Back to the Basics with Glass 101

A Refresher Course on Glass Types and Options Available

In the design and use of architectural glass, the responsible design professional must consider carefully the performance characteristics of the six basic types of glass and their differences as they relate to the various construction requirements. This is the view of the Primary Glass Manufacturers Council (PGMC), an organization committed to assisting design professionals with glass performance characteristics, design objectives and building code requirements. With this goal in mind, the PGMC granted the *Architect s Guide to Glass* permission to reprint a portion of the *Specifiers Guide to Architectural Glass*.

While the following information contains only a small portion of materials in the guide, the entire guide may be viewed on the PGMC s website, www.primaryglass.org. Additionally, the PGMC suggests that architects, specifiers and builders should contact PGMC member companies to take advantage of the expertise and technical services available. The three member companies are: Guardian Industries Corp., Pilkington North America and PPG Industries Inc.

Types of Glass

In addition to annealed float glass there are five other types of float glass available: heat-strengthened glass, fully tempered glass, laminated annealed glass, laminated heat-strengthened glass and laminated fully tempered glass. These glass types can be used individually, or in combinations, for various architectural applications. Each has its own specific properties and performance characteristics that can be related to the requirements established by the design community. A review of these characteristics is summarized in Table 1 *(see page 10)*.

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Please note that the information provided refers only to float glass products. In addition to float glass, other glass products exist. A brief description and information on those products can be found in table 2 *(see page 12)*.

Annealed Glass

Annealed glass has the surface strength that provides the wind-load performance and thermal-stress resistance needed in most architectural applications. In areas of high wind loads, or in conditions where higher-than-normal thermal stresses occur, heat-treated glass may be required.

Annealed glass in standard thicknesses does not meet the safety glazing standards of the Consumer Product Safety Commission (CPSC) 16 CFR 1201 or the American National Standards Institute (ANSI) Z97.1.

ASTM C1036 Standard Specification for Flat Glass is the standard that specifies the required thickness, dimensional tolerances and characteristics of annealed glass.

Heat-Strengthened Glass

Heat-strengthened glass is produced by heat-treating annealed glass under regulated thermal conditions. In this process, annealed glass that has been cut-to-size is carefully heated in a furnace that is controlled between 1100 1500 degrees Fahrenheit (593 815 degrees Celsius) and then quickly air-cooled. This sudden cooling causes a compression envelope around the glass surface and edges, along with a balanced tension stress within the glass itself. This equilibrium of stresses increas-

Performance Characteristics	Monolithic Annealed
Wind-loading strength	Basic glass strength (1x)
Thermal stress breakage resistance (edge-length)	Low resistance to high thermal stress
Impact resistance[1]	Moderate
Break pattern upon impact	Many cracks forming large, long and narrow shards
Penetration resistance (after breakage)	Limited after breakage

es the strength of the glass to approximately two times that of the original annealed product when tested under uniform pressure such as wind loads. In addition, when broken, glass that has a low to moderate degree of heat strengthening will generally exhibit few cracks and tends to break into large pieces that initially may remain in the glazed opening. (Note: glass should be removed and replaced as soon as possible after breakage.) As the degree of heat-treating increases, the break pattern of the glass will more closely resemble that of tempered glass.

A significant advantage of heat-strengthened glass is its ability to withstand high thermal stresses due to partial shading and heat build-up from solar loading. With its edge compression levels in excess of 5500 pounds per square inch (38 MPa) and surface compression levels in the 3500 to 7500 psi range, heat-strengthened glass has performed well in demanding architectural applications, such as in direct contact with insulation or with dark applied frit (durable, colored ceramic material) in spandrel areas. This ability to withstand high thermal stresses, and its wind-loading resistance, make heat-strengthened glass a preferred choice in many architectural applications.

The increased toughness of heat-strengthened glass also reduces the likelihood of glass breakage during shipment, handling, installation and in-service use. Heat-strengthened glass, because of its break pattern, does not meet the safety glazing standards of CPSC 16 CFR 1201 or ANSI Z97.1.

ASTM C1048 Standard Specification for Heat-Treated Flat Glass is the standard that specifies the required tolerances, characteristics and compression levels for heat-strengthened glass.

Fully Tempered Glass

Fully tempered glass is created in a process that is similar to heat-strengthened glass. Cut-to-size, annealed, float glass is heat-treated and air-cooled, creating an edge compression greater than 9700 psi (67 MPa) and a surface compression greater than 10,000 psi (69 MPa). Fully tempered glass may show more visual distortion of reflected images than heat-strengthened glass. Its key performance characteristics are increased strength and the ability to meet the requirements of safety glazing standards (i.e., CPSC 16 CFR 1201 or ANSI Z97). Fully tempered glass when fractured tends to break into small irregular shaped fragments that meet the criteria of the aforementioned safety glazing standards.

Under uniform static loads, fully tempered glass is about four times stronger than annealed glass of the same thickness, and twice as strong as heat-strengthened glass of the same thickness. It also has significant resistance to breakage by blunt projectiles. The increased strength of fully tempered glass (due to its compression stresses) makes it an option for almost any exposure.

The increase in compression stresses and equilibrium center tension stress in fully tempered glass also contribute to infrequent occurrences of spontaneous breakage *(see related article April 1998 **USG**lass magazine page 66)*. All heat-treated glass will break when the compression layer is penetrated. Surface or edge damage, which does not completely penetrate the compression layer, may be propagated by thermal or wind loads, building creep and static fatigue, resulting in spontaneous breakage. This breakage may occur days or even months after the initial damage, therefore the cause is not readily apparent. Spontaneous breakage may be the result of one or more of the following: surface or edge damage to the glass; deep scratches or gouges in the glass surface; severe weld splatter on the glass surface; glass to metal contact; thermal loading; and nickel sulfide inclusions.

Nickel sulfide inclusions refer to the existence of certain types of rare and very small, undissolved nickel sulfide stones that are extremely difficult to detect. Glass manufacturers take extraordinary steps to minimize the potential for nickel sulfide inclusions. Considering that a large furnace may produce up to 600 tons of glass per day, total elimination of contaminants is impossible.

Laminated Glass

There are several laminated glass manufacturing processes. The first calls for two or more lites of glass and one or more interlayers of plasticized polyvinyl butyral resin permanently bonded togeth-

Heat-Strengthened	Fully Tempered	Laminated Annealed	Laminated Heat-Strengthened[2]	Laminated Fully Tempered[2]
Two times basic glass strength of the same thickness (2x)	Four times basic glass strength of the same thickness (4x)	75%-90% as strong as monolithic annealed of the same thickness	Almost twice as strong as laminated annealed of the same thickness (1.5x-1.8x)	Almost four times as strong as laminated annealed of the same thickness (3.0x-3.6x)
Resists high thermal stresses	Resists high thermal stresses	Low resistance to high thermal stresses	Resists high thermal stresses	Resists high thermal stresses
Stronger than annealed	Stronger than heat-strengthened—can qualify for "safety glazing"	Moderate—can qualify for "safety glazing"	Stronger than annealed—can qualify for "safety glazing"	Stronger than heat-strengthened—can qualify for "safety glazing"
Simple, few cracks and larger pieces	Entire life breaks into small, irregular shaped fragments	Starburst pattern from impact point, one or both lites may break	Simple, few cracks and larger pieces, one or both lites may break	One or both lites may break into small, irregular shaped fragments
Limited after breakage	None after breakage	Good penetration resistance (proportional to interlayer thickness)	Good penetration resistance (proportional to interlayer thickness)	Good penetration resistance (proportional to interlayer thickness)

SOURCE: Primary Glass Manufacturer's Coucil

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er under heat and pressure. The second is two or more lites of glass and polycarbonate, bonded together with aliphatic urethane interlayers under heat and pressure. The third type of laminate utilizes a cured resin as the interlayer material.

This bonding of materials provides a variety of performance benefits in architectural applications. The most important characteristic is the ability of the interlayer(s) to support and hold the glass when broken. This provides for increased protection against fall-out and penetration of the opening. Most building codes require the use of laminated glass for overhead glazings as monolithic lites, or as the lower lite in multiple glazed units. Other applications include acoustical insulation, resistance to smash-and-grab burglaries, security, bullet resistant and safety glazing.

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Laminated glass is 75 percent to 90 percent as strong as annealed glass of the same thickness depending on exposed temperatures, aspect ratio, plate size, stiffness and load duration. The edges of laminated glass are less resistant than annealed glass to handling and installation damage. Laminated glass, however, can be made with both heat-strengthened and fully-tempered glass for additional benefits, such as resistance to additional wind loading strength, increased impact resistance or resistance to thermal stress. Quality standards for laminated glass are defined in ASTM C1172 Standard Specification for Laminated Architectural Glass.

Availability of Various Glass Options

The art of melting and forming glass into flat and decorative shapes has been around for thousands of years. The names given to different types of glass often depend upon the products used in the glass batch and the process used to form the glass. Soda-lime glass is the most common term used for the majority of flat glass product formulations, while ceramic and borosilicate glasses are typically specialty glass compositions.

Float glass is the term that applies to the most common flat glass production method. An earlier methodology that no longer exists in the United States is the sheet glass process, where a ribbon of glass is pulled directly out of the molten glass pool. The term plate glass typically refers to a process where molten glass was poured onto a table, rolled until flattened, then exposed to systematic grinding and polishing.

Rolled glass refers to the processing of passing molten glass through a series of rollers to produce such products as patterned glass (where the glass has a decorative pattern imprinted on it) and wired glass (where a welded steel mesh is introduced into the molten glass).

Please note that the information provided refers only to float glass products. Table 2 has been provided to show the existence and availability of other types of glass. ■

RESOURCES

- Primary Glass Manufacturers Council (PGMC): www.primaryglass.org;
- American Society for Testing Materials (ASTM): www.astm.org;
- U.S. Consumer Product Safety Commission (CPSC): www.cpsc.gov;
- American National Standards Institute (ANSI): www.ansi.org;
- See related **USG**lass article, April 1998, page 66.

Glass Type	Float	Sheet	Patterned	Wired	Ceramic	Borosillicate
Clear Annealed	Yes	Limited	Yes	Yes[1]	Yes[1]	Yes
Tinted Annealed	Yes	Imported	Imported	Imported	No	No
Heat-Strengthened	Yes	Yes	Rare	No	No	Yes
Fully Tempered	Yes	Yes	Yes[2]	No	No	No
Laminated Annealed	Yes	Yes	Yes	Yes	No	No
Laminated Heat-Strengthened	Yes	Limited	Difficult	No	No	No
Laminated Fully Tempered	Yes	Limited	Difficult	No	No	No
Reflective Coatings	Yes	Rare	Rare	No	Unlikely	Unlikely
Low-E Coatings	Yes	Rare	Rare	No	Unlikely	Unlikely
Sealed Insulating Glass	Yes	Yes	Yes	Yes	Unlikely	Limited

SOURCE: Primary Glass Manufacturer's Coucil