NISTIR 5779

Polymer Film Applied to Glass: Effectiveness at Mitigating Damage from Flying Glass Due to Explosions

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Prepared for:
General Services Administration
Public Building Service
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Washington, DC 20405

CONTENTS

ABSTRACT

Prompted by the terrorist attack in Oklahoma City, the Department of Justice has recommended the application of polymeric film to exterior glass in Federal buildings to reduce the possibility of damage resulting from flying glass from explosive blasts. Before deciding to undertake an extensive retrofit of all Federal facilities, the General Services Administration (GSA) requested the National Institute of Standards and Technology's (NIST) Building and Fire Research Laboratory (BFRL) to search pertinent English language bibliographic databases for research reports, test data or other available information in the literature on polymer film applied to monolithic glass. The scope of the literature search included: 1) blast effects on architectural glass; 2) performance of polymeric film on glass under blast conditions; and 3) the application, durability and maintainability of polymeric films on glass. This report does not address or attempt to assess the performance characteristics of any other glazing product, composite or application. The documentation available to date does not contain statistically significant evidence indicating that the use of polymer film as a retrofit on the daylight surface of monolithic glass measurably reduces the possibility of damage due to flying glass from explosive blasts.

1. INTRODUCTION

Prompted by the terrorist attack in Oklahoma City, the Department of Justice has recommended the application of polymeric film to exterior glass in Federal buildings to reduce the possibility of damage resulting from flying glass from explosive blasts. Before deciding to undertake an extensive retrofit of all Federal facilities, the General Services Administration (GSA) requested the National Institute of Standards and Technology's (NIST) Building and Fire Research Laboratory (BFRL) to search pertinent English language bibliographic databases for research reports, test data or other available information in the literature.

The scope of the work included:

• Blast effects on architectural glass
• Performance of polymeric film on glass under blast conditions
• The application, durability and maintainability of polymeric films on glass.

We contacted film manufacturers and performed on-line literature searches of several databases:

• RAPRA Abstracts (1972-1995/Aug. © 1995 RAPRA Technology Ltd., Engineering Index)[1]
• Ei Compendex*Plus (TM) (1970-1995/Oct. © 1995 Engineering Info. Inc.)
• National Technical Information Service (NTIS) Database, (1964-1995)
• Architectural Database (1978-1995)
• Defence Technical Information Center (DTIC)

We used the relevant keywords (blast, explosion, impact, glass, polymer, film, coating, hurricane, and earthquake). This search yielded literature which we categorized into five sections:

A) Standards and Regulations
B) Reports on Behavior of Various Types of Glass and Other Glazing Materials Under Lateral Pressures
C) Reports Containing Information on Behavior of Various Types of Glass Under Impact Loads,
D) Reports on Blast Effects on Glass
E) Product Literature

This report does not address or attempt to assess the performance characteristics of any other glazing product, composite or application.

We examined the literature contained in all these sections to minimize the possibility that important references to studies of blast effects on glass would be missed. This document summarizes the literature yielded by our search. A bibliography organized under the five sections outlined above is attached. A copy of each of the items in the bibliography is also supplied.

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1. Certain trade names and company products are mentioned in the text or identified in an illustration in order to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

2. SUMMARY

2A. Standards and Regulations.

None of the documents in this category were found to contain any information directly relevant to behavior under blast loading. However, information pertaining to behavior under impact loading is available.

According to the definition of the American National Standard for Safety Glazing Materials Used in Buildings -- Safety Performance Specifications and Methods of Test (ANSI Z97.1-1984), safety glazing materials are designed to promote safety and to reduce or minimize the likelihood of cutting and piercing injuries when the glazing materials are broken by human contact. Examples of safety glazing materials include: laminated glass, consisting of two or more sheets of glass held together by an interlayer of plastic material, which will crack and break under sufficient impact but whose broken pieces will tend to adhere to the plastic and not to fly; tempered glass which, when broken, tends to break into innumerable small granular pieces; wired glass; plastic safety glazing material; organic coated glass whose pieces, after breakage under sufficient impact, will tend to adhere to the coating and not fly; and safety insulating units, where two or more sheets of glazing material, at least one of which complies with the standard, are separated by one or more air spaces.

Part 1201 of the Safety Standard for Architectural Glazing Materials (Code of Federal Regulations (CFR) Title 16, 1994) indicates that about 230,000 days of restricted activity were due to injuries, treated in emergency rooms, from architectural glazing products (the period during which those injuries occurred is not specified). The Standard notes that organic coated glass which has the film applied to annealed glass at the factory may no longer be available for use in architectural products other than certain products (Category II) having no single piece of glazing material with area in excess of 0.83 square meters (see also Section C below). The reason indicated in the Standard is the inability of organic coated glass to pass impact test provisions of the Standard.

In conclusion, no information directly or indirectly useful for the assessment of behavior of glass under blast loads was found in the standards and regulations yielded by the search. However, a newly approved ASTM test method F1642-95 titled "Standard Test Method for Glazing and Glazing Systems Subject to Air Blast Loadings." has been developed by ASTM task Group 12.15. This test involves an open-air-blast where the glazing material or glazing system must remain in it's frame and must maintain closure of the building envelope so that the blast pressure does not enter the building in 3 out of 3 tests. Some spalling of glass will be allowed but no penetration of the witness panel to the rear of the specimen can occur. The Standard test method is in press.

2B. Reports on Behavior of Various Types of Glass and Other Glazing Materials Under Lateral Pressures.

A number of reports found during the search are concerned with behavior under lateral pressures. Reports on annealed and heat-treated glass and on laminated glass deal with behavior under short duration loads, such as gusty wind, and longer duration loads, such as snow. In addition results on temperature effects for laminated glass are included. Some of these results are based strictly on pressure tests. Others are based on stress distribution and fracture mechanics theory used in conjunction with experimental results for both new glass and aged glass. However, none of the results available in the reports concerning behavior under lateral pressures provides information applicable to assessment of behavior under blast loads.

2C. Reports Containing Information on Behavior of Various Types of Glass Under Impact Loads.

The report "Dynamic Racking Performance of Curtain Wall Glass Elements" by Deschenes, Behr, Pantelides and Minor (1991) has some relevance to the problem of glass behavior due to blasting effects insofar as the latter include inter-story drift. The tests did not involve blast pressures, however. Monolithic annealed glass with a film backing is among the types of glass for which test results are given in the report. It was found that the adhesive film prevented small fragments from falling out, but caused whole glass panels to fall out after severe cracking had occurred. Other reports provide information on behavior under cyclic loads simulating windstorm environments. In the report "Reducing Glass Fallout from Tall Buildings During Windstorms and Earthquakes" by J. Minor it is pointed out that the best performance under cyclic pressure loading and repeated impact by missiles occurred for heat-strengthened laminated glass with a poly(vinyl butyral)/poly(ethylene terephthalate)/poly(vinyl butyral) (PVB/PET/PVB) interlayer.

In the paper "Damage to Polymer-coated Glass Surfaces by Small Particle Impact" Chaudri and Smith (1991) concluded that soda-lime glass coated with 0.06 mm thick self-adhesive tape or a 0.35 mm thick polyurethane rubber layer provides very little protection to damage due to impact by 1 mm steel spheres with velocities over 100 m/s. This is attributed to the high strain rate induced by the dynamic loading. It is not clear whether the behavior under impact by spheres can be correlated quantitatively with behavior under blast loads.

The Cologne, Germany railway station was recently covered with plastic (polycarbonate) glazing with an ultraviolet radiation absorbing coating. According to a paper by P. R. Szigeti (1984), the behavior of this composite under impact by hail loads was found to be satisfactory.

ETL Testing Laboratories reports (1991) include results of impact tests conducted in accordance with CFR Title 16 part 1201 (see Section A above). The reports conclude that organic coated glass (3.2 mm (1/8 in) annealed, 6.4 mm (1/4 in) annealed, and 6.4 mm (1/4 in) heat strengthened) retrofitted with 3M (SH4 CLAR) overlay film, trimmed to the sight line (daylight application) of a window pane (rather than to the glass edge), did *not* comply with 16 CFR 101 requirements for Category II safety glazing.

2D. Reports on Blast Effects on Glass

The report "Survey of Window Glass Broken by the Oklahoma City Bomb on April 19, 1995" (Norville et al., May 1995) documents the response of a variety of types of glass to blast effects. It offers a detailed photographic record of the glass breakage resulting from the detonation of the bomb (~2000 kg) in front of the Alfred P. Murrah Federal Building. The photographs were taken by the authors of the report on April 20 and 21, 1995. The report divided the area around the blast into three zones: buildings in Zone 1, within a 1 to 2 block radius of ground zero, suffered extensive glass breakage and structural damage, buildings in Zone 2, within a 2 to 4 block radius of ground zero suffered moderate damage, and buildings in Zone 3 lying between 4 and 20 blocks from ground zero, suffered only sporadic glass breakage. The report cites many instances where polymer film on glass appeared to have either fallen out of the frame and/or incompletely retained the glass fragments. At the Fred Jones Manufacturing building (in Zone 3) the only glass that was fractured by the blast was the store front glass that had polymer film attached over the daylight surface. The glass panes with film shattered, the panes fell out of the frame and scattered glass pieces out on to the sidewalk and into the building. The monolithic annealed glass in the store front window without film did not break. The report shows that in most cases laminated glass windows, installed in and around the entrances to many buildings, in Zone 1 and Zone 2, broke without scattering glass shards and remained in the frame.

The article "Terror Strikes Oklahoma City" by Conrath and Walton (1995) summarizes the U. S. Army Corps of Engineers survey of the site. The article states that "glass fragments that became high velocity projectiles or that fell from high-rise windows presented an added danger. Some fragments penetrated several layers of gypsum wallboard and still had enough velocity to stick in the next wall layer. Even where fragment retention film had been used on the glass, fragments had broken loose. Both close in and far away from the blast laminated glass survived best. ... Even when the laminated glass broke, it remained in the window frame."

In the report "Tests of Blast Resistant Windows with Dupont Spallshield™ Composite," Norville (1995) examines Spallshield™ composite, which consists of a 0.18 mm thick PET film laminated to either monolithic annealed or annealed laminated window glass with a 0.76 mm thick layer of PVB. Three tests were performed at two blast over-pressure ranges (213-275 kPa and 72-93 kPa) for each of three nominal 6.4 mm (1/4 in) thick glazing materials (annealed laminated glass, annealed monolithic glass with Spallshield™ applied edge-to-edge, and annealed laminated glass with Spallshield™ applied edge-to-edge) which were mounted in specially designed steel frames. The report concludes that annealed monolithic and annealed laminated glass with nominal 6.4 mm (1/4 in) thickness used in conjunction with Spallshield™ composite is an effective blast resistant glazing material if the glazing (glass and film) is captured securely in a properly designed frame. The report also concludes that Spallshield™ composite helps to reduce glass spall under blast loading.

A recent report "Shatter Resistant Films" published by the Australian Bomb Data Centre examines "the effectiveness of the "Scotch Shield" shatter resistant film produced by 3M corporation." This study concludes "the 3M films greatly enhance the protective capability of the glass. ... The use of such film is recommended as an element of blast protective measures." Only one test of each type of glass was run so the statistical significance of the data is limited. Furthermore, the glass/film combination remained in the frame in only one test at the 236 kPa blast overpressure level, though 7 tests were performed on various glass with film combinations at this blast intensity. In the copy of the report that BFRL obtained the annex (G) containing information regarding the framing of the window/film combination was absent. Therefore we were not able to determine from the report if the film was captured in the frame or applied only to the daylight surface of the glass. The report cautions "The use of shatter resistant films will not guarantee safety to all personnel; in some cases the entire window came free of the frame and fell to the ground, such an event may cause injury to a limited number of people."

In "Resistance of Architectural Glazing to Small Bomb Blasts," Norville (1991), reports on a research program in which over 300 window glass and window glass constructions were subjected to detonations equivalent to 4.5 kg of TNT. The conclusions state "Security film applied to monolithic window glass ... as a retrofit protective device, although probably better than nothing, does not strengthen the glass to which it is applied nor does it aid in maintaining the building envelope in response to a blast overpressure in excess of 100 kPa." The conclusions also indicate that the use of laminated glass and insulated glass units (with laminated glass towards the interior) in the fabrication of glass constructions will result in structures capable of maintaining the building envelope in the event of a blast of short duration.

The report "Glass Prediction Model for Arnold Engineering Development Center" by Norville and Minor (1987) estimates expected window breakage due to solid rocket motor class 1.1 propellant detonation events equivalent to 8,400 kg (20,000 lb) and 12,600 kg (30,000 lb) TNT explosions at one site and 42,000 kg (100,000 lb) TNT explosions at another site. The estimates are described as very approximate and are based on dynamic analyses and probabilistic mechanics modeling. They suggest that the accidental motor detonation events would cause considerable damage to the glazing at the sites. The model assumed that no polymer coatings were used on the glazings.

Finally in an assessment by Beers (1991), "Remedial Window Film Applications", the issues of appearance, durability, longevity and cost (in 1991 dollars) are reviewed for polymer films on glass. Ten case studies of actual remedial film installations and cost analyses are included. In some case studies the film was intended to protect against flying glass from blasts or earthquake damage. Life-cycle costs for the installation and maintenance of anchored film and standard film on glass systems are compared to costs of glass with no film. The conclusion reached is that "maintaining a remedial film application during the life of a building is far more expensive than any other remedial option, including total replacement." The report also concludes: "There is serious doubt as to the use of filmed glass as a safety glazing material....Even if film did meet safety glazing requirements, there is no way to determine how long it will function as intended, before deterioration affects its performance. Safety glazing products such as laminated and tempered glass do not deteriorate and do not lose their safety properties." The author views laminated glass as the "product most suited for the untested (at the time of this report) applications with which film is currently being employed...". The author also cautions that "Relevant testing is needed for each and every circumstance in which the film is supposed to perform. ... For explosions, the film should be tested to withstand blast waves and hold the fractured glass fragments in the frame."

2E. Product Literature

Evaluation of the product literature revealed that the pertinent technical information contained therein was taken primarily from the reports summarized above.

2F. Information obtained at ASCE Workshop on Protective Glazings

In an oral presentation, at the American Society of Civil Engineers Workshop on Protective Glazing held on November 3, 1995 at City University, New York, Mr. Simon Trundle of Grendon Design Agency Ltd., UK, indicated that a guide issued by the British government recommends retrofitting with film on the daylight surface of glass in conjunction with the provision of a specially designed blast curtain at the most exposed levels of a building. According to the presentation, documentation pertaining to this recommendation or its theoretical or experimental basis would become available in 1996. However, none could be obtained to date.

3. CONCLUSIONS

The following statements are warranted based on the observations and tests results contained in the reports yielded by the literature search:

I) The documentation available to date does not contain statistically significant evidence indicating that the use of polymer film as a retrofit on the daylight surface of monolithic glass measurably reduces the possibility of damage due to flying glass from explosive blasts.

II) Much of the information contained in the documentation available to date is anecdotal. A few reports deal with blast testing of film applied to glass; however, they fail to do so in an exhaustive and definitive manner. This information does not provide sufficient technical evidence to support a decision to use polymer film as a retrofit on the daylight surface of monolithic glass. Additional testing and analysis would be necessary to establish the usefulness of such retrofit. Questions about the effectiveness of aged films and of different film types or brands would need to be addressed. The newly approved ASTM test method F1642-95 should be considered for further evaluations.

III) Laminated glass with polymer film applied to the outer surface from edge-to-edge where the glass and film are captured in a suitably designed frame, has been assessed as providing a degree of protection against flying glass occurring in explosive blasts.

4. ACKNOWLEDGMENTS

The authors would like to thank Nora H. Jason for performing the literature searches and for preparing the bibliography. We also acknowledge the assistance of Regina Burgess and Kathy Whisner .

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NIST-114
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MANUSCRIPT REVIEW AND APPROVAL

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ERB CONTROL NUMBER	DIVISION
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PUBLICATION DATE	**NUMBER PRINTED PAGES**
January 1996	

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TITLE AND SUBTITLE (CITE IN FULL)

Polymer Film Applied to Glass: Effectiveness at Mitigating Damage from Flying Glass due to Explosions

CONTRACT OR GRANT NUMBER

TYPE OF REPORT AND/OR PERIOD COVERED

AUTHOR(S) (LAST NAME, FIRST INITIAL, SECOND INITIAL)

GILMAN, J.W.
SIMIU, E.

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LABORATORY AND DIVISION NAMES (FIRST NIST AUTHOR ONLY)

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SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

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ABSTRACT

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KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

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