Safety/Security Window Film

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Introduction

Glass is truly an amazing and most useful product. Its presence is seen and felt every day by virtually every living individual. Despite its wondrous benefits, however, glass poses a potential risk to human life and property when it breaks. Unfortunately, it is not a matter *"if"* a particular piece of glass will break, but more likely *"when"* it will break!

Equally amazing as glass is a product referred to as Safety Film. It is a product whose purpose is to mitigate or lessen the harmful consequences of glass that is broken by man or nature. Like glass, Safety Film is optically clear and highly transparent. Safety Film allows visible light to pass through it, but unlike glass, it is not brittle and easily subject to "breaking". In fact, it is considered "elastomeric", that is, having the ability to stretch. Safety Film is installed (applied) to the interior surface of existing glass using extremely aggressive pressure sensitive acrylic adhesive. This adhesive/Safety Film combination helps hold together glass that is broken by some outside event.

Safety Film – A Brief Historical Overview

The first generation of Safety Film is believed to have been developed in the early 1970's. The product was developed for the British Government as a way to mitigate the deadly effects of flying and falling glass in terrorist bombings that were rampant throughout England, Northern Ireland and Europe at that time. Because of its success in the field, the product gained broader exposure and awareness leading to greater usage in Europe and other overseas markets.

In the United States, where violent terrorism was generally unknown, interest in window film gravitated more towards solar control films. In particular, attention rapidly began to focus on the automotive market and small retail storefronts exposed to extreme sunlight and heat conditions primarily in Florida and other southern "sunbelt" states. Arizona, California, and Texas also contributed prominently in the growth and interest in solar control films.

In time, many additional technological gains were achieved, and product quality vastly improved during the 1990's. As window film technology improved, and the number of dealer installers who actively pursued commercial and residential business increased, the "flat glass" window film market segment began to grow rapidly. Automotive film sales, however, still rule the roost in the U.S. market by a margin of as high as 4-to-1 over commercial and residential sales.

Meanwhile, both interest in and sales of Safety Film in the U.S. in the early 1990's was negligible despite the enterprising activities of a few individuals and companies. In these instances the film was primarily promoted as a deterrent to crime (burglary and "smash and grab") and protection against glass-shattering effects of earthquake activity and hurricanes. Domestic manufacturers, however, were doing most of their business with overseas customers as the specter of terrorism mushroomed in many foreign countries.

It is worth mentioning that for the most part Safety Film was being manufactured and sold almost solely in the CLEAR form. The concept of incorporating solar control benefits with safety protection was an idea "waiting to happen". The dual benefits of safety and solar heat control are opening new doors for the marketing and sales of Safety Film to a broader range of potential customers worldwide.

Safety Film sales in the U.S. were significantly impacted by several highly publicized random events and natural disasters in the late 1980's and early 1990's:

- August 1989 – Hurricane Hugo batters the Carolinas and East Coast

PHOTO HURRICANE HUGO

- October 1989 – San Francisco Bay Area Shaken by the Loma Prieta earthquake

PHOTO EARTHQUAKE DAMAGE (1)

- August 1992 – Hurricane Andrew devastates South Florida

HURRICANE ANDREW RADAR

- March 1993 – Terrorists strike the World Trade Center in New York

- April 1995 – Oklahoma City bombing destroys A. P. Murrah Federal Building

PHOTO MURRAH BUILDING

These highly publicized headline events awakened citizens throughout the U.S. to the dangers of natural disasters and terrorism. The loss of life and property damage wrought by these events was staggering. People also witnessed numerous disasters such as tornadoes and floods, along with increasing instances of vandalism, social disobedience, and crime throughout the country. Most importantly, people began to see and understand (with the help of window film manufacturers and dealers) the unfavorable role that broken glass played in all of these events.

PHOTO MURRAH BUILDING (2)

JUST WAITING FOR A BREAK!

PHOTO BROKEN GLASS – FG 4-1

How Does Glass Break

Glass breakage occurs in five broad categories:

1) Tensile stress from the weight of the glass
2) Thermal stress from absorption of solar radiation
3) Mechanical flexing stress, i.e. from wind pressure
4) Impact stress from flying objects (windblown and thrown objects)
5) Twisting stress from building movements, i.e. earthquakes

Breakage from tensile stress is not generally an issue for the window film industry as it is the domain and responsibility of engineers, architects, and specifiers to develop the proper size and weight "specs" for the glazing system in question.

The Vulnerability of Glass

Existing glass (excluding the laminated variety, and some types of tempered glass) was not designed to resist wind blown debris, earthquakes, explosions, terrorist bombs, vandalism, forced entry, or any other host of events that produce undue stress on glass. Subject to such stresses, glass often breaks into lethal shards and falls (or is blown) from the window frame endangering building occupants and passersby, and also causes substantial property damage. In addition, the interior of the building can suffer immediate damage from the broken glass and the related aftermath of the glass breakage event (e.g. wind, dust, and water damage from the exposed opening).

Most current injuries from broken glass are caused by "accidental glass breakage" with people walking into, or through, a pane of glass. The Consumer Product Safety Commission reported that in 1991 there were over 150,000 glass related accidents in the U.S. Many more injuries go unreported. Legislation mandating the use of the safer "tempered glass" did not come about until the mid 1970's. Compliance and enforcement of these regulations took time to become effective. Consequently, there is still a vast amount of "unsafe glass" in many older commercial and residential buildings. Still, a lot of new glass being installed today is of the weaker "annealed" variety that is used in most glazing systems not covered by safety regulations. For example, in homes it is required that tempered glass ("safety glass") be used where there are floor to ceiling glass windows, any glass doors, or glass panels next to doorways. However, glass in all other windows in the home does not have to be tempered, and usually is not. Similar requirements are mandated for commercial buildings and any glass areas exposed to heavy pedestrian traffic.

Aside from the many forms of accidental glass breakage, personal injury and property destruction also occur from unpredictable events of nature like hurricanes, tornadoes, severe windstorms and earthquakes. Similarly, there are random acts of mankind such as forced entry, burglary, vandalism, terrorist bombings, and industrial explosions. All of these events expose people to the vulnerability of flying glass.

Mother Nature Creates Havoc

The incidence of severe weather and frequency of major earthquakes are on the rise in both the U.S. and abroad. Examples of the magnitude of property damage contributed to glass breakage abound.

According to a March 17, 1995 article by Knight-Ridder/Tribune News Service, the federal bill for emergency disaster aid has amounted to nearly $120 billion dollars since 1977.

The insurance industry has adopted the designation Mega Catastrophe (MC) for disasters that exceed $1 billion in claims. Since 1990, there have been six such disasters. Of the 25 largest insured catastrophes in the U.S., 21 have occurred in the last decade. Nearly **50%** of all catastrophe related insurance claims that have been settled in the past 50 years have been paid out since 1990!

Hurricanes, Tornadoes, and Severe Wind Storms

PHOTO HURRICANE (1) X

Hurricanes and tornadoes produce intense winds and varying atmospheric pressures. Continuous and uneven buffeting of glass for long periods of time combined with flying debris will cause annealed glass to break. Once the glass is broken and the opening breached, significant wind, dirt, and water intrusion can occur. Also, if the building has been poorly constructed with inadequate wall and roof support features, unequal atmospheric pressures can literally cause the roof to be blown off and the walls to collapse. This occurrence was witnessed time and time again in reviewing the damage wrought in South Florida in 1992 by Hurricane Andrew. This catastrophe prompted significant changes to local area building codes (a subject covered in more detail later).

PHOTO HURRICANE DAMAGE (1) X

Prior to the devastation of Hurricane Andrew, 49 lives were lost in North and South Carolina and $4.2 billion in insurance claims were paid out as a result of Hurricane Hugo in 1989. (Hurricane Andrew caused $30 billion in damage and an estimated $7.3 billion in private insurance claims). Tornadoes in 1998 in Tennessee, Alabama, and Arkansas caused significant property damage, deaths, and personal injuries. In March of 2000 a violent tornado ripped through the downtown portions of Fort Worth, Texas causing considerable property damage and personal injury from flying glass.

PHOTO FORT WORTH TORNADO (1)

PHOTO FORT WORTH TORNADO (2)

PHOTO SEVERE STORM X

Long-range predictions by government forecasting agencies suggest a probable increase in severe weather. According to meteorologist William Gray at Colorado State University, in the past few years Atlantic Ocean hurricanes have totaled well above the normal average of six hurricanes a year. Gray believes this could be the beginning of a 10-to 20-year cycle of increased hurricane activity. A new paper recently published in *Science*, in which other meteorologists have concluded that cycles in ocean and atmospheric conditions were changing, supports Gray's observations. Meteorologists believe these changing patterns reflect the conditions present from the 1920's through the 1960's when a number of powerful storms battered the U.S. coastlines.

Unfortunately, more and more people are also choosing to live in harm's way on the edge of the ocean, in low-lying river valleys, along the Midwest's tornado alley, or right on top of some of the most unstable areas of the earth's crust. It is estimated that half of all Americans live within 50 miles of the Atlantic, Pacific, or Gulf Coast. An unpublished survey conducted by the Insurance Institute for Property Loss Reduction, estimates the value of property in Florida has grown by 54 % in the five year period from 1988 through 1993, from $566 billion to $872 billion. This rate of growth in property value in high-risk, disaster prone areas is a major concern for the insurance industry.

Earthquakes

Seismic or earthquake activity also produces hazardous broken glass. The stress caused by earthquakes is somewhat different from that caused by hurricanes and is related to twisting (or mechanical flexing) of the glass, caused by the shifting action of the ground beneath the earth's surface. The intensity of the earthquake can cause thousands of panes of glass to break and explode into dangerous projectiles of glass (flying at tremendous speeds) that can result in significant injury or loss of life.

During the 1989 World Series, the Loma Prieta Earthquake measuring 7.1 rocked the San Francisco Bay area, killing 67 people, injuring over 3,000, damaging over 100,000 buildings, and causing billions of dollars in damage. In 1994, the Hayward Earthquake in the San Fernando Valley measuring 6.6 killed 61 people, injured over 8,000, and caused an estimated $13-20 billion in damages. Similarly, an earthquake in the same year near Northridge, California caused more than $70-million in damage to more than 6,000 multi-family homes and 9,000 single-family dwellings.

A long predicted major earthquake in the Los Angeles area could bring an estimated $180 billion in private insurance claims. A Federal Government report also estimates a 70% chance for a quake of 6.7 magnitude or greater will strike the San Francisco area before 2030.

The hazard potential due to falling or flying glass during an earthquake is magnified by the fact that people tend to "take to the street" during the earthquake. In addition to the serious potential of human injury and loss of life, considerable economic consequences are at risk. For instance, after a moderate earthquake has racked a building the repair efforts necessary to restore building serviceability could be extremely expensive. Necessary repairs could include replacing glass that has cracked or fallen out, repositioning glass panels that have shifted that are now allowing air, moisture, and dirt to enter into the building interior. The repairs are difficult, expensive, and time consuming. The accumulated costs over large, populated areas would be catastrophic

Earlier references highlighted the loss of life and property experienced in recent earthquake occurrences in California. Unfortunately, earthquakes are not the exclusive domain of California. The dome of the capitol building in Olympia, Washington and several buildings in the surrounding area suffered significant damage during the spring of 2001. This is the second time since 1959 that the Olympia area has experienced such activity. The presence of an active volcanic range of mountains extending from California runs through the Northwest all the way to Alaska.

DIAGRAM US SEISMIC HAZARD MAP

Outside of the U.S., the 7.2 earthquake that struck Kobe, Japan on January 17, 1995, killed more than 5,000 people and caused over $100-billion in property damage. Similar to the situation witnessed in Miami from hurricane Andrew, substandard construction of homes and buildings contributed significantly to the problem. Japanese officials reported very little damage to recently constructed glass tower buildings that incorporated recently revised building codes and standards.

Manmade Chaos and Destruction

In addition to nature, mankind is also responsible for creating chaos and destruction on a large-scale basis. Explosions from various causes, industrial, anti-social behavior, and terrorist bombings claim thousands of lives and destroy countless millions of dollars of property every year. Safety Film has the ability to protect lives and lessen property damage in virtually all kinds of manmade disasters.

Industrial Explosions

PHOTO BUILDING ON FIRE

Manufacturers of paint and chemicals and the refiners of petroleum and natural gas have a potential to create massive explosions such as those that rocked the petrochemical industry in Texas and Louisiana in the 1980's. However, injuries, death, and property destruction are not limited in effect to the specific industries where the explosion occurs. Such explosions can also cause glass breakage in nearby businesses, shops, and homes. More and more explosions are occurring in rural areas from a variety of small to medium-size businesses that are located nearer to towns in which their labor base lives. Deaths and injuries have occurred at hotels and motels from faulty pool heaters and restaurant equipment. People would be surprised to visit their local fire departments and learn how the department "red-lines" or rates various surrounding businesses for fire and explosion potential.

PHOTO FIREFIGHTERS X

Anti-Social Behavior and Bombings

Every year thousands of small explosive devices are discovered throughout the United States. Some are found before an explosion occurs, others not until after they have been detonated. These bombs are not the work of terrorists, but rather anti-social and sometimes emotionally disturbed individuals seeking revenge or retribution against employers, the government, or society at large.

Theodore J. Kaczynski, identified by the FBI as the "Unabomber", is the most noted perpetrator of anti-social bombing in recent times. His arrest capped a random bombing spree that took the lives of three people and severely injured twenty-three others over an 18-year period from 1978 until 1996.

Bombings at abortion clinics around the country are another grim reminder of the violent nature of people, even when their intentions are cloaked under the mantle of moral and religious conviction. Of 44 major bombing instances reported in 1995 by the Pinkerton Investigation Services, twenty-one were directed at abortion clinics.

The following terrorist, criminal, and violent acts occurring in the U.S. in the past few years suggest that no building is necessarily immune, especially from glass breakage:

- The Midwest, 1994-95 – Members of the white supremacist Aryan Republican Army go on seven-state crime spree, leaving behind pipe bombs as they rob 22 banks
- Spokane, WA, April-July 1996 – Three self-described "Phineas Priests" commit bank robberies and bomb offices of Spokesman-Review Newspaper, Planned Parenthood, and a local bank
- Phoenix, July 1996 – Federal agents arrest 12 members of the Viper Militia and seize over 300 pounds of ammonium nitrate, a key ingredient of the Oklahoma City bombing
- Atlanta, July 1996 – A pipe bomb explodes at Centennial Olympic Park
- Clarksburg, WV. – FBI agents arrest Mountaineer Militia members for possession of explosives and for allegedly plotting to blow up the FBI's fingerprint facility where 2,000 people work.
- Kalamazoo, MI, March 1997 – Authorities arrest local militia activist for allegedly giving 11 pipe bombs to a government informant and plotting to bomb government offices, armories, and a local TV station.
- Yuba City, CA, April 1997 – A blast that shatters area windows leads police to 550 pounds of petrogel, a gelatin dynamite, allegedly stored by local militia activists – enough explosives were found to level three city blocks
- Wise County, Texas, April 1997 – Federal agents arrest four Klu Klux Klan members who plan to blow up a natural-gas refinery and use the disaster as a cover for an armored car robbery.

Unfortunately, many such bombs are inexpensive and easy to make. Anyone with a computer and modem can obtain bomb-making instructions over the Internet. If placed in an opportune location, even a small device can create a lethal scenario by creating flying shards of glass, potentially injuring and killing many innocent victims.

Terrorism and Bombings

Terrorism in the U.S. reached unparalleled heights in the September 11, 2001, shocking suicide bombing of the World Trade Center (WTC) and Pentagon Building. The use of domestic U.S. airliners as a "delivery mechanism" for such an atrocity has stunned U.S. political and military leaders, as well as the general public. This terrorist action supports an earlier report from *U.S. News and Reports Magazine* (December 29, 1997) warning of the potential for increased domestic terrorism. That story indicated that over 900 potential or actual cases of suspected terrorism were reported in 1997 compared to only 100 cases in 1995.

PHOTO WTC (5)

PHOTO WTC (4)

PHOTO PENTAGON 9.14.01 X

PHOTO PENTAGON INSIDE X

PHOTO PENTAGON EXTERIOR

Prior to this catastrophic September attack, the U.S. had witnessed several other high profile attacks including:

- World Trade Center, New York City, 1993
- Alfred P. Murrah Federal Building, Oklahoma City, 1995
- U.S. Air Force housing facility, Khobar Towers, Dhahran, Saudi Arabia, 1996
- American Embassy, Nairobi, Kenya, 1998

PHOTO KHOBAR TOWERS X

PHOTO KHOBAR TOWERS (2) X

PHOTO KHOBAR TOWERS (3) X

In a report by the General Accounting Office (GAO), an agency of Congress, entitled *Combating Terrorism: Federal Agencies Efforts To Implement National Policy and Strategy*, dated September 26, 1997, it was stated that "The threat of terrorist attacks against U.S. citizens and property is a high-priority national security and criminal concern". The General Services Agency (GSA), the federal agency responsible for managing federally owned buildings, has identified 8,400 buildings as vulnerable to terrorist attacks. Much of the vulnerability relates to glazing systems where safety film can play a positive role. It is sad to say, that at the time of this writing, little progress had been made in reducing the overall state of vulnerability that such potential attacks pose. A fortunate exception, however, did include a portion of the Pentagon Building where significant glazing security updates had been implemented. These security upgrades substantially reduced the deadly impact created by the airliner crashing into the building.

According to U.S. intelligence agencies, it is believed that conventional explosives will continue to be the weapon of choice for terrorists. However, the subsequent *"anthrax attack"* (by unknown entities at the time of this writing) clearly indicates that this form of terrorism is not to be underestimated despite operational difficulties and the unpredictable results of such acts. Similarly, at this time one must assume that the use of nuclear weapons (a favorite ploy of Hollywood film producers) is also within the realm of possibility. Truly, these are uncertain and dangerous times for one and all of us.

In summary, the implication of continued widespread use of conventional explosives by terrorists means injury from the resulting broken glass is a very big concern. However, this potential risk is capable of being limited by the use safety film.

Burglary and Vandalism

Another form of the destructive behavior of mankind connected to the vulnerability of glass involves burglary, vandalism, and social unrest (looting, etc.). Although national statistics indicated that burglary in the U.S. has shown a slight decline in recent years, the incidence and dollar loss from such crimes is still very significant. In 1998, 2.3 million burglaries were reported. Nearly 67% of all burglaries occurred in residential settings, with the remaining 33% listed as commercial. One-third of all illegal entries occur through broken windows.

PHOTO BURGLAR X

In the commercial area, the "smash and grab" type of theft is a popular form of theft. This is particularly true for retail shops that display merchandise in a front window setting. Individuals use blunt instruments to break the glass, or they throw items through the window. Once the glass is broken, the thief grabs what he or she can as quickly as possible and departs the scene rapidly. Several Blockbuster video stores in the Miami area had huge numbers of video copies of the popular movie *Titanic* stolen in quick store break-ins after hours.

The preventative benefit of Safety Film is that the film forms a barrier that delays penetration of the glass. If the glass and film is penetrated, the opening created is normally confined to the size of the device used to create the opening. It is therefore difficult to gain easy and immediate access, requiring more effort and noise by the perpetrator. It is an accepted fact that most burglaries depend on stealth and speed. If the burglar's initial efforts are met with a degree of resistance as a result of the presence of Safety Film, the individual will usually quickly give up and move elsewhere.

Vandalism is another type of destructive social behavior that can lead to personal injury and property damage. Vandalism falls into three broad categories:

- Mischievous behavior – individual(s)
- Malicious behavior - organized
- Civil disobedience

Mischievous behavior usually involves one or more young adults causing glass breakage through prankish actions, i.e. throwing an object that breaks a window. Such behavior may also take the form of a more serious nature involving all ages, i.e. racial and religious persecution, etc. In any event Safety Film may provide protection against the potential hazards of broken glass resulting from these activities.

Malicious behavior is usually more organized in nature and carried out by multiple numbers of people (gangs, etc.). One type of organized gang type activity that has been fairly common in parts of the U.S. has been "glass tagging". In this type of activity individuals use sharp instruments to etch initials (gang insignias) into the glass, usually shop front or hotel type windows. As a counter measure, commercial building owners have used CLEAR Safety Film applied to the "outside" surface of the glass windows and doors to prevent "tagging". In many cases the film is referred to as "anti-graffiti film". Individuals, who are participating in trying to etch the glass, merely cut the outer surfaces of the film without penetrating to the glass surface. The abused film can be subsequently removed and replaced with new film. The cost of film removal and replacement is substantially less costly, and can be replaced more quickly and with less disruption to the building, than there would be to replaced the abused glass.

GLASS AND GLAZING SYSTEMS

Float Glass Manufacturing Process

The majority of glass used today in architectural applications is float glass. It is manufactured in a continuous process by melting glass batch (soda, lime, silica sand and other materials used for heat absorbing or tinted glass when desired) and floating it on a bath of molten tin. This ribbon of glass is slowly and carefully cooled to produce annealed glass. Annealed glass is the predominant base product used to fabricate all other types of architectural glass.

Raw ingredients are weighed and mixed with broken glass (called cullet) into batches. The mixed batch is heated in special furnaces (up to 2900 degrees Fahrenheit) into a molten mass, which is then floated onto a tin bath where the ribbon of "float" glass is pulled (or drawn) through the bath. The glass ribbon then enters an annealing lehr where it is cooled in preparation for cutting. The annealing lehr cools the glass to approximately 200°Fahrenheit in a precise, uniform manner. The lehr uses small amounts of electric heat to keep the edges of the sheet from cooling faster than the center. The ribbon of glass emerges from the lehr, and continues through the cooling process to be prepared for cutting, packing, and shipping.

Types of Glass

It is important to have a basic understanding about the different types of glass, their vulnerability to stress, and how Safety Film performs when applied to the surface of each type. There are essentially four types of glass categorized by the amount of heat and cooling used in the manufacturing process.

- Annealed Float Glass
- Heat-treated Glass
- Tempered Glass
- Chemically Strengthened Glass

Generally speaking, a higher temperature coupled with a more rapid cooling rate in the production process will produce glass that is stronger and more resistant to breaking.

Annealed Float Glass (annealed glass) is manufactured in the process described above. The molten glass tends to seek a level configuration as it floats on the surface of the molten tin. The thickness of glass is relative to the rate at which the molten glass flows from the tank. If the flow rate is slowed down, the glass thickness builds up. Because the melting point of the tin is much less than that for glass, the glass solidifies as it cools on top of the tin. Once the glass solidifies, it is fed into an annealing oven where it is slowly cooled so that the residual stresses are minimized. This process results in the production of a glass product, which is very flat with nearly distortion-free, parallel surfaces.

Since annealed glass has a minimum amount of residual surface compression, it is subject to easy breakage. However, it is the most common type of glass found, not only in past production years, but also in current production both in the U.S. and overseas. Its greater popularity is attributed to its lower production costs and ability to be easily cut (on-site, if necessary) to fit any particular glazing unit.

When annealed glass breaks, it does so in many small and large sharp, irregular-shaped pieces (shards). Depending on the cause of glass breakage these jagged pieces of glass can be propelled at high speeds, and are capable of producing serious bodily injuries and even death (particularly in cases of explosions, earthquakes, and severe wind storms.)

Heat-treated Glass is more resistant to breakage. In the production process the glass is only heated to about 1150° F and is cooled more slowly. The results are a product that has compressed outer surfaces with compensating inner tension. This type of glass has less bow and warp than tempered glass, but only has a strength factor that is equal to about twice the strength of annealed glass.

Although heat treated (strengthened) glass is more resistant to heat induced stress, wind-loads and impacts by wind-borne debris, it generally is not considered a fire resistant glazing, nor is it accepted as a safety glazing product as it tends to break in a similar way to regular annealed glass.

Tempered Glass is a type of glass that is the result of heating and rapid cooling to induce a change in structure leading to an increase in strength. Monolithic (single) sheets of annealed glass are heated to temperatures around 1200° F. This is the temperature at which annealed glass begins to soften. The outer surfaces of the glass are then rapidly cooled. This creates high compression in the surfaces.

This type of glass is about four times stronger than regular annealed glass. The change in structure has two main benefits. First, the glass is much stronger, and second when the glass is broken, it breaks into small cubical pieces as opposed to the larger shards created by annealed glass (See photos). This is a major benefit in areas that are high risk for accidental (human impact) glass breakage. Tempered glass is also more resistant to breakage as a result of thermal stress fracture (a topic covered more fully later).

It should be noted that tempered glass is often referred to as *Safety Glass*. This name originated from the mid 1970's when Federal and State Governments mandated such glass in public areas for safety. This legislation was initially targeted at preventing what is termed "accidental glass breakage" (or human impact), i.e. people walking into or through glass doors and floor to ceiling windows. The fact is, however, such glass can and will break under a variety of more stressful situations such as wind-blown debris from violent windstorms and hurricanes, seismic activities, industrial explosions, and terrorist bombings. (Demands for new testing methods and better building codes to achieve greater safety from glass breakage in these types of events will be covered in a later section.)

While heat-treated and tempered glass provides greater safety protection, both forms of glass are more expensive to produce versus annealed glass. Another disadvantage is that neither heat-treated nor tempered glass can be cut or re-sized. These glass types must be manufactured to the dimensions of a specific glazing system. For example, a glass dealer cannot take a larger sheet of heat-treated or tempered glass and cut it into a smaller size to replace a broken window.

Chemically Strengthened Glass is another type of glass. It is produced when glass is submerged in a molten salt bath at temperatures below normal annealing. This results in an exchange of ions at the surface level of the glass. This is a complex process beyond the scope of this document.

Chemically strengthened glass has similar compressive strength to heat treated glass. The product is generally not used for window glass, but more commonly seen in industries where very thin, strong glass is needed. However, when broken, this glass has similar breakage patterns to annealed glass and is therefore not generally recommended for safety glazing. (Chemically strengthened glass is sometimes used in security glazing as a laminate.)

Types of Glass (Window) Constructions

The three types of glass mentioned above are found in six broad categories of glass (window) constructions:

- Monolithic Glass (Single pane)
- Insulated Glass (Double pane)
- Laminated Glass
- Ballistic
- Blast Resistant Glass
- Other Glass Types

Monolithic Glass is the simplest glass (window) construction type. It consists of a single (mono) flat piece of glass of variable, but constant thickness. It can be annealed, heat-treated, or laminated as previously described. Most glass in use today is annealed, monolithic glass. It is usually 1/8" thick for residential (3/16" in sliding doors, and tempered if installed after the mid 1970's), and 1/4" for commercial.

DIAGRAM 2.1 FG

Insulated Glass more aptly describes how the glass is fabricated into an Insulated Glass (IG) Unit. An IG Unit consists of two sheets of glass separated by airspace of constant thickness (usually ½"). The purpose of the intervening airspace is to reduce heat transfer by conduction and convection through the glass. Some IG Units use an inert gas such as Argon or Krypton in place of air. The glass used is generally clear, annealed and monolithic. Today more than 90% of all windows sold in North America are IG Units.

DIAGRAM 2.3 - FG

Laminated Glass features two layers of glass bonded together by an interlayer of polyvinyl butyral (PVB). The two layers of glass are tightly compressed together and heated to the point that the (PVB) literally melts, forming a tremendous bond between the two pieces of glass. Laminated glass is used in automotive and aircraft windshields, and more recently in commercial and residential glazing systems for increased safety and security. Its use in these areas is limited because of increased cost and high incidence of impact breakage compared to that of tempered glass. Its most significant benefit is its ability to maintain structural integrity even after it is broken. Thus, it usually remains in the opening to protect against exposure to the elements and unauthorized entry. Laminated glass and Safety Film provide very similar safety protection against personal injury and property damage.

DIAGRAM 2.2 - FG

Bullet and Blast Resistant Glass is normally comprised of multiple laminates of glass and polycarbonate. It is very heavy and expensive. In most cases, the existing frames are not generally strong enough or deep enough to support the additional weight of ballistic material. Therefore, ballistic glass is usually placed in specially designed frames. Due to the thickness and layering of the material, vision may be distorted. This type of glass is generally not a candidate for any type of solar film application. In some instances clear film may be installed on the interior to act as a spall shield to hold small fragments of glass, which fly off the interior surface of the glass as a result of a bullet or bomb blast's shockwave.

SAFETY FILM

Safety Film Defined and Described

Safety Film is probably best described by two names given to it by the U. S. Government, *glass fragment retention film*, or *anti-shatter film*. The U. S Army Corps of Engineers and the General Service Administration (GSA) developed these names to describe the ability of Safety Film to hold glass together in the event it is broken.

Safety Film is comprised of optically clear, tinted or reflective layers of polyester film. The immediate discussion will deal with the CLEAR variety of Safety Film with tinted or reflective varieties known as *Solar Safety Film* to be discussed later.

Safety Film is always described in terms of "mils", which is a measurement of thickness as one-thousandth of an inch. One mil equals 25.4 microns (micrometers). Safety Film ranges in thickness from 4-mils (usually considered the minimum thickness) to upwards of 15-mils, and thicker. The varying thickness is achieved by mechanically laminating multiple layers of film together with aggressive adhesive coatings. The material is packaged in rolls of varying lengths and widths, ranging upwards to 79 inches, to accommodate today's larger commercial size windows. (Normal sizes available are 36-, 48-, 60-, and 72-inch widths in lengths of 65 to 100 feet.)

Safety Film is usually "retrofitted" to existing glass in window frames already in place. Occasionally, the film is applied on new glass before the glass has been installed. Typical film installations cover the visible portion of the interior surface of the glass all the way to the edge of the frame, but do not extend to the glass edge within the frame. (This is referred to as a "daylite installation".) The performance level of Safety Film can be enhanced through installation techniques that attach the film to the framing system (See Section on Safety Film Installation Guidelines).

When properly installed, Safety Film forms an almost invisible protective coating (membrane) on the interior side of the glass surface. The film is attached to the glass with extremely aggressive pressure sensitive adhesive. This adhesive is applied to the film at time of manufacture and is protected by a release liner until installed. When stress causes the glass to break, the film has the ability to stretch and absorb some or all of the energy generated by the stress. The result is that the broken glass may remain intact within the framing system preventing shards of glass becoming lethal projectiles.

However, if the stress on the glass is too great, as in the case of an explosion, the film will be stretched to its maximum at which point it may tear and burst. However, potential personal injury is significantly reduced because the film will reduce the amount of glass shards produced and the velocity and distance that they are propelled, and will allow a portion of the destructive blast shock wave to dissipate (prior to the glass and film failing), substantially reducing damage and life threatening injuries (refer to discussion concerning bomb blast explosions).

Basic Construction of CLEAR Safety Film

CLEAR Safety Film is manufactured with single or multiple layers of clear polyester film laminated together in a variety of constructions. For example, a 4-Mil film is laminated to a 4-Mil film to produce an 8-Mil film, or three separate 4-Mil films can be laminated to form a 12-Mil film. Generally speaking, the more layers or plies that a particular Safety Film construction contains the greater its ability to uniformly absorb impact energy when the glass is broken until the film reaches its actual "bursting point". Such a film has a higher manufacturing cost, as each layer requires a separate production pass through the coating and laminating machinery.

Safety Film is almost always applied to the interior side of the glass surface by means of an aggressive adhesive coating (usually referred to as an adhesive system). A thin protective "release" liner that is removed before the film is installed on the window protects the adhesive system. Safety Films always use a Pressure Sensitive (PS) acrylic adhesive system to bond the film to the glass. A scratch resistant protective coating is usually applied to the film's exposed interior ("room side") surface. (See diagram)

DIAGRAM 3.6 - FG

Laminating and Mounting Adhesives

Safety Film generally features two types of specialized adhesives: a *laminating adhesive* and a *mounting adhesive*. In constructing the thicker varieties of Safety Film, laminating adhesives are used to laminate or bond one or more polyester film substrates together. For example, 3 separate 4-mil polyester substrates can be laminated together as show in diagram xxx to produce a very strong 3-ply, 12-mil film.

Subsequently, a mounting adhesive is then used to apply the film to the surface of the glass. The mounting adhesives used in Safety Films vary significantly from those used in the normal, thinner Solar Control Films. The basic difference between the two mounting adhesive systems used between the two types of films can be described as follows. The mounting adhesive used for Solar Control Films is designed to ensure that the film remains adhered to the glass. As the film itself is very lightweight, it does not require a great deal of adhesive strength (peel strength) to keep the film adhered to the glass surface.

Safety Films, on the other hand, are designed in a manner that in the event of glass breakage, the glass remains adhered to the polyester film substrate. Since there is a vast difference between the weight of glass and film, the adhesive must be thicker and more aggressive (tacky) in order for the broken heavy pieces of glass to remain attached to the film. The "strength" of the adhesive is measured by its peel and shear strength, which is tested according to ASTM standards and listed by most manufacturers in the specifications table that accompany most Safety Film samples.

Pressure Sensitive (PS) Adhesive System

To date, Safety Films only employ a Pressure Sensitive (PS) adhesive system. That is, when the protective release liner (see diagram) is removed, it exposes the relatively soft and sticky surface of the film adhesive. At this point the film is ready to be applied to the prepared wet (for positioning purposes) surface of the glass.

It is suggested that readers might want to review the IWFA Flat Glass Guide to learn about two other adhesive systems that are used on regular solar control film (DPS and Dry Adhesive).

SOLAR SECURITY FILM

Basic Construction of Solar Security Film

Solar Security Film is a name gaining in favor for a relatively new category of Safety Film that offers significant solar heat (and UV) control in addition to the standard protection benefits of CLEAR Safety Film. These "tinted" films come in varying light transmissions and thickness. The film construction is similar to standard solar control film, and features the same very aggressive adhesives as CLEAR Safety Film (See diagram).

DIAGRAM 3.5 - FG

Solar Heat Control

As detailed in more depth in the IWFA Flat Glass Education Guide, the sun sends energy to the earth in the form of electromagnetic radiation or energy waves. The energy is in the form of visible radiation (normal daylight) and invisible radiation (infrared solar heat and ultraviolet radiation). Roughly 44% of the sun's radiant energy is received in the form of visible light. Invisible infrared solar heat radiation accounts for approximately 53% of the sun's energy, and the remaining 3% is in the form of invisible ultraviolet or UV radiation.

Unshaded windows can account for over 40 percent of a home or office's air conditioning cost, according to studies conducted by Southface Energy Institute. Basic solar control films are designed to control heat gain through glazing systems to reduce energy consumption. Depending on the climatic environment and window configuration, industry studies conducted by the IWFA and the U.S. Department of Energy predict a payback in energy savings within four years. (Added labor installation costs and higher product costs will increase the payback period for Safety Film featuring solar control properties.)

Generally speaking, Solar Security Film begins with a basic clear polyester substrate that is metallized, usually through a deposition technology (vacuum coating), or sputtering, or some other specialized manufacturing process. These processes introduce a variety of metallic alloys to become embedded or fused into the clear polyester substrate. These metallic alloys are responsible for absorbing and reflecting infrared solar heat.

Until recently, the generally accepted measurement of a window film's ability to provide heat control was determined by its *Shading Coefficient*. Industry experts suggest that for a reasonable energy savings and significant improvement in comfort for the residential market, a Shading Coefficient of 0.45 – 0.55 is desirable. Many of the *Silver Films* used for commercial installations have a Shading Co-efficient range of 0.25 and 0.30. Films for the residential market sacrifice a little less heat rejection for less reflectivity, which improve aesthetic looks.

It should be noted that the *Solar Heat Gain Coefficient* (SHGC) has replaced the Shading Coefficient as the standard indicator of a window's shading ability. This measures the fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently re-radiated inward. It is expressed as a number without units between 0 and 1. A window with a lower SHGC transmits less solar heat, and provides better shading.

Ultraviolet (UV) Absorbers and Radiation Control

All Safety Films, both CLEAR and SOLAR types, are able to reject nearly all UV radiation (generally up to 99%). The rejection of UV radiation is accomplished through the use of UV Absorbers. These UV Absorbers are used to prevent the sun's rays from degrading the polyester film and adhesives that are used to laminate the layers of polyester film together. UV Absorbers can be present in either the adhesives and/or be impregnated in the base (substrate) polyester film. While the UV Absorbers work to protect the window film itself, in the process they provide protection against fading to interior furnishings and fabrics.

Ultraviolet (UV) Radiation and Fading

It is important to state upfront that:
NO WINDOW FILM OR GLAZING PRODUCT WILL TOTALLY PREVENT OR STOP FADING.

Readers are encouraged to review the IWFA Flat Glass Education Guide concerning the matter of fading. As that guide states, "It is generally accepted that UV radiation can be responsible for roughly 40% - 60% of all fading." There are a number of very broad factors that cause fading:

- Normal sunlight and indoor artificial lighting
- Humidity and Moisture
- Poor dye fastness in the fabric
- Chemical vapors in the air

The pie chart diagram below represents the rough percentages of fading caused by UV radiation, normal visible sunlight, all forms of heat, and miscellaneous factors such as dye fastness, chemical vapors, etc. (It is worth noting that wood flooring is highly susceptible to fading.)

DIAGRAM 3.1 - FG

BASIC TEST STANDARDS

Introduction

There are several basic test standards required for Safety Film: 1) human impact, 2) forced entry, 3) fire tests, and 4) surface abrasion. As attention has shifted from focusing primarily on human impact issues, test standards are being developed for seismic, severe windstorm, and bomb blast situations. Each of those important topics will be covered subsequently in separate sections.

Human Impact – ANSI Z97.1 (1984)

Injuries from glass breakage have always been a major concern for people. This concern was paramount in the early days of the automotive industry leading to the gradual development and growth of tempered and laminated glass for windshields. Attention was slower to come to the residential and commercial markets. Concern for public safety in high pedestrian traffic areas as well as for the general public as a whole, prompted the U.S. Government to initiate legislative action in the early 1970's to establish commercial building codes requiring the installation of *Tempered Glass*, referred to by many also as *Safety Glass*, in glazing systems exposed to high injury risk, e.g. doors of all types, windows (particularly floor-to-ceiling), glass partitions, etc. Later, such codes extended installation requirements to include residential buildings for such glazing systems as:

- Storm doors or combination doors
- Doors and sidelites (glass immediately adjacent to doors)
- Bathtub doors and enclosures
- Shower doors and enclosures
- Sliding glass doors

The safety requirements are designed to reduce or eliminate unreasonable risks of death or serious injury to consumers when glazing material is broken by human impact. These *Human Impact* tests were developed by the federal government and adopted by the American National Standards Institute (ANSI) in 1984 and became known as *ANSI Z97.1 – (1984).*

This test standard attempts to simulate the effect of a certain size and weight individual walking through a piece of glass roughly the size of a standard sliding glass door (34" X 76"). The test involves releasing a leather bag filled with 100 pounds of lead shot from a height of 12" against a pane of glass mounted in a stationary framing system. At a distance of 12" the impact on the center of the glass pane is equivalent to 100 foot-pounds of impact per square foot.

This is a *Pass* or *Fail* type test. If glass breaks after being impacted and the 100-lb leather bag does not penetrate the glass pane or cause a fissure in the glass that allows a 3" steel ball to be passed through it, then the glazing system is deemed to have *Passed.* (The test actually requires that four successive glazing specimens meet this requirement for an official *"Pass"* to be recorded.) If the specimen(s) does not break at the 12" height level, the pendulum is increased to a level of 18" and the drop repeated (this level represents 150 foot-pounds of impact). If the specimen(s) does not break at this level, the pendulum is raised to 48" and the drop is repeated (this level represents 400 foot-pounds of impact).

While the test procedures call for increasing height levels for the pendulum drop in actuality the specimen only has to achieve success at the 12" level in order to meet an official *"Pass"* standard.

CPSC CFR 1201 Category I and II

The Consumer Product Safety Commission (CPSC) has also developed a test standard that is similar to ANSI. This test standard is referred to as *CPSC CFR 1201 Category I and II.* The same testing apparatus is used (fixed frame with pendulum swing and 100-lb leather bag). In the *Category I* phase the pendulum drop is from 18" representing 150 foot-pounds of impact. In the *Category II* phase the pendulum drop is raised to 48" or 400 foot-pounds of impact. Again, this is a *Pass* or *Fail* type test.

Conclusions – Human Impact Tests

Generally speaking, all window film manufacturers have passed both the ANSI and CPSC standards through independent test laboratories with one or more Safety Film variations, e.g. 4-mil, 7-mil, 12-mil, etc. (Actual test results are usually available from the respective manufacturers.) Also important to note is that the successful passing of these tests can be accomplished by means of standard "daylite" installation techniques (a topic to be discussed a little later).

The simple conclusion to be reached with regard to test standards involving *Human Impact* vis-à-vis Safety Film and laminated glass is that both products are very effective injury mitigation devices that satisfy the acceptable standard of performance as established by ANSI and CPSC.

Forced Entry – Burglary Resisting Glazing Material, UL 972

The most commonly used test method to determine the suitability of glazing for burglary resistance is Underwriters Laboratory Inc., Test UL 972. Underwriters Laboratories is a not-for-profit organization established in 1874 and headquartered in Northbrook, Illinois. The organization's purpose is to establish, maintain, and operate laboratories for the examination and testing of devices, systems and materials to determine their relation to hazards to life and property, and to ascertain, define and publish standards, classifications and specifications for materials, devices, products, equipment, constructions, methods, and systems affecting such hazards.

There are several parts to Test UL 972, whose scope and procedures are also approved by ANSI. The objective of the test is to develop standards for material intended to resist burglary attacks of the "smash and grab" type. Each test utilizes a five-pound steel ball.

A minimum of 37 glazing sample specimens 24" x 24" are to be used. In the basic test phase a steel ball is dropped at a distance of 10 feet onto the two-foot square sheet of glass (with film applied to the lower surface of the glass). The procedure requires that multiple drops of the steel ball be made on the same glazing specimen five times in succession within a specified area in the center of the specimen. The test requires that the steel ball not penetrate the specimen on any one of the five impacts on nine of the ten samples tested during each of the test phases. Penetration is considered to occur if the ball passes completely through the glazing material.

The difficulty posed for Safety Film in passing this test, is that the ball cracks the glass, and on each successive drop small pieces of glass begin to cut the film until the weight of the ball causes it to drop through 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 wherein the steel ball is dropped from a vertical height of 40 feet. Complete details of the test and procedure can be obtained over the Internet (http://standards.ul.com:82/), is available in written form by calling Global Engineering Documents at (303) 397-7956.

Surface Abrasion – ASTM D1044-94

Manufacturers utilize numerous types of scratch resistant coatings applied to the exterior surface of the film to protect it from normal wear and tear and abuse by humans or by the natural environment. The film is normally tested to ASTM D1044-94 (Test for Resistance of Transparent Plastics to Surface Abrasion). This is often referred to as the Taber Abrader Test, as this is the name of the equipment used to perform the test. This device repeatedly scratches the surface of the film, and after a certain amount of cycles the amount of haze (scratching) created by the abrader mechanism is measured using a different test method and equipment. The resultant haze is measured as a percent. While there is no pass-or-fail criteria, window film is considered scratch resistant if the *delta haze* is 5% or less.

Fire Testing

There are four primary fire tests that are recognized as necessary for meeting the requirements of current building codes:

1) Flammability - ASTM D635-81
2) Surface Burning – ASTM E84-95b
3) Ignition Properties – ASTM D1929-91a
4) Smoke Density – ASTM D2843-77

These ASTM fire tests are test methods, and do not specify a pass or fail criteria. The results are compared against control products and assigned a rating. The rating is then used to determine if a product is suitable for its intended use or not. In the case of window film this determination is usually made by building codes, and would require that window film is a "Class A" building material. Consult directly with the manufacturer to determine their specific test results.

BOMB BLAST PROTECTION

Introduction

During the 1990's interest in glass breakage mitigation shifted gradually from human impact to mitigating the effect of seismic, severe windstorm, and bomb blast impact on glazing systems. This shift took the form of two distinctly different, but parallel courses involving bomb blast protection, and protection from natural disasters like earthquakes and hurricanes. First, we will examine the situation as it relates to bomb blast protection, and later review what has, and is, occurring in providing protection of glazing systems during natural disasters.

Bomb Blast Events

As previously noted, injuries, loss of life, and property damage have occurred at an increasing rate over the last few years. According to the FBI Bomb Data Center in Arlington, Virginia, bombings of all types of buildings in North America increased by 20% per year throughout the 1980's and 1990's. The country is witness to a countless variety of small-improvised explosive devices (IED's) aimed at abortion clinics, state and federal buildings, small and big businesses, and individuals. Bombs used for these types of purposes are neither extremely difficult nor expensive to make. Information on how such bombs are made is widely available over the Internet, and the materials are available from any major hardware store.

PHOTO WTC (1)

Interest and attention in terrorist bombing activities in the U.S. reached a crescendo with two tragic events:

- March 1993 bombing of the World Trade Center in New York
- April 1995 bombing of the Alfred P. Murrah Building in Oklahoma City

PHOTO MURRAH BUILDING (3)

PHOTO MURRAH BUILDING (4)

The World Trade Center bombing took the lives of six people, injured over a thousand people, and caused significant structural damage and glass breakage to portions of the building. At the same time there was a conspiracy to attack other landmark buildings in New York City, such as the Holland Tunnel and the United Nations Building. Fortunately FBI personnel were able to intervene to prevent these bombings from occurring.

PHOTO WTC (6)

The bombing of the A. P. Murrah building in Oklahoma City resulted in 168 deaths, many of whom were very young children. The force of the bomb was so great that many nearby buildings had structural damage, and most buildings within a 10-block radius suffered significant glass breakage. Ensuing rainstorms that occurred 24 hours after the explosion significantly hampered rescue operations. Similarly, many broken windows could not be boarded up in time, leaving building interiors and valuable computer equipment exposed to the elements. Property damage as well as loss of life was staggering.

Federal Government Response

After the Oklahoma City bombing, President Clinton issued Presidential Decision Directive 39 (PDD 39). This Executive Order directed the Department of Justice (DOJ) to assess the vulnerability of federal office buildings in the United States, particularly to acts of terrorism and other forms of violence. (Prior to this study, there were no government-wide standards for security at federal facilities, and no central database of the security currently in place in such facilities.)

A special committee was given 60 days to develop a report, which was directed along two primary lines:

1) Survey the state of existing security
2) Establish recommended minimum security standards based on levels of risk

The length and depth of the findings and recommendations of the final report are far too exhaustive to recount in this Education Guide. (Readers are advised to consult the actual report: *Vulnerability Assessment of Federal Facilities – June 28, 1995.* It is available in hard copy form from the IWFA administrative office (e-mail at admin@iwfa.com, telephone 276/666-4932, facsimile 276/666-4933).

Injuries and death from bomb blasts have long been attributed to the hazardous breaking of glass, not only at or near the immediate point of the blast, but also significantly removed from the immediate blast site. The use of Safety Film to mitigate such injurious scenarios had been an established fact in many overseas locations in England, Europe, South Africa, and the Middle East. In fact, the U.S. State Department and Department of Defense had previously had many buildings so outfitted. Therefore, a limited body of information did exist on the practical application of Safety Film before the two tragic bombing events previously mentioned.

PHOTO WTC (2)

Under the direction of the General Services Agency (GSA), the governmental arm generally responsible for establishing performance criteria for products purchased and used by the government, efforts were made to evaluate Safety Film and other protective devices such as laminated glass, blast curtains, etc. At the same time other agencies were also involved in various bomb blast testing, e.g.

The U.S. Army Corps of Engineers released *Engineer Technical Letter 1110-1-136* stating, “Safety Film can absorb most, if not all, the power and impact generated when glass is broken or shattered.”

PHOTO WTC (3)

Bomb Blast Test Methodology

There are primarily three bomb blast methods for testing the effectiveness of Safety Film (and laminated glass):

1) Open Frame Testing
2) Shock Tube Testing
3) Open Air Arena Testing

Open Frame Testing

During the mid 1980’s and into the early 1990’s most U.S. window film manufacturers tested the effects of Safety Film in a variety of bomb blast scenarios. Most of these experiments involved using a relatively simple form of testing known as *Open Frame Testing.* This method usually consists of placing two panes of glass specimens side-by-side mounted in rigid frames with no enclosure behind the frame. Safety Film is applied to the surface of one specimen while the other is left untreated. An explosive charge is detonated near the two specimens. The specimen treated with Safety Film is shattered by the blast, but the pieces of glass are held intact within the frame (sometimes the complete pane is blown out of the frame and lands nearby in one large piece). The unprotected specimen is blown into thousands of jagged pieces over a wide area. Generally the tests would include only annealed and tempered glass. (Had standard laminated glass been demonstrated the results would have been similar to those obtained by annealed or tempered glass that was treated with Safety Film.) The focus of the test is to illustrate that Safety Film can provide protection against lethal glass shards from a minor blast explosion. By inference, the objective of the tests is to position Safety Film as being able to provide a wide range of protection from bomb blasts to other lesser glass breaking events, e.g. thrown objects.

Often these *Open Frame Tests* were not conducted in conjunction with official independent laboratories, but rather in metropolitan markets involving local police and/or fire departments. The local media was also usually invited to witness the event and provide news coverage. These “events” made for good copy on the local 6 o’clock news and were effective in getting the point across to viewers that Safety Film was an amazing product that helped prevent injuries from breaking glass. However, from a professional engineer’s perspective this form of testing is only anecdotal in nature and is not considered valid.

Shock Tube Testing

In this test procedure a special shock tube is employed. The tube directs a simulated bomb blast positive pressure-impulse wave of considerable magnitude against a glazing system. The positive pressure-impulse against an untreated glazing system (either annealed or tempered glass) will cause the glass to explode into an enclosed room with a “witness panel” at the end of enclosed room. Glass from the untreated glazing system will embed itself in the panel, which is an indication that significant injury from the broken glass could occur. The test is repeated with treated glass (i.e. with various thickness of Safety Film applied to the interior side of the glass surface). Ultimately, these tests show that glass treated with Safety Film has a definite mitigating effect in reducing the amount of glass shards striking the witness panel.

Shock Tube Testing is a serious and useful test method for studying some facets of blast mitigation dynamics. It is less costly than the third method of testing, *Open Air Arena Testing*. However, *Shock Tube Testing* suffers from two significant deficiencies. First, the positive-impulse phase is usually over energetic and does not exhibit a force that decreases gradually over a sustained time frame. Secondly, this test method does not produce a negative phase. (In actuality, a bomb blast produces both a positive forward moving force, and a negative backward force that will function in a manner so as to “suck” the window outwardly from its frame.) Both of these *Shock Tube Testing* limitations are accounted for in the *Open Air Arena Testing* method, a procedure that generally receives greater credibility from the engineering community.

Open Air Arena Testing

The preferred and more recognized method for testing the performance level of glass fragment retention is *Open Air Arena Testing* with large explosive charges and glazing systems mounted in an enclosed reaction structure (See photos). Such tests are very expensive. However, this type of testing more closely replicates the actual results of a bomb blast situation, as it would affect untreated glass, laminated glass, and Safety Film treated glass, and other glass breakage mitigation devices and techniques.

PHOTO BLAST TEST REACTION STRUCTURE

Subsequently, the GSA hired independent test laboratories to develop guidelines for evaluating blast mitigation alternatives that were conducted as *Open Air Arena Tests* in 1996 and 1998. Various types of glazing systems were evaluated: annealed, heat treated, and tempered glass in monolithic, laminated, and insulated unit configurations. A variety of framing systems was also used, non-responding steel frames, as well as commercially available aluminum frames.

PHOTO GSA TEST ANNEALED GLASS NO FILM ATTACHED

PHOTO GSA TEST DAY-LITE 7 MIL FILM

PHOTO GSA TEST IG UNIT 7 MIL FILM ATTACHED 4 SIDES

Normal and high-speed photography was used to record and document the various glazing system responses. Control specimens with no protection were included to demonstrate the potential hazards of unprotected glass. Other samples were retrofitted with single and multi-layer Safety Films: 4, 6, 7, and 11 mil thickness. Laminated glass in deep rebated frames and blast curtains commonly used in the

U.K. were also tested. All tests were performed in accordance with the GSA *"Standard Test Method for Glazing and Glazing Systems to Air Blast Loadings"*.

PHOTO 600 LB ANFO X

The Interagency Security Committee (ISC) adopted similar test criteria. The GSA/ISC glazing performance criteria is presented in Figure 6.1 and described in Table 6.1. The approach compares potential hazards based on the type and location of glass fragments in the interior of the cubicle. These criteria indirectly reflect the velocity (hence potential lethalness) of the fragments based on their distance from the window.

GSA GLAZING PERFORMANCE CRITERIA DIAGRAM 1.1

GSA GLAZING PERFORMANCE CRITERIA TABLE 1.2

The U.S. Department of State (DOS) and Department of Defense (DOD) also have performance criteria for mitigating glass fragment hazards. These criteria are in some cases more stringent than the GSA/ISC criteria. There are also two other criteria ratings – one developed by the United Kingdom (UK) and the other by the Army Corps of Engineers. A comparison of these various criteria is shown in Table 6.2

Observations

The following general observations can be made from these tests:

- Laminated glass and glass clad polycarbonate, and polycarbonate sheets can be engineered to withstand significant blast loads provided adequate framing rebates and anchoring methodologies are provided
- The failure mode for laminated glass exhibited a tendency to be pulled out of the window bite or framing system if not design engineered correctly
- Safety Film properly installed on windows provided significant hazard mitigation
- Safety Film performed better on heat-treated and/or tempered systems versus annealed glass (annealed glass at higher pressure levels initiated tears in the film which lowered the overall protection performance), especially when attachment systems are utilized.
- Increasing film thickness generally improved the blast mitigation performance.
- Methods of film attachment, mechanical or otherwise provided better protection than "daylite" installed film applications
- Blast curtains provided significant protection that could be enhanced with greater technology improvements, and should be considered as an added protection enhancement with laminated glass and/or windows treated with Safety Film.

Readers are encouraged to review the report prepared for the AIMCAL-Window Film Committee(*A White Paper on Performance of Window Film Subjected to Blast Loading*) in its entirety for greater understanding of the issues involved. (Copies of the report can be purchased from the IWFA Administrative Office).

HURRICANE PROTECTION

PHOTO HURRICANE FRAN X

Introduction

In 1992, Hurricane Andrew became the most destructive storm of all times in terms of dollar costs. The storm cost estimate was in excess of $30 billion dollars. Follow up investigations and studies highlighted significant shortcomings in the Southern Florida residential housing market. Weak building codes, lax enforcement of codes, poor construction design, and shoddy workmanship all played a part in creating a situation whereby the forces of wind and water easily compromised the structural integrity of thousands of homes and small businesses. Broken windows and doors played a key role in allowing unequal atmospheric pressures to in effect raise roofs and collapse walls. This phenomenon was most noted in two story homes versus one story and homes, and homes with gable roofs versus homes with a hip roof design.

The challenge of how to protect buildings from damage during a hurricane or other severe windstorms is very complex, causing disagreement even among experts. There are several dynamics involved. For example, a glazing system must withstand the pressure of high winds against the glazing surface (referred to as wind-load). Generally speaking, glass fitted with Safety Film is capable of withstanding high wind-loads. In a hurricane, however, wind pressures are not always constant. The pressure on the glazing system may alternately, "push" and "pull" the unit inward and outward. This type of loading is referred to as cyclic loading. Again, Safety Film generally performs well in this type of loading situation. However, the constant back-and-forth movement exerts tremendous pressure on the framing system often leading to failure. In advertising and promoting Safety Film as providing "*hurricane proof*" protection, dealers are creating potential legal lawsuit liabilities for themselves as well as giving the industry overall a "black-eye".

The most difficult challenge in hurricanes and other severe windstorms is protecting against wind-borne debris. Significant time, effort, and dollars have been, and will continue to be spent in studying this variable and attempting to determine what is a reasonable and appropriate level of protection needed to protect glazing systems from wind-borne debris.

PHOTO HURRICANE DAMAGE (5) X

Unfortunately, some Florida (and Texas) coastal counties have adopted a test method (Dade County Protocol) that is highly restrictive (conservative) and focuses its attention almost exclusively on a large missile impact in wind conditions of an extreme and unlikely nature. As a result, Safety Film and other products have to be tested on a "one-size-fits-all" *Pass/Fail* basis for their ability to resist wind-borne debris. This test procedure can benefit thick (not typical) laminated glass, which, in some constructions, has the ability to pass the criteria.

It should be noted that the SBCCI SSTD 1297 Test Standard for Determining Impact Resistance from Wind-borne Debris has been revised to reflect different levels of performance based on the wind speeds and missile weight. Additionally, it should also be noted that a study conducted by Applied Research Associates, Inc. (discussed below) indicates, the “probability of large missile impacts on windows for a typical house is less than five percent”. With a potential success rate of *ninety-five percent* Safety Film deserves broader recognition and acceptance as a legitimate mitigation device for hurricane protection.

Dade County Protocol

August 24, 1992 is a date that many residents of Florida are likely to remember the rest of their lives. That was the day Hurricane Andrew (Category 4) devastated southern Florida, delivering an unprecedented blow to the state’s economy and undermining the confidence of residents in the ability of their homes and businesses to withstand strong hurricane winds.

Andrew’s destruction made it evident to construction professionals that changes were needed in the design and construction of residential and commercial buildings. The Metro Dade County Building Code Evaluation Task Force was formed to survey and investigate the damage caused by the hurricane. Studies were conducted to determine how so many buildings failed, and to provide more rigorous testing and evaluation procedures to enhance the performance of hurricane-resistant building materials (particularly glazing systems).

Investigations identified the loss of windows, doors, and roofing materials as a major contributing factor in the destruction of commercial and residential dwellings during the hurricane. The reason is simple to understand: when windows and doors fail, the integrity of the building envelope is breached, producing intense internal pressurization of the structure. This pressurization often led to a complete collapse of the walls and roof of the building. The main culprit causing the breach in a building’s "envelope" was found to be wind-borne debris. The debris would strike and shatter the glazing system allowing wind (and water) to enter, thus causing the destructive internal pressurization imbalance.

In recognition of this wind-borne debris problem, Dade County adopted tough new building standards in 1993 that govern the performance of glazing. In essence, the South Florida Building Code requires that every exterior opening in a newly constructed house or business be protected against flying debris propelled by hurricane-force winds.

The counties of West Palm Beach, Monroe and Broward in Florida have adopted similar codes and testing procedures. In addition, as of July 1998, the Texas Department of Insurance will require hurricane-glazing protection in 14 counties which are at high risk of windstorm damage. Other states, such as New York and North Carolina, are also considering similar action.

PHOTO HURRICANE DAMAGE (3) X

The tests devised in Florida to determine whether adequate protection exists consist of two major components: *Impact Testing and Pressure Testing*. To measure impact performance, two different kinds of "missiles" are shot at the glazing system. A large missile, defined as a nine-pound two by four, is launched from an air cannon at 34 mph (50 ft/second). Manufacturers seeking hurricane resistance qualification supply three test specimens, each of which must survive two impacts—one in the center and one in the corner—without penetration. According to the new codes, windows, doors and skylights installed 30 feet or less from ground level must be made of materials that pass the large missile tests.

A second impact test uses smaller missiles because it is assumed that even in hurricane winds, large objects are unlikely to be traveling at high speeds (if at all) above 30 feet. The test missile is intended to represent roof gravel weighing two grams moving at 55 mph (80 ft/second). Currently, the missile being used is a 5/8" diameter steel ball bearing. Again, manufacturers supply three specimens, but in this test 30 impacts are required on each specimen—ten in the center, ten along the edge, and ten near the corner. All three windows must survive the impacts without penetration.

The glazing sample specimen from the impact phase is then subjected to a wind-load cyclic pressure test. Hurricane winds don't blow at a constant rate, so this test seeks to simulate hurricane force loading at 9,000 wind cycles, where each cycle is a function of the maximum wind speed (converted to pressure) to which the product will be "rated."

To pass, a manufacturer's specimens must pass the impact tests without penetration and during the cyclic pressure test, the specimens must remain in their frames and have no tear or crack longer than five inches and wider than 1/16 inch through which air can pass. In addition, weathering tests are conducted on all of the glazing materials used in the system to assess how the materials can be expected to perform in a storm even after long-term exposure to the elements.

PHOTO HURRICANE DAMAGE (4) X

Safety Film is not an approved mitigation device for new construction within Dade County (and other counties and states that have chosen to follow similar building codes), as it does not meet the large missile impact test criteria. It should be noted that another key component in the Dade County Protocol revolves around mapping and assigning areas with potential high levels of risk from wind-borne debris (referred to as ASCE 7). If a new building is located within a "high risk boundary", then it must conform to the code.

What About Existing Buildings in Dade County?

Essentially, the Dade County Protocol does not prevent dealers from selling and installing, or consumers from buying Safety Film to upgrade the protection level of the glazing systems in existing buildings. Sales of Safety Film in South Florida and other areas of the state continue to grow. The problem confronting window film dealers for the most part is overcoming confusion in the marketplace about which standards and codes are adopted by whom, what they really mean, and what is required of them (i.e. Safety Film is not approved, laminated glass is, etc.). There is a sufficient body of test research evidence that support the benefits of Safety Film as a protective mitigation device, and it is important to note that the Dade County codes *are only mandatory on new construction.*

Applied Research and Associates Hurricane Wind Study

In understanding the hazards posed by hurricanes and potential benefits of Safety Film in providing protection for life and property it is helpful to review a major study compiled by Applied Research Associates, Inc. The report, funded by the insurance industry and presented in 1996, was based on actual on-site surveillance of the damage caused by Hurricane Erin and Opal during the two-year period 1994-95 in the Northern Panhandle of Florida. The data was analyzed in conjunction with previous findings available from Hurricane Andrew in South Florida in 1992.

The study concentrates primarily on the aspect of roof integrity as roof failures contributed significantly to the total number of potential wind borne missiles, and complete building failure. The missile types produced by roof failure most often consisted of roof tiles, roof planks, sheathing, fascia boards, and other small rock and gravel-type debris.

General observations and computerized simulations confirmed what basic logic would tell one: *The greater the wind intensity of the storm, the more number of missiles produced, and the greater their velocity.* For example, the computer simulation projected 738 missiles produced in a storm with 110 mph winds, versus over 7,186 missiles for storm of 170 mph. These projections attempted to take in account the type and number of homes within a specific geographical area, and the various potential types and sizes of windborne missiles.

The study was limited to quantifying debris impact parameter risk. The assessment of damage, such as perforation and breach of alternative window coverings, was not considered. (In other words, the relative merits of Safety Film, shutters, laminated glass, etc. was not being measured, i.e. is one better than another.) The important point that the study made was, "Except for unprotected standard glazed openings, we know that the impact of a single missile above the threshold does not necessarily equate to failure. Even if the missile perforates the covering, the perforation hole may not be large enough to result in pressurization of the house."

The study demonstrates "that protection from windborne debris in strong hurricane winds is clearly needed for houses in residential suburban developments." However, "the strongest conclusion that can be drawn from this study is that large missile protection for peak wind speeds less than 110 mph (91 mph fastest mile) does not seem warranted. The probabilities of large missile impacts on windows for a typical house is less than five percent …"

This is the crux of the issue with Safety Film and satisfying the Dade County Protocol or Large Missile Impact Test. Some window film manufacturers have subjected various types of Safety Film to the testing protocol, and several have passed the standards necessary for the Small Missile Impact Test. However, to its detriment no Safety Film to date "passes" the standard for the Large Missile Impact Test, while thick (not typical) laminated glass may meet the criteria, as do several other protective products such as shutters.

Tornadoes and Severe Windstorms

Tornadoes and other severe windstorms also pose serious potential injury to life and damage to property. Similar to the above discussion on hurricanes, wind-blown debris is again the major culprit in the destruction wrought by such violent acts of nature. The conclusions are also similar. However, one point of difference is the greater suddenness of tornadoes over the advance predictability of hurricanes. Modern meteorological advances provide reasonable warning for approaching hurricanes enabling people to use protective shutter-type devices. However, the more rapid and sudden occurrence of tornadoes and violent windstorms favors "passive protective systems" like Safety Film and laminated glass as a preferred protection device.

FEMA TORNADO MAP

Conclusions

Although Safety Film does not pass the requirements outlined in the Dade County Protocol, it may be legally sold and promoted in Dade County and any other city, county, and state in the country as a very useful and legitimate retrofit mitigation device for hurricane and other severe windstorm protection.

Safety Film does work, and can provide substantial personal protection from broken glass while helping to maintain the integrity of the building envelope in the face of increased wind-loads and windborne debris.

EARTHQUAKE PROTECTION

Introduction

While considerable attention in building codes and standards over the past few years has been focused on the design of architectural glazing to resist the impact of windborne debris, only a minimal effort has been given to seismic or earthquake activities.

A limited, but growing body of information and research now exists with regard to evaluating potential seismic performance of architectural glazing systems that are being employed in contemporary curtain wall systems. Glass elements in curtain wall systems are becoming more prevalent in modern building envelope design. Numerous commercial (and even some large residential homes) in the U.S. and abroad have exterior walls comprised predominately of glass. These curtain wall systems are considered by convention to be non-load bearing, since they do not directly support the weight of the building. However, this thought is misleading, since the curtain walls must have an ability to resist loadings imposed by natural phenomena such as hurricanes and earthquakes.

The current structural design practice of architectural glass, as specified in model building codes, is based on uniform lateral pressures intended to simulate wind effects, but little or no direct consideration is given to earthquake loadings. This deficiency is surprising considering the significant loss of life and personal property damage experienced in recent earthquake disasters here in the U.S., Mexico, Central and South America, and abroad.

PHOTO EARTHQUAKE DAMAGE (2) X

Mexico City Study

Impetus for increased earthquake research can be attributable to the aftermath studies of the 1985 Mexico City Earthquake. In follow-up investigations involving 263 buildings, inspectors recorded glass failure as the second most serious nonstructural damage, following the damage to infill walls. Serious glass damage was recorded in 63 of the 263 buildings surveyed. The following observations were drawn from the Mexico City Earthquake Surveys:

- Buildings with complex or irregular configurations received almost twice as much structural damage and serious glass breakage as those with regular configurations
- Smaller window glass areas received less serious damage than larger glass areas
- Vertical glass shapes received twice as much serious glass damage as horizontal or square shapes
- More flexible glazing systems (metal frames) received twice as much serious glass damage as did more rigid systems
- Buildings adjoined by other buildings 25 to 75 percent as high received twice as much serious glass damage as buildings with much lower or higher adjoining buildings, due to pounding between buildings.

In the Mexico City Earthquake, glass panels used in shop front windows of single story or low-rise commercial buildings were observed to be extremely vulnerable to seismic movement. Similar observations were made in a number of earthquakes in the U.S. – 1987 Whittier, and later 1994 Northridge. For example, in the 1994 Northridge earthquake where only 14 structures were "red tagged" as having serious structural fault, roughly 60 percent of all small commercial buildings lost their shop front windows replicating the Mexico City experience.

Earthquake Engineering and Structural Dynamics

A multiyear project was initiated in 1992 at the University of Missouri-Rolla (UMR) to investigate the seismic performance of architectural glazing systems. Dynamic racking tests were performed at various frequencies and included in-plane and out-of-plane, and torsional motions. These tests, called "crescendo tests" because of their progressively increasing racking amplitudes at a constant frequency, have produced distinct and repeatable results in identifying in-plane drift magnitudes associated with predefined seismic limit states for architectural glass.

Crescendo tests were initially performed on architectural glass commonly employed in storefront wall systems. A subsequent series of tests were conducted on a variety of glass commonly employed in popular curtain wall systems used on mid-rise buildings. (It should be noted that the overall performance level of the total glazing system is affected by three elements: 1) the type of glass, 2) the wall framing system, and 3) the silicone structural glazing used.)

The tests were designed to investigate and measure the breakage and fallout behavior of various types of glass. Unfortunately, Safety Film was only a secondary focus of the overall test series. Only a 4-mil thick film was involved, and used solely in an unanchored format. (More comprehensive testing of various film types with and without anchoring systems could prove highly beneficial for future sales for the industry.)

The tests established the following two broad performance definitions: 1) "serviceability drift limit" (SDL) and 2 "ultimate drift limit" (UDL). (SDL) is defined as drift that causes glass to become crushed and cracked (a condition that would necessitate glass replacement, but would not pose an immediate life safety hazard). (UDL) is defined as drift that causes glass to fallout (a condition that would pose serious life hazard to building occupants and pedestrians).

Test results indicate that thicker heat-strengthened monolithic glass panels and laminated glass units were found to be resistant to more severe serviceability (cracking) drift limits. The application of Safety Film to annealed monolithic glass panels provided similar resistance to severe serviceability drift limits.

Laminated glass exhibits the highest fallout resistance of any glass type tested. Similarly, the attachment of 4-mil Safety Film (unanchored) also increases the fallout drift limit for annealed monolithic glass.

PHOTO EARTHQUAKE DAMAGE (3)

(At the time of this writing, a major seismic research/testing effort is being implemented by the AIMCAL-Window Film Committee for completion in late 2002.)

MISCELLANEOUS INFORMATION

Window Cleaning Tips

A scratch resistant coating on the outside surface of the film is used to protect it from damage. However, care and caution must still be used in cleaning the surface of the glass on which film has been applied to reduce possible damage:

- Use any normal household glass cleaning solutions, or plain soapy water.
- **Do not use** any solution that contains abrasive material, e.g. baking soda, scouring powder, etc. Be careful not to use sharp instruments that could gouge the film.
- Use soft clean lint-free towels or synthetic sponges to apply cleaning solutions.
- Use soft cloth or rubber squeegees for drying the glass.

Exterior Window Films

On occasion it may be necessary to apply window film to the exterior side of a window. This may be necessary for a variety of reasons. In some cases, it may be so difficult to reach the interior side of the window due to fixtures, fittings or other items that are so close to the window, that it is impossible to maneuver between them and the glass to install the film. Another reason may be that the glass is a composite structure, i.e. laminated glass. In such cases, the installation of the window film on the interior surface may cause the glass to crack as a result of the temperature differentials (thermal stress fracture).

Many window film manufacturers make a few products for exterior applications. As these films are subjected to an extreme amount of weathering and may easily be abused because of their locations, or as a result of careless window cleaning, they have a somewhat limited life. These products generally have limited warranties for shorter periods of time.

There are also films specifically designed for installation on the exterior of windows to protect against graffiti ("glass tagging") on the glass itself. Conventional films should not be mounted on the exterior of windows as they are not manufactured for this usage and will typically deteriorate more rapidly.

Application – Louvered Windows

Because of the nature of the design of louvered windows, any film applied to them is likely to be exposed to the elements at some stage. Furthermore, louvered windows expose an edge of the glass and film to exterior weather, which can lead to the film peeling or corroding along the edges. For this reason, exterior grade film should be used for this application. The end user should be advised that this film is unlikely to have the same sort of longevity that film installed on the interior of glass on a regular window would have.

Application – Wired Glass

CLEAR Safety Film can be considered as an option to install on wired glass for glass breakage mitigation protection. However, neither solar control nor Solar Security Film should be applied to the interior surface of wired glass. The wire contained within the glass absorbs heat and if solar control type film is installed on the interior surface, the heat reflected out of the film greatly increases the heat absorption of the wire, leading to a high rate of expansion. The wire expands to a point that the glass can no longer tolerate, resulting in spontaneous glass breakage. In cases where it is necessary to install solar control type films, the film should be applied to the exterior surface of the glass, using exterior window film.

Application – Tinted Glass

Tinted glass is a major absorber of heat, and leads to a great deal of stress within the glass. Window film (even CLEAR Safety Film) absorbs a certain amount of heat, and if the combined absorption of the window film and tinted glass is very high, this can result in the glass cracking due to thermal stress. This is particularly true for annealed monolithic type glass. Dealers should avoid installing films that exhibit an absorption rate exceeding 50% on any tinted annealed glass. Tempered glass that is tinted should generally be safe for applying most solar control films. However, dealers and installers are advised to consult with their respective window film manufacturer before installing films on tinted glass (generally, all manufacturers publish "Film-to-Glass Recommendation Charts" to assist dealers and customers).

Application – Patterned or Textured Glass

Patterned or textured surfaces will not allow window film adhesives to form an adequate or appropriately strong bond to the glass surface. Obviously, the type and degree of the texture or pattern will influence the potential bonding action. In some cases, if the texture is minimal, it may be possible to install film, but this is not recommended, as the adhesive bond will probably be inadequate. In most cases, this type of glass is installed with the smooth side facing the exterior of the building, and if this is the case, there is no reason why an exterior film cannot be installed on that surface.

Application – Thicker Glasses and Large Windows

It should be noted that the thickness of glass does increase its absorption rate so it is generally not advisable to apply a Safety Film with solar control properties that also exhibit high absorption rates. Dealer and installers should consult with their window film manufacturer.

Similarly, extreme caution should be used when applying Safety Film to large panes of glass. The pressure required to squeegee the moisture out from behind the film may result in breaking the glass.

Application – Skylights

The application of window film to skylights is much more restricted versus vertical glazing systems. Dealers and installers should consult with their manufacturer's technical adviser, and also be aware of any code restrictions involving the proposed installation. If the film is installed on the outside surface of the skylight, it may have a shorter life span. This is due to the fact that most skylights accumulate moisture as the result of rain, snow or humidity. This moisture, either in standing form or as a result of condensation, is likely to lead to rapid breakdown of the film's construction, and in the case of metallized film, subsequent demetallization. Many manufacturers recommend edge sealants for exterior applications.

Application – Plastics

Window film should not be applied to acrylic or polycarbonate windows, unless it is specifically designed for that purpose. These are plastic sheeting products and they all have the potential to "out-gas". Heat and visible light from the sun cause "out-gassing", which is the release of chemical components and/or moisture absorbed by the plastic. This "out-gassing" interferes with the window's adhesive system, and results in bubbling between the plastic sheet and the film. It should be noted that "out-gassing" typically occurs in direct sunlight or when there are relatively large temperature differentials. Interior windows made of plastic materials, which are not exposed to direct sunlight, have been successfully tinted. However, precaution should be taken relative to any warranties provided to a customer. It should also be noted that many window film adhesive systems, when applied to plastics will create a permanent bond, and in the event that the film should have to be removed, it will be almost impossible to do without damaging the surface of the plastic sheet.

Application – New Construction

Window film should generally be installed in new or renovated buildings only when all other work has been concluded. There are many reasons for this. There is little sense in applying window film to windows that have frames that may need to be painted; leading to paint splatters on the film itself.

Other reasons could be the potential damage to the film due to the high amount of activity in a construction environment. Also, in many cases, there is a high level of dust and particles such as carpet fibers in construction areas that could become trapped between the glass and the window. Most important, many contracts require the installer to be responsible for and to protect their work until final inspection. If the installed film gets damaged, the installer (dealer) is responsible.

Attaching Items on Windows with Film

While all interior films have a protective scratch resistant coating they are still subject to physical abuse and damage. A particularly contentious problem can occur when foreign materials are applied to the filmed inside surface. This is a very real issue for commercial retail accounts such as convenience stores, fast-food outlets, grocery stores, and clothing stores where the use of "merchandising signs" is a common practice, i.e. special offers, holiday sales, etc.

Signs that are made of polyvinyl chlorine (PVC), also known as "static cling", are preferable and should cause no damage to the window film if properly applied and removed. Various tapes with "sticky" adhesive can leave a residue on the window film when removed, or worse, it can remove the "scratch coating". The residue will eventually attract dust and other airborne particles, giving the window a cloudy appearance. Such tape residue can only be removed with a cleaning solvent such as "Goo Gone" (precautions should be taken to use a soft cloth (not paper towel) to dry the window). Some types of tape do not leave a residue. However, if at all possible, tape should be avoided. Signs, which are affixed, to the glass by suction cup devices should not damage the window film.

SAFETY FILM INSTALLATION

Basic Installation Techniques

A review of Safety Film installation techniques evolve naturally from the previous discussion dealing with *Open Air Arena Testing.* There are three general installation techniques:

1) Daylite
2) Edge to Edge
3) Anchored (Mechanical and Wet)

Daylite Installation

This installation technique is the most widely used and accepted method of applying Safety Film (and Solar Control Film) in the industry. The technique involves cutting and applying the film onto the surface of the glass leaving a slight space between the edge of the film and the edge of the framing system. This form of application is generally more than sufficient to hold broken annealed glass intact within the framing system under instances of human impact, small missile impact, and small explosive charges. It also provides sufficient resistance to attempted forced entry.

Edge-To-Edge Installation

In this method the film is applied to cover 100% of the glass surface. The technique is generally more associated with application to new glass that is awaiting installation in a frame (versus a retrofit situation) whereby the glass would be removed from the framing system and the film applied on an "edge to edge" basis.

Anchored Installation

There are two broad forms of anchored installation methods, generally referred to as "Mechanical" and "Wet" installations. In a "Mechanical" installation the Safety Film not only covers the entire surface of the glass, but it also extends to overlap the framing system and is held in place by mechanical means in a bar and batten type of attachment system. The system can be attached on the top of the frame ("doggy door") or on two sides – at the top and bottom of the frame, or on all four sides.

DIAGRAM DAYLIGHT APPLICATION X
DIAGRAM SINGLE BASE PLATE X
DIAGRAM WRAP AROUND BASE PLATE X

In the "Wet" system the film is applied in similar fashion as previously outlined for a "Daylite" installation. However, there is no visible gap between the film and the edge of the framing system. The installer may use a knife to cut the rubber gasket surrounding the frame, flush with edge, or at a slight under-cut angle. A special sealant material is then applied to all four sides of the film to create a tight bond between the glass, film, and framing system. The adhesive (caulking) must extend onto the glass and framing system (excluding the gasket) at least 3/16" or more.

DIAGRAM WET GLAZED X

Both "Mechanical" and "Wet" anchor type systems significantly enhance the performance level of the entire glazing system to maintain its integrity in the event that the glass is broken. The performance level of an anchored system is generally on par with the results typically achieved by deep-rebate, anchored laminated glass framing systems.

An installation using an anchoring system is more labor intensive, and thus more costly than a daylite installation, but still considerably less than the cost of laminated glass. Depending on the type of anchoring system, and how it is implemented may determines the aesthetic look of the system.

Catch-bar and/or Catch Systems
Another method of assisting day-lite application of a fragment retention window film is using a catch-bar and/or catch-system. There are a number of methods that can be employed:

Static Catch-bar
This method is used where an aluminum or steel bar-stock is bolted horizontally or vertically into the existing frame of the glazing system and/or sub-strata. The basis for this type of system is to contain the broken glass and day-lite applied fragment retention film when vacating the existing frame from a blast-load and keep it from entering into the occupied space.

Energy Absorbing Systems
Another method, where frame attachment cannot be used, are systems that will work with a day-lite applied film or laminated glass which can absorb the initial blast -load with deployable cables, cords, aluminum tubing or the combinations thereof. As mentioned above these systems would be attached to the existing glazing frame horizontally or vertically beyond the glazing frame and anchored into the sub-strata, i.e. wall, concrete, steel etc. This method offers an increased level of performance for existing day-lite applications by relieving the load-transference from the existing frames and anchors to the film, broken glass and the energy absorbing system. This method would not be recommended for insulating window units for reasons of "blow-by", glass from the outer panels blowing around the filmed glass and into the occupied space, and although the glass fragments would be of a low-velocity, they could still be a potential hazard.

Catch Nets and Straps
There have been installations of a cargo net or cargo strapping type material use in situations of older windows i.e., a large opening with small multiple windows. These methods have been used in petrol chemical plants usually in areas where visual esthetics are not a big concern. These products would be installed to cover the entire area of the opening, either to existing frame or again to the sub-strata.

Secondary Glazing Systems
There are occasions when the historical significance of a building will take precedence. Often these buildings will have large openings with small multiple panes glazed into wood, metal or perhaps other exotic materials. Usually, altering the existing window system is not allowed. A secondary glazing frame can be designed to match the existing frames and then glazed with glass either with surface applied fragment retention film and/or laminated glass. Film is sometimes installed on laminated glass in combination as a spall-shield. This method, when designed properly, has excellent performance capabilities.

VISUAL INSPECTION STANDARDS FOR APPLIED WINDOW FILM

As adopted by the IWFA – May 15, 1999 *

1. Installed film on flat glass surfaces is not expected to have the same level of visual quality as glass. The following criteria apply to the installed film only and not to any defect inherent in the glass.

2. Installed film has a discrete time for full adhesion to be effected since installation utilizes a detergent solution in water to float the film onto the glass: the excess water is squeegeed out, but inevitably, residual water will remain between the film and glass. The time to achieve full adhesion is often referred to as the *adhesive cure time.* Adhesion will be increasing from a lower value during this time. Visual and *adhesive cure time* is related to thickness of the film and various metallic coatings on the film. Typical visual cure times may be extended or shortened according to climatic conditions.

3. Inspection for optical quality can be made before full visual cure is attained. Table 1 provides a guide for typical visual cure times. It should be noted that effects during curing, such as water bubbles, water distortion, and water haze, are not to be regarded as defects.

4. The glass with applied film shall be viewed at right angles to the glass from the room side, at a distance of not less than 6 feet (2 meters). Viewing shall be carried out in natural daylight, and not in direct sunlight, and shall assess the normal vision area with the exceptions of a 2-inch (50mm) wide band around the perimeter of the unit.

5. The installation shall be deemed acceptable if all of the following are unobtrusive (effects during visual cure should be disregarded): Dirt Particles, Hair and Fibers, Adhesive Gels, Fingerprints, Air Bubbles, Water Haze, Scores and Scratches, Film Distortion, Creases, Edge Lift, Nicks and Tears.

   Inspection may be made within 1 day after installation. Obtrusiveness of blemishes shall be judged through the film installation under lighting conditions described in 4.

6. The 2-inch (50mm) wide band around the perimeter shall be assessed by a similar process to that noted in 3 and 4, but a small number of particles is considered acceptable where poor frame conditions mitigates against the high quality standards normally achieved.

7. Edge gaps will normally be 1/32 – 1/16 inch (1-4mm). This allows for the water used in the installation to be squeegeed out. This ensures that film edges are not raised up by contact with the frame margin. Contact with the frame margin could lead to peeling of the film.

8. For thicker Safety Films, the edge gaps will normally be 1/32 – 1/16 inch (1-4mm), with 1/32 – 1/8 inch (1-5mm) being acceptable for films greater than 7-mil (175 µ). Combination Solar Control Safety Films will also fall within this standard.

   An edge gap of up to 2mm is recommended, especially for darker (tinted, metallized, and sputtered) films, to minimize the light line around the edge of the installed film.

9. Splicing of films is necessary when larger panels of glass are treated, where both length and width exceed the maximum width of the film. The splice line itself should not be viewed as a defect. This line should be straight and should be parallel to one edge of the frame margin. The two pieces of film may be butt jointed. The maximum gap in any point in the splice line should be 1/64 inch (1mm). Film may be overlapped, spliced or butt jointed.

10. Certain films with special high performance coating may have lengthened cure times. Consult the manufacturer for cure times of these films.

Table 15.1 – Typical Cure Times

Film thickness in mils	Film thickness in microns (μ)	Curing days
Up to 4-mil	Up to 100μ	30
4 to 8-mil	100 to 200μ	60
8 to 12-mil	200 to 300μ	100
Over 12-mil	Over 300 but not More than 425μ	140

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