemblies and reduce glass fragmentation. Combined with appropriate structural silicones for wet glazing or the use of mechanical perimeter anchoring, safety films may greatly improve the survivability of building fenestration during storm or blast events. Safety films can be laminated to the interior surface of the glazing system and mechanically attached to the frame to offer maximum levels of protection. Safety films have proven most effective when attached to the frame of the window, distributing loads to framing members rather than the glazing perimeter alone. Most suitable anchoring systems incorporate smooth curves rather than sharp angles to prevent tearing of the film under rapid load. Since a combination of commercially available safety films, adhesives and anchoring systems exist, and since retrofit does not involve the replacement of the existing glazing system, retrofit may be accomplished at cost significantly lower than replacing existing glazing with safety glass.

2.1. Airblast Testing

The U.S. General Services Administration (GSA) has been active in the development of criteria related to glass fragment mitigation including establishment of design loads and required levels of protection since the early development of the GSA Draft Security Criteria. Based largely on ASTM F1642, GSA developed a “Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings,” since updated in January 2003 to the GSA “Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings”. Category C facilities, or those facilities under moderate threat levels, such as a GSA field office with <450 employees and <150,000 ft$_2$ (14,000 m2) of floor area, require window fragment protection from blast loads with a peak pressure of 4 psi (27.58 kPa). A performance condition “4” (Table 1) is permitted for Category C facilities. GSA specifications which do not comply with ASTM F1642 criteria include the number of test specimens (3 minimum) and the fail criteria. ASTM F1642 requires a failure rating for any penetration in the daylight opening. The GSA fail criteria is determined by what extent the glass is retained by the frame and how far glass fragments travel.

Table 1: GSA Performance Conditions for Window Systems Response (GSA, 2003)

Performance Condition	Description	Fragments Exterior to Structure	Fragments Interior to Structure
1	Glass not cracked, fully survived and/or fully retained by frame and no glass fragments either inside or outside structure.	None	None
2	Glass may be cracked but is retained by the frame.	Yes	No significant fragments. Dusting or very small fragments near sill or on floor acceptable.
3a	Glass failed and not fully retained by the frame.	Yes	Yes – land on floor no more than 40 inches from window.
3b	Glass failed and not fully retained by the frame.	Yes	Yes – land on floor no more than 10 ft from window.
4	Glass failed and not fully retained by the frame.	Yes	Yes – land on floor more than 10 ft from window and impact vertical surface located not more than 10 ft behind window and no higher than 2ft above floor level.
5	Glass fails catastrophically.	Yes	Yes – land on floor more than 10 ft from window and impact vertical surface located not more than 10 ft behind window above a height of 2 ft.

In March 2004, ABS Consulting conducted blast testing on twenty-seven (27) windows in accordance with GSA test protocols. Simulated blast loads were applied using a “shock tube”, a device that generates a sudden burst of compressed air that applies a blast pulse to a test specimen attached to the end of the tube. Test specimens consisted of monolithic and insulated annealed glazing with daylight openings measuring 47 inches x 66 inches. Frames consisted of extruded aluminum with glass secured by gasket or structural silicone. Deviating from both GSA and ASTM protocols, blast loads were repeated or increased until failure for glazing that did not fail on the first test. Following each test, glass fragments were collected and weighed by zone in the test enclosure. Fragments striking and embedding in a “witness panel” of foam board positioned vertically 10 feet from the test specimens were collected and documented. GSA performance conditions for each test were assigned (Table 2, Fig. 1-2).

Table 2: Sample measured blast loads test specimens (Barker, 2004)

Test No.	Specimen	Mass of Glass by Zone (g)		Penetrations number / depth (mm)		GSA Performance Condition
		3A	3B	4	5	
1	¼” monolithic AG, no upgrade	2,239	26,399	-	2/16	5
14	¼” monolithic AG, 8-mil safety film, mechanical attachment on 4 sides	0	0	-	-	2
16	¼” insulated AG w/ ½” AS, 8-mil safety film, mechanical attachment on 2 sides	40	5	-	-	2
18	¼” insulated AG w/ ½” AS, 8-mil safety film, wet glazed 4 sides w/ struct silicone	4,990	4,990	-	-	3B

AG = Annealed Glass, AS = Air Space

Figure 1: Test specimen 1 (Barker, 2004)

Figure 2: Test specimen 14 (Barker, 2004)

2.2. Windload Testing

Perhaps a more eminent threat than terrorist use of explosives are wind loads and airborne debris from major weather events. In March of 2001, American Test Laboratories of South Florida (ATL) conducted ASTM E1996 "Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Storm Shutters Impacted by Windborne Debris in Hurricanes" on 3/16 inch (4.76 mm) tempered sliding glass doors laminated on the inside surface with an 8-mil safety film. The daylight opening on the test specimens measured 45 inches (1.14 m) wide and 91 inches (2.31 m) in length. Doors were pocket glazed on extruded aluminum using a 3/16 inch (4.76 mm) vinyl gasket with a 0.522 inch (13.26 mm) bite. The perimeter was wet glazed using a structural silicone with a 0.340 inch (8.64 mm) overlap on the glass. In accordance with ASTM E1996, large missile impact testing consisted of projecting a #2 Southern Yellow Pine 2 inch (50.8 mm) by 4 inch (101.6 mm) cross-sectional timber, approximately 47.5 inches (1.21 m) in length and 4.5 lbs (2.04 kg) in weight, at three test specimens, A, B and C. The projectile impacted each test specimen at 40.3 ft/sec (12.28 m/sec). None of the impacts penetrated the specimens and there was no separation of the glass from the glazing systems. Following impact testing, cyclic wind load simulation (cycle) tests were then conducted on the test specimens. Specimens showed no resultant failure or duress after cycle tests and no separation of glass from the aluminum frame (Hattem et al., 2001)

3. CMU Elastomeric Coatings

Steel or reinforced concrete structures with infill masonry unit walls are a common type of envelope construction throughout the U.S. Unfortunately, unreinforced masonry offers little protection from lateral wind or airblast loads. When subjected to these overpressures, infill walls typically disintegrate and cause considerable injury and loss of life to occupants from fragmentation. Conventional methods of retrofitting existing CMU walls with high-tensile strength materials such as steel reinforcing and cast-in-place concrete (CIP) or secondary interior steel framed channels and partitions can result in considerable cost and impact to existing building systems, as well as extended loss of space use during retrofit.

A new approach consists of the use of high-tensile strength spray-on elastomers. An elastomer is composed of long polymer chains, usually cross-linked or connected by chemical bonds (DoD, 2002). Cross-linking makes elastomers reversibly stretchable within a range of deformations. The technique of using elastomer wall coatings on the interior surface of unreinforced masonry takes advantage of the toughness and resiliency of new polymer materials to effectively absorb and dissipate airborne projectile and blast overpressure energy while containing wall fragments. The retrofit method applies directly to buildings with steel or reinforced concrete and non-load bearing CMU in-fill walls. A 0.25" polymer coat is applied to the interior of the CMU wall with a six inch (6") minimum bonding overlap onto structural members to distribute airblast or windloads to the structure (DoD, 2002). The polymer allows the wall to deform rather than fail in a sudden and catastrophic manner from applied lateral loads. Once cured, the polymer is non-toxic. The volatile organic compound (VOC) emissions are below National Institute for Occupational Health and Safety (NIOSH) time weighted averages for continuous 10-hour exposures 24 hours after being applied. The CMU wall assembly coated with the polymer meets the temperature and structural requirements of ASTM E 119 Standard Test Method for Fire Tests of Building Construction and Materials, for a period of 120 minutes without any significant impact on the assembly fire rating (DoD, 2002). Elastomers may be applied to interior finish gypsum wallboard without the need to remove wallboard and furring strips attached to CMU walls. The surface is impervious to water and may provide added flood protection, reduced air infiltration (energy savings) and ease of maintenance. Pigments can be added to the polymer to produce desired wall colors and textures.

3.1. Airblast Testing

Figures 3 and 4 below show airblast testing conducted 31 July 2002 at Tyndall AFB, Florida. A 15-mil safety film was mechanically attached to fenestration framing and spray on elastomer applied to unreinforced masonry connected in shear to the test article at the top and bottom of the wall. Airblast positive phase pressure loads exceeding 30 psi (206.85 kPa) were recorded from the detonation of 1,000lbs (453.6 kg) of ammonia nitrate fuel oil (ANFO) at approximately 50 feet (15.24 m). Unprotected, monolithic annealed glass and unreinforced masonry would typically fail at 2 and 5 psi respectively. As a result, the wall section in this test survived largely intact while experiencing blast loads more than six times its expected lateral yield strength. Since the force of the blast wave corresponds logarithmically to the proximity of the explosive device, these retrofit measures would enable a one-half reduction in stand-off distance.

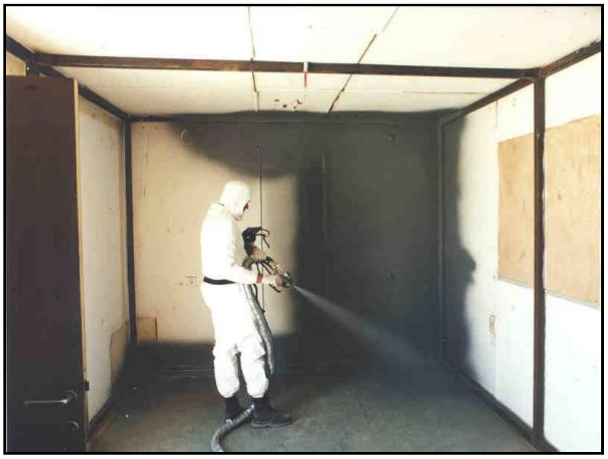

Figure 3: Pre-test elastomer application, TAFB, 2002

Figure 4: Post-test elastomer survivability, TAFB, 2002

4. Benefit-Cost

According to a 1999 University of Florida technical report, the average window protection costs for fixed panels, roll-down shutters and impact resistance glass ranges from $10.28 to $30.04/sf (Shanker, 1999). According its product developer, Madico Inc., the cost for ASTM E1886 or Miami-Dade comparable 15-mil safety film and perimeter anchoring is approximately $9.50/sf-$15.00/sf. The glazing films provide a marginal insulation value (U-value) benefit but may soon be developed to provide spectrally selective or low-emissivity (LoE) energy savings.

According to the Department of Defense ETL 02-4, Airblast Protection Polymer Retrofit of Unreinforced Concrete Masonry Walls, the material cost for the elastomeric masonry coating during test and evaluation was approximately $5.50/sf, although this cost could be expected to decline with market entry. As an impervious material, the elastomer wall coating would additionally provide water protection during storm or flood events, and would likely result in added moisture and outside air infiltration control to mitigate “sick building” bio-growth and reduce both sensible and latent HVAC loads for added energy savings. The elastomer may also provide an easily washable, durable interior surface applied with desired texture and color pigmentation for aesthetics. These and other dual-use retrofit alternatives are being explored not only for their apparent potential to mitigate both natural and unnatural hazards, but also for their potential to partially or fully subsidize their cost through everyday operations and maintenance savings.

5. Conclusion

This paper illustrates that building technologies meeting natural hazard standards are capable of addressing a new era of human-caused hazards. Recommended is an all-hazards approach to next generation test standards and building codes to minimize costly code duplication and testing required of protective building materials and products. Integrating natural and human-caused hazards within the international code sanctioning body will not be without challenges as many existing standards are only applicable to certain geographic regions, occupancy groups and exposure categories. However, many of the same characteristics that make buildings vulnerable to natural hazards, also make buildings vulnerable to terrorism.

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