THE GLASS

Float Glass

History of Flat Glass Production

In order to better understand the glass and glazing industry, a brief history of glass may be helpful.

Glass was discovered over 4000 years ago. It was considered precious and used by royalty and for religious purposes. During the Roman Empire, glass making reached a high degree of quality and use, but declined significantly during the Middle Ages when the main achievement was “stained glass.” In the 7th century, Syrians developed the “crown” method for forming flat glass, whereby the molten glass was taken in lump form and spun on a cylindrical disc to flatten the glass. Interestingly, this represented the most common method to produce flat glass for the next 1000 years.

In the early part of the 20th century, inexpensive sheet glass was formed by drawing the glass ribbon vertically out of the molten glass pool. Unfortunately, sheet glass still suffered from distortion because of the differences in viscosity of the molten glass. In order to obtain relatively distortion-free glass for use in coach windows or mirrors, the plate glass process was developed. Plate glass was made by pouring molten glass onto a table and rolling it until flattened, then grinding and polishing it into a plate. This process eventually advanced by feeding the molten glass though continuous rollers, grinders and polishers. Sheet glass is no longer commercially produced in the United States.

In 1959, the float glass process was introduced. This unique glass making process revolutionized the flat glass industry. In the float process, molten glass from the furnace flows by gravity and displacement onto a bath of molten tin where a continuous ribbon is formed. This glass ribbon is pulled or drawn through the tin bath and upon exiting is guided on rollers through an annealing lehr where it is cooled, under controlled conditions, until it emerges at essentially room temperature. The product is now flat, fire-finished and has virtually parallel surfaces. Automatic cutters generally are used to trim the edges and cut across the width of the moving ribbon. This creates sizes, which can be shipped or handled for further processing. The float glass process accounts for almost all of the flat glass presently produced in the United States.

Commercial float glass is nearly colorless with a visible light transmittance ranging from 75% to 92% depending on thickness. With the exception of specialty low-iron glass, a faint green or blue-green color may be noticeable in glazing applications where the glass thickness approaches or exceeds 3/8" (10 mm). Specialty low-iron glass has a higher visible transmittance than commercial float glass of the same thickness.

Tinted or Heat-Absorbing Glass is made by adding various colorants to the normal, clear glass batch to create a desired color. The typical colors produced domestically include bronze, gray, dark gray, aquamarine, green, deep green, blue, deep blue and black. Some companies in Europe produce other colors, for instance rose and emerald green. Visible light transmittance will vary from 14% to 85%, depending on color and thickness. The color density is also a function of thickness. As the thickness increases, visible light transmittance will decrease.

Tinting reduces the solar transmittance of glass and increases solar heat absorption. Because of this heat buildup, heat-treating (heat-strengthening or tempering) is sometimes required for tinted glass.

Color of tinted/heat-absorbing glass is a major consideration for either design and aesthetic reasons or for color matching requirements. Tinted heat-absorbing glass should be viewed as installed for color comparison. Colors may vary considerably among different manufacturers and from run to run. No published color standard exists; the manufacturer should be consulted for color information.

Annealed Glass

Upon exiting the tin bath, the float glass ribbon is guided on rollers through an annealing lehr where it is cooled, under controlled conditions, until it emerges at essentially room temperature. The product is now flat, fire-finished and has virtually parallel surfaces. Automatic cutters generally are used to trim the edges and cut across the width of the moving ribbon. This creates sizes that can be shipped or handled for further processing. This glass is referred to as annealed glass.

Annealed glass may be used in its original state or it can be further fabricated by cutting, heat-treating, coating, laminating, or insulating. Annealed glass provides the least resistance to mechanical and thermal stresses when compared with heat-strengthened and fully tempered glass.

Industry production quality requirements, product tolerances and test procedures for annealed glass are defined in the ASTM International (ASTM) document C 1036 *Standard Specification for Flat Glass*.

Heat-Treated Glass

In order to provide greater resistance to thermal and mechanical stresses and achieve specific break patterns for safety glazing applications, annealed float glass products may be subjected to a heat-treating process. The most commonly used process for heat-treating architectural products calls for glass to be cut to the desired size, transported through a furnace and uniformly heated to approximately 1150° F (621° C). Upon exiting the furnace, the glass is rapidly cooled (quenched) by blowing air uniformly onto both surfaces simultaneously. The cooling process locks the surfaces of the glass in a state of high compression and the central core in compensating tension. Heat-treated glass has two compression layers or zones, one starting at each surface, plus an interior tension zone centered in the middle of the glass. Each of the two compression zones is approximately 20% of the glass thickness. The middle 60% of the glass thickness is the tension zone.

The color, clarity, chemical composition and light transmission characteristics of glass remain unchanged after heat-treating. Likewise, hardness, specific gravity, expansion coefficient, softening point, thermal conductivity, solar transmittance and stiffness remain unchanged. The only physical properties that change are improved flexural and tensile strength and improved resistance to thermal stresses and thermal shock. Under uniform loading, heat-treated glass is stronger than annealed glass of the same size and thickness. Heat-treating glass does not reduce the deflection of the product for any given load.

Heat-Treated Glass is separated into two products, ***heat-strengthened glass*** and ***fully tempered glass***, by definition of the degree of residual surface compression or edge compression. Most furnaces can produce both. A furnace and its quench must be adjusted by its operator for one or the other of a product “run.” The adjustments may include changes in furnace temperature, exit temperature of the glass, residual time in the furnace, and volume and pressure of the quench air.

Production of Heat-Treated Glass

There are two basic methods for producing air-quenched heat-treated glass. The most commonly used heat-treating furnace, a horizontal roller hearth, transports glass on horizontal rollers through the heating and quench processes.

A limited amount of heat-treated glass is produced in vertical furnaces, which call for the glass to be held in a vertical position by tongs as it is transported through the heating and quench processes.

Each method produces some degree of bow and warp, which is an inherent characteristic of all heat-treated glass. Tong-held glass, the vertical process, may exhibit a long arc or “S” curve plus some minor distortion at the tong points. Horizontally heat-treated glass will have characteristic waves or corrugations caused by the transport rollers. Industry fabrication requirements, product tolerances and testing procedures for heat-treated glass are defined in the ASTM International (ASTM) document C 1048 *Standard Specification for Heat-Treated Flat Glass - Kind HS, Kind FT Coated and Uncoated Glass*.

Heat-Strengthened Glass

Heat-strengthened glass is produced with surface and edge compression levels less than fully tempered glass, as specified by ASTM C 1048. The lower compression levels yield a product that is generally twice as strong as annealed glass of the same thickness, size and type. The size and shape of the break pattern of heat-strengthened glass varies with the level of surface and edge compression achieved in the heat-treating process. Heat-strengthened glass with low compression levels will tend to fracture into large fragments, similar to annealed glass breakage. As the compression levels increase, the size of the particles of broken glass tend to become smaller.

ASTM C 1048 requires that heat-strengthened glass have a surface compression level between 3,500 pounds per square inch (psi) to 7,500 psi. The break pattern of heat-strengthened glass is relatively large. The glass pieces typically remain engaged in the glazing pocket, decreasing the probability of fall out. Broken glass should be removed and the opening boarded up or reglazed as soon as possible.

Heat-strengthened glass does not meet the safety glazing requirements of the American National Standards Institute (ANSI) Z97.1 *American National Standard for Safety Glazing Materials Used in Buildings - Safety Performance Specifications Method of Test* or the federal safety standard Consumer Products Safety Commission 16 CFR 1201 *Safety Standard for Architectural Glazing Materials*.

Fully Tempered Glass

Fully tempered glass is required in ASTM C 1048 to have either a minimum surface compression of 10,000 psi (69 MPa or an edge compression of not less than 9,700 psi (67 MPa) or meet ANSI Z 97.1 or CPSC 16 CFR 1201. The higher compression levels yield a product that is generally four times stronger than annealed glass and twice as strong as heat-strengthened glass of the same thickness, size and type.

When broken by impact, fully tempered glass immediately disintegrates into relatively small pieces thereby greatly reducing the likelihood of serious cutting or piercing injuries in comparison with ordinary annealed glass. To qualify as a safety glazing material as defined by ANSI Z97.1 and CPSC 16 CFR 1201, the ten largest particles taken from a broken fully tempered lite of glass shall weigh no more than the equivalent weight of 10 square inches (64 sq. cm) of the original specimen when tested according to the standards. Fully tempered glass that meets ASTM C 1048 does not automatically qualify as a safety glazing material.

Chemically Strengthened Glass

Chemical strengthening of glass is produced through a process known as ion-exchange. One of the methods used to chemically strengthen glass calls for the lites to be submersed in a molten salt bath at temperatures below the strain point of the glass. In the case of soda-lime float or soda-lime sheet glass, the salt bath consists of potassium nitrate. During the submersion cycle, the larger alkali potassium ions exchange places with the smaller alkali sodium ions in the surface of the glass. The larger alkali potassium ions “wedge” their way into the voids in the surface created by the vacating smaller sodium ions.

Chemically strengthened glass production requirements and test procedures are defined in ASTM C 1422 *Standard Specification for Chemically Strengthened Flat Glass*. The specification covers the requirements for chemically strengthened glass products, which originate from flat glass for use in building construction, transportation and other specialty applications.

Under the specification, chemically strengthened glass is classified on the basis of independent levels of surface compression and case depth. Increasing levels of surface compression permit an increasing amount of flexure. Greater case depths provide increased protection from strength reduction caused by abuse and abrasion. Consumers should consult with chemically strengthened glass fabricators regarding the recommended surface compression and case depth levels required for their individual application. Product classification levels may be confirmed through laboratory testing in accordance with the specification.

Chemically strengthened glass can be significantly stronger than annealed glass, depending upon the glass product, strengthening process, level of abrasion, and the application. Chemically strengthening glass is often the alternative to thermal tempering when applications call for glass that is very thin, small in size, or complex in shape.

Although chemically strengthened glass can be cut after treatment, it is not recommended, as edge strength will be reduced to that of annealed glass.

When broken by impact, chemically strengthened glass exhibits a break pattern similar to annealed glass, and therefore, does not meet safety-glazing requirements in a monolithic form. When safety-glazing performance is required, chemically strengthened glass should be laminated.

While chemically strengthened glass is often used monolithically, product usage has increased in laminated constructions for security, detention, hurricane/cyclic wind-resistant, blast and ballistic-resistant glazing applications.

Coated Glass

Flat glass products may be coated to enhance the thermal and optical performance characteristics of products used in residential and commercial glazing, and transportation applications. There are two basic types of coated glass: **solar control (reflective)** and **low-emissivity (low-e)**. The major differences are visible light transmission, UV, visible, and near infrared wavelengths of energy that are reflected and the directions in which these wavelengths are usually reflected.

The solar spectrum consists of ultraviolet light with wavelengths ranging from 300-390 nm, visible light (390-770 nm) and infrared light (770-2100 nm). The distribution of energy within the solar spectrum is approximately 2% ultraviolet (UV), 46% visible and 52% infrared (IR).

Solar-control glass may have a variety of metal coating layers that are highly reflective of solar energy, i.e., those energy wavelengths from 300-2100 nanometers (nm) that constitute the solar spectrum.

The major benefits of reflective **solar control glass** include the following:

Aesthetic appeal: Colors of silver, blue, copper, golden and earth-tone coatings, applied to the wide range of clear and tinted float glass, allows the architect considerable flexibility with exterior design.

Energy savings: through its ability to reflect, absorb and radiate solar energy, solar reflective glass substantially reduces interior solar heat gain. The added cost of the coating will generally be offset by the reduced size and operating cost of the heating and cooling systems.

Occupant comfort: is improved when heat gain is reduced and interior temperatures are easier to control.

Low-emissivity (low-e) coated glass may have various combinations of metal, metal oxide and metal nitride layers of coatings that are nearly invisible to the eye. Some low-e coatings are highly reflective for the infrared (IR) part of the solar spectrum and all low-e coatings reflect long wave IR energy. Long wave IR can be described as the radiant heat given off by an electric coil-type heater, as well as the heat that comes from a hot air register. The re-radiated heat from room furnishings that have absorbed solar energy is still another form of radiant heat.

While some low-e coatings can be used in monolithic or laminated glass constructions, the coatings provide maximum performance when sealed within an insulating glass unit. The location of the low-e coating within a unit affects the product performance. A low-e coating on the second (#2) surface of an insulating glass unit is more effective at reducing solar heat gain, especially when used in conjunction with tinted glass. The low-e coating will reflect re-radiated heat (IR), while the tinted glass reduces the solar radiation through the glass, resulting in less glare and heat gain. When using low-e glass in commercial buildings and residential applications in warm climate regions, this is generally the most practical way to maintain comfort levels.

In cold climate regions where building owners and occupants want to maximize solar heat gain from the sun while minimizing radiant heat loss, insulating glass units commonly incorporate clear glass with a low-e on the third (#3) surface. The low-e coating reduces heat loss through the glass in winter by reflecting interior long wave IR back into the home or office.

Center of glass U-values in the range of 0.25 - 0.36 can be achieved with low-e coatings on the second or third surface of insulating glass units. Low-e coatings can be combined in an insulating unit with a solar-control / reflective coating and gas filling to create an insulating unit having lower U-values and a lower shading coefficient. Since technology continues to advance and because the combinations of substrates and coatings are too numerous to list, it is best to consult the coated glass manufacturers' published literature for comparisons. A generic listing of U-values of various glazing products is provided in the GANA *Glazing Manual*.

The major benefits of low-e coated glass are:

Aesthetic Appeal: the virtually invisible nature of low-e coatings provide a transparent appearance to the glazing material and building façade.

Energy Savings: through its ability to reflect long-wave infrared energy low-e coated glass reduces winter heat loss and summer heat gain through the glass, and provides high levels of visible light transmittance into the building. The combination of thermal control and reduction in interior lighting requirements reduces energy consumption for residential, and commercial buildings.

Occupant Comfort: is improved when heat gain/loss is reduced by keeping the interior temperature stable regardless of the exterior environment and when natural daylight is introduced into the building.

Optical and aesthetic quality requirements for coatings applied to glass are addressed in ASTM C 1376 *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass*.

Laminated Glass

Laminated glass is traditionally defined as:

1. Two or more lites of glass and one or more interlayers of plasticized polyvinyl butyral (PVB) permanently bonded together under heat and pressure;
2. Two or more lites of glass and polycarbonate with an aliphatic urethane interlayer between glass and polycarbonate permanently bonded together under heat and pressure.
3. Two or more lites of glass bonded with one or more interlayers of a liquid resin cured and permanently bonded together by exposure to ultraviolet light, heat, or chemicals.
4. Two or more lites of glass with an ionoplast rigid sheet interlayer (similar to a PVB yet more rigid) permanently bonded together under heat and pressure.
5. Two or more lites (or sheets) of polycarbonate (or acrylic) with an aliphatic urethane interlayer between polycarbonate or acrylic bonded together under heat and pressure.
6. Two or more lites and polyester (PET) film with a polyvinyl butyral (PVB) interlayer between glass and PET permanently bonded together under heat and pressure.

Annealed, heat-treated, chemically strengthened, wired, tinted, patterned and coated glass, as well as one- and two-way mirrors, can be incorporated into the laminated unit.

This union of materials provides a variety of performance benefits in architectural, security and other specialty applications. Its most important characteristic is the ability of the interlayer to support and hold the glass when broken and/or plastic sheet when cracked. This provides for increased protection against fall-out and penetration of the opening. Most building codes require the use of laminated glass for overhead glazing as monolithic lites, or as the lower lite in multiple glazed units. Other applications include safety, security, detention, seismic-resistant, blast-resistant, bullet-resistant, burglary-resistant, hurricane/cyclic wind-resistant and sound reduction applications. Laminated glazing materials are also used in specialty applications such as aquariums, animal enclosures, glass stairs, floors and sports stadiums.

Laminated glass with PVB interlayers are generally 75% to 100% as strong as annealed glass of the same thickness depending on exposed temperatures, aspect ratio, plate size, stiffness and load duration. Laminated glass, however, can be made with heat-strengthened, fully tempered or chemically strengthened glass for additional benefits, such as increased wind-load resistance, impact resistance, or resistance to thermal stress. The ability of the interlayer to resist various kinds of penetration may also be dependent upon thickness, temperature and other variables. Check with the fabricator for any additional limitations, such as roll distortion, that may result from this additional processing of laminated glass. There are several grades of PVB having different physical properties. Care should be taken to specify the correct grade for a given application. Consult the interlayer manufacturer / glass fabricator for full details. Typical applications for laminated glass with PVB interlayers and cured resins include locations where safety glazing is required, such as doors and skylights, shower and bath doors and enclosures. Other locations where safety glazing may be specified include operable windows and fixed glazed panels, balconies, railing systems, elevators, sports stadiums, atriums, greenhouses, skylights and sloped glazing. Laminated glass resists glass fall-out from windblown debris in hurricane / cyclic-windstorm prone areas and provides various levels of security protection in seismic, blast-resistant, bullet-resistant and burglary-resistant applications.

Laminated glass with ionoplast interlayers are similar to PVB laminates; however, the rigid interlayer provides additional performance in high design pressure and high security applications where lower deflections and higher penetration resistance is required after the glass lites have been broken.

Glass-clad polycarbonate contains glass layers to the exterior and one or more polycarbonate layers on the inside. This product combines the heat, chemical and abrasion resistance of glass with the impact resistance of polycarbonate. This laminated construction may also be unbalanced or asymmetrical, where a polycarbonate layer is exposed to the interior. Although not truly a “glass-clad” product, the industry recognizes the product under the same category. Glass-clad polycarbonates provide resistance to forced entry and ballistics and are commonly used in prisons, detention centers, jails, psychiatric facilities and other architectural settings where security is a primary concern.

Organic coated glass-butyral consist of at least one lite of glass with its interior or protected surface laminated under heat and pressure to a composite sheet of PVB with a scratch-resistant polyester (PET) film. Optionally, the organic coated glass-butyral can be applied onto multiple-ply laminated glass. The composite organic coating consists of an abrasion resistant polyester-film combined with a sheet of PVB for factory lamination to glass. The PVB is used to adhere the PET film to the glass surface. The composite must face towards the building’s interior. These laminates are generally used in security applications where there is a requirement for zero spalling on the inside of a building or room following attack from the outside.

Polyester (PET) films can also be laminated inside the laminated glass using polyvinyl butyral (PVB) to bond the PET to the glass. This PET film can provide additional resistance to penetration and cyclic wind pressure.

Quality standards for laminated glass are defined in ASTM C 1172 *Standard Specification for Laminated Architectural Glass* and ASTM C 1349*Standard Specification for Architectural Flat Glass Clad Polycarbonate*. Laminated glass for use as safety glazing is covered by ANSI Z97.1 and CPSC 16 CFR 1201 Cat. I and II.

Insulating Glass

In order to reduce heat gain or loss through glass, two or more lites may be sealed together to create an ***insulating glass (IG) unit***.

The majority of insulating glass units consist of two lites of glass enclosing a hermetically sealed air space. The lites are held apart by a spacer around the entire perimeter. The spacer contains a moisture-adsorbent material called desiccant that serves to keep the enclosed air free of visible moisture. The entire perimeter of the assembly is sealed.

The most commonly used edge construction contains a metallic spacer of roll-formed aluminum, stainless steel, coated steel or galvanized steel. It is sealed with a single seal of polysulfide, polyurethane or hot-melt butyl, or with a dual seal consisting of a primary seal of polyisobutylene and a secondary seal of silicone, polysulfide or polyurethane. The corners of the metallic spacer may be square-cut and joined with a metal, plastic or nylon corner key, may be miter-cut and brazed, welded or soldered, or may be bent. Recent years have seen the introduction of warm edge technology products as spacer materials. These products include extruded butyl materials, foam rubber based materials, formed plastics and metal strip based products, many with desiccant included as a component.

Improvements in edge of insulating glass U-values as a result of warm-edge technologies play a vital role in meeting overall window performance requirements for state adopted residential fenestration codes.

Thermal performance of insulating glass units is enhanced by using solar control substrates and coated glass (low-emissivity or reflective), coated polyester suspended films, insulating gases (such as argon, krypton or xenon) and warm edge technology products. Initial heating and cooling equipment costs and ongoing operating costs are reduced.

Insulating glass units also offer benefits by reducing sound transmission. Laminated glass constructions and sulfur hexafluoride (SF_6) gas filling further enhance the sound reduction characteristics of the insulating glass unit.

Industry product classification, performance requirements and testing procedures for insulating glass units are defined in the following ASTM International documents:

E 773 *Standard Test Method Accelerated Weathering of Sealed Insulating Glass Units*
E 774 *Standard Specification for Sealed Insulating Glass Units*
E 2188 *Standard Test Method for Insulating Glass Unit Performance*
E 2189 *Standard Test Method for Testing Resistance to Fogging in Insulating Glass Units*
E 2190 *Standard Specification for Insulating Glass Unit Performance and Evaluation*

Most insulating glass fabricators voluntarily participate in insulating glass certification programs. The purpose of the certification programs is to assure the user that the purchased product is a faithful replica of one that has passed certain prescribed tests. Therefore, participants in a certification program must complete the following requirements: 1) submit specimens of their production product to independent testing laboratories for the prescribed tests; and 2) agree to periodic, unannounced inspections of their regular production by an independent agency to ensure that actual production employs the same materials and techniques as the tested specimen.

Spandrel Glass

Spandrel glass is glass that has been rendered near opaque, i.e., it is non-vision glass. Its major use is to mask materials or construction from view from the exterior of a building. Such areas are commonly the hung-ceiling area above a vision lite or the knee-wall area below a vision lite. It is sometimes used to hide a column in what is normally the vision-glass area.

The indoor surface of spandrel glass is not suitable for use as a finished wall. Additional suitable material, such as sheet rock, must be installed on the indoor side when used in quasi-vision areas such as transom lites, column covers, etc.

In order to reduce the probability of glass breakage due to thermal stresses, spandrel glass should be heat-strengthened.

Methods of Fabricating Spandrel Glass

The most commonly used methods of rendering spandrel areas opaque are:

Ceramic Frit Opacification

Ceramic frit opacification consists of a coating of durable, colored ceramic material that is compatible with the base glass and is fire-fused into one surface of the glass during the heat-treating process. Since the basic purpose is generally to render the glass opaque, the ceramic frit is typically applied to the #2 surface of monolithic glass or the #4 surface of an insulating unit. The opacity can be improved with thicker or multiple coats of ceramic frit.

If the application requires the unit to be visible from both the exterior (#1) and interior (#4) surfaces, ceramic frit with thicker and/or multiple coats can be applied in order to provide an architectural finish when viewed from the inside of the building. Note: In this case, the exterior lite must have a very low level of light transmittance because of inherent characteristics (pinholes, uneven appearance of the coating etc.) in the ceramic frit layer. The manufacturer/fabricator should be consulted for guidance in these applications.

Ceramic frit coatings are available in a wide range of colors. The coating can be applied to otherwise uncoated glass or, in most cases, to the interior surface of a pyrolytically coated solar-control reflective glass, regardless of which surface has the pyrolytic coating. Light color ceramic frit applications may require a double coat in order to achieve a more uniform appearance.

Glass with a fired-on ceramic frit should not be used except with an opaque backup construction. If it is used where light may be seen through the glass, consultation with the glass fabricator is mandatory. Pinholes and uneven appearance of the ceramic coating may be visible prior to the completion of the opaque backup construction. These conditions are inherent in the product and are not reason for rejection.

Film Opacification

Film opacification consists of a factory applied polyester film adhered to the coated surface of vacuum deposition or pyrolytic coated glass by means of a solvent based adhesive. The polyester opacifier was designed to be adhered to a metal surface and therefore, should not be applied to the float glass surface of uncoated monolithic glass or the uncoated inboard lite of an insulating unit. Film opacified glass fabricators typically recommend against adhering insulation or other materials to the opacifier surface. The fabricator should be consulted for guidelines concerning contact of other spandrel materials with the polyester surface and airspace requirements behind the polyester surface.

A lite of glass with complete coverage of polyester film opacifier can be fabricated to meet the optional fallout resistance test contained in ASTM C 1048 *Standard Specification for Heat-Treated Flat Glass - Kind HS, Kind FT Coated and Uncoated Glass*.

For structural silicone glazing applications, the polyester film opacifier must be cut back to allow for structural bonding to the coated glass surface. Glass in this application will not meet the optional fallout resistance test contained in ASTM C 1048.

Silicone Opacification

Silicone opacification consists of an elastomeric film of liquid silicone rubber applied to any glass substrate via; spray, roller coater, or curtain coater. The chemistry utilizes strong bonding to the similarly composed glass substrate for adhesion and durability. Silicone opacifiers are applied after the heat-treating process and may employ a large variety of color and specialty pigments.

The basic purpose of the product is to render the glass opaque, thus can be applied to both monolithic and insulating glass units. For monolithic applications, the silicone opacification is applied to the #2 surface, and for insulating glass units, to the #2, #3, or #4 surface, depending on application. Edge deletion is required for all structural applications, as well as the interior surface of an application of an insulating glass unit. Compatibility confirmation should be obtained from the spandrel manufacturer prior to installation.

Standard application thickness for opacity is 8 mils wet or 3.5 mils dry. Opacity can be improved with thicker or multiple coats of the silicone opacifier. To attain fallout certification, the silicone opacifier must be applied at a thickness of at least 13 mils wet or 5 mils dry. Silicone spandrels will meet this classification if proper testing is documented per GANA Tempering Division Specification No. 89-1-6 – *Environmental Durability of Fully Tempered or Heat-Strengthened Spandrel Glass with Applied Opacifiers*, ASTM C 1048, and CAN/CGSB-12.9-M91 – *Spandrel Glass*.

A wide variety of silicone color coatings can be applied to all glass substrates, including especially pyrolytic and sputter coated reflective glass substrates, without harming the reflective coating. As with all spandrel products, silicone spandrels should not be used except with an opaque backup construction. If it is used where light may be seen through the glass, consultation with the glass fabricator is mandatory.

Water-based silicone opacification can be used and certified as “green” for the use in “green” building applications, due to polymer chemistry and pigment usage.

Silicone opacification product performance may vary between manufacturers. Consult with the manufacturer/fabricator to confirm compliance with specification performance requirements.

Shadow Box Opacification
Shadow box opacification is achieved by enclosing the space bounded by the vertical and horizontal mullions behind the glass. This is accomplished by securing a painted metal pan or dark matte-finished insulation board back from the glass. Typically, the inner face of the pan or insulation is flush with the inner plane of the vertical mullions. Shadow box detailing must also ensure that surfaces of the glazing system and surrounding materials have a dark surface to prevent read-through under some lighting conditions.

Bent Glass
Bent glass is fabricated from flat glass, which has been heated to between 1000°F (538°C) and 1100°F (593°C), gravity or mechanically formed, and then allowed to cool to the desired shape. Advances in the technology of bending glass have enabled glass benders to offer designers and architects a wide variety of options, including large lites of glass that can be bent to compound curves or to several radii with straight legs on one or both ends. Glass can also be bent to relatively sharp angles. Bent glass is available in various types including annealed, heat-strengthened and fully tempered. Bent glass can be laminated or built into insulating glass units. Check with fabricator for limitations. Pyrolytic solar control glass can be bent, although the radius of the bend may be limited by lower bending temperatures to avoid crazing of the coating. Lites with baked-on ceramic lines or dots, as well as many patterned glasses, may also be bent.

ASTM document C 1464 *Standard Specification for Bent Glass* addresses the requirements for bent glass used in general building construction, display and various other non-automotive applications.

Mirrors
Virtually all mirrors for interior use are manufactured by the conveyor, wet deposition method. Annealed or fully tempered glass is thoroughly cleaned by the application of cleaners and passing contact with oscillating scrub brush units. After the glass is cleaned and rinsed, the surface of the glass is sensitized with a diluted solution of tin chloride. This surface treatment allows for the deposition of silver. Silver nitrate is sprayed onto the sensitized surface of the glass along with other chemical configurations. The final outcome is the formation of a uniform silver layer on the glass.

Once the silver layer is formed on the glass, methods to protect the silver layer from oxidation are employed. A layer of copper is then deposited directly onto the silver. Copper can be applied in two ways: chemically or galvanically. Recent technological advances have lead to the development of copper free protective films, which also prevent silver oxidation.

Once the metal layers are attached to the glass, they are covered by a protective mirror backing paint. The mirror backing paint protects the metal layers from corrosion and from mechanical scratching. The paint can be applied either by passing the glass through a curtain of paint or by passing glass in contact with a roller paint coater. There are many mirror backing paint products available from a number of suppliers. They offer paint systems that are applied as a single coat or double coat. Both coating systems are effective.

Tinted mirrors are produced using the methods described above. The silver coating is applied to one of the various tinted glass substrates available on the market. Tinted mirrors are generally used in decorative applications where color and diminished light reflection are desirable.

Quality requirements for silvered annealed monolithic clear and tinted flat glass mirrors are provided in the ASTM document C 1503 *Standard Specification for Silvered Flat Glass Mirror*.

Tempered mirrors are manufactured using fully tempered glass as the substrate. There are optical characteristics inherent in tempered mirrors, including roll distortion and the lack of a quality surface for silvering.
Laminated mirrors are manufactured by combining clear glass, either annealed, heat-strengthened or fully tempered, and mirrored glass.

Safety backed mirrors are known as Organically Coated Mirrors in the CPSC 16 CFR 1201 and ANSI Z97.1 standards. These are manufactured by applying a sheet of adhesive backed polyethylene material to the back of annealed mirrors. The backing material does not prevent breakage of mirrors, but lessens the potential of injury on impact by retaining the fragments.

Non-Silvered Mirrors
There are two types of non-silvered mirrors: pyrolytic mirrors and transparent/two-way mirrors.

Pyrolytic mirrors are highly reflective coated glass products with performance characteristics approaching that of silvered mirrors. This product is promoted for use in shower doors and other areas where moisture can affect the substrate of silvered mirrors.

Transparent/two-way mirrors are composed of reflective glass products, and as such are not silver mirrors. Transparent mirrors are manufactured by both the pyrolytic deposition and vacuum deposition coating processes. Heavy density coatings are offered on clear and gray tinted glass.

Transparent or two-way mirrors are designed to permit vision through one direction while giving the appearance of a standard mirror from the opposite side. Their major application is to permit undetected observation for study or surveillance in interior conditions such as learning centers in schools and universities, medical and psychiatric clinics, and security stations in casinos or high-traffic retail stores.

The transparent mirrors work by reducing the visible light transmittance through the glass. To ensure proper performance the room lighting design and surrounding conditions must be carefully planned and executed. The glass surface in the subject room must appear to be standard mirror. In order to achieve this condition, the coated surface should be toward the subject room and the lighting ratios tightly controlled. For applications utilizing clear glass, manufacturers recommend a lighting ratio of 10:1 subject's side to observer's side. If the lighting ratio drops to approximately 5:1, the subject may detect movement or silhouettes through the mirror. If 10:1 lighting ratios cannot be maintained, a gray transparent mirror should be specified. Lighting ratios of 5:1 can be successfully used for gray transparent mirror products.

Design considerations call for bright contrasting colors in the subject room and dark, non-contrasting colors in the observer room. Light color surfaces or objects may be noticeable to the subject. The design of the observation room should also prevent sudden light ratio changes. Special care must be taken if transparent mirrors are used on more than one wall.

Glass Cleaning

Proper Procedures for Cleaning Architectural Glass Products

Architectural glass products play a major role in the comfort of the living and working environment of today's homes and commercial office spaces. By providing natural daylight, views of the surroundings, thermal comfort and design aesthetics, glass usage and condition often affect our selection of where we live, work, shop, play and seek education.

Architectural glass products must be properly cleaned during construction activities and as a part of routine maintenance in order to maintain visual and aesthetic clarity. Since glass products can be permanently damaged if improperly cleaned, glass producers and fabricators recommend strict compliance with the following procedures for properly cleaning glass surfaces.

As dirt and residue appear interior and exterior glass surfaces should be thoroughly cleaned. Concrete or mortar slurry that runs down (or is splashed on) glass can be especially damaging and should be washed off as soon as possible. Before proceeding with cleaning determine whether the glass is clear, tinted or reflective. Surface damage is more noticeable on reflective glass as compared with other glass products. If the reflective surface is exposed either on the exterior or interior special care must be taken when cleaning, as scratches to the reflective glass surface can result in coating removal and a visible change in light transmittance. Cleaning tinted and reflective glass surfaces in direct sunlight should be avoided since the surface temperature can be excessively hot for optimum cleaning. Cleaning should begin at the top of the building and continue to the lower levels to reduce the risk of leaving residue and cleaning solutions on glass at the lower levels. Cleaning procedures should also ensure that the wind is not blowing the cleaning solution and residue onto already cleaned glass.

Cleaning during construction activities should begin with soaking the glass surfaces with clean water and soap solution to loosen dirt or debris. Using a mild non-abrasive commercial window washing solution, uniformly apply the solution to the glass surfaces with a brush, strip washer or other non-abrasive applicator. Immediately following the application of the cleaning solution a squeegee should be used to remove all of the cleaning solution from the glass surface. Care should be taken to ensure that no metal parts of the cleaning equipment touch the glass surface and that no abrasive particles are trapped between the glass and the cleaning materials. All water and cleaning solution residue should be dried from window gaskets, sealants and frames to avoid the potential for deterioration of these materials as the result of the cleaning process.

It is strongly recommended that window washers clean a small area or one window then stop and examine the surface for any damage to the glass and/or reflective coating. The ability to detect certain surface damage, i.e. light scratches can vary greatly with the lighting conditions. Direct sunlight is needed to properly evaluate a glass surface for damage. Scratches that are not easily seen with a dark or gray sky may be very noticeable when the sun is at a certain angle in the sky or when the sun is low in the sky.

The glass industry takes extreme care to avoid glass scratches by protecting all glass surfaces during glass manufacturing and fabrication as well as during all shipping and handling required to deliver the glass to the end user. A large percentage of damaged glass results from non-glass trades working near glass. This includes painters, spacklers, ironworkers, landscapers, carpenters and others who are part of the construction process. They may inadvertently lean tools against the glass, splash materials onto the glass and/or clean the glass incorrectly, any of which can permanently damage glass.

One of the common mistakes made by non-glass trades people including glass cleaning contractors is their use of razor blades or other scrappers on a large portion of the glass surface. Using two, three, four, or five inch and larger blades to scrape a window clean carries a large probability of causing irreparable damage to glass.

The entire industry of glass manufacturers, fabricators, distributors, and installers neither condones nor recommends widespread scraping of glass surfaces with metal blades or knifes. Such scraping will often permanently damage or scratch the glass surfaces. When paint or other construction materials cannot be removed with normal cleaning procedures a new one-inch razor blade may need to be used only on non-coated glass surfaces. The razor blade should be used on small spots only. Scraping should be done in one direction only. Never scrape in a back and forth motion as this could trap particles under the blade that could scratch the glass. This practice can cause hairline concentrated scratches that are not normally visible when looking through the glass but are be visible under certain lighting conditions.

Jobsite storage and construction conditions can lead to stains on the glass surface. Cleaning and removal of such stains may require the use of a more aggressive cleaning solution and procedure. If conditions are found that cannot be cleaned using the above procedures contact the glass supplier for guidelines on stain removal.