Architectural glass

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Architectural glass has been used in buildings since the 11th century. Glass is typically used in buildings as a transparent glazing material for windows in the building envelope. Glass is also used in glazed internal partitions and as an architectural feature.

Glass in buildings is often of a safety type, including toughened and laminated glasses.

Crown glass: The earliest style of glass window

the concentric arcs that distort some of these panes indicate they are crown glass, possibly of the 16th century.

The earliest method of glass window manufacture was the *crown glass* method. Hot blown glass was cut open opposite the pipe, then rapidly spun on a table before it could cool. Centrifugal force forced the hot globe of glass into a round, flat sheet. The sheet would then be broken off the pipe and trimmed to form a rectangular window to fit into a frame.

At the center of a piece of crown glass, a thick remnant of the original blown bottle neck would remain, hence the name "bullseye." Optical distortions produced by the bullseye could be reduced by grinding the glass. The development of diamond pane windows was in part due to the fact that three regular diaper shaped panes could be conveniently cut from a piece of Crown glass, with minimum waste and with minimum distortion.

This method for manufacturing flat glass panels was very expensive and could not be used to make large panes. It was replaced in the 19th century by the cylinder, sheet and rolled plate processes, but it is still used in traditional construction and restoration.

Sheet glass

The uneven surface of old glass is visible in the reflection on this window pane.

Sheet glass (sometimes called window glass or drawn glass) was made by dipping a leader into a vat of molten glass then pulling that leader straight up while a film of glass hardened just out of the vat. This film or ribbon was pulled up continuously held by tractors on both edges while it cooled. After 12 meters or so it was cut off the vertical ribbon and tipped down to be further cut. This glass is clear but has thickness variations due to small temperature changes just out of the vat as it was hardening. These variations cause lines of slight distortions. You may still see this glass in older houses. Float glass replaced this process.

Rolled plate glass

The glass is taken from the furnace in large iron ladles, which are carried upon slings running on overhead rails; from the ladle the glass is thrown upon the cast-iron bed of a rolling-table; and is rolled into sheet by an iron roller, the process being similar to that employed in making plate-glass, but on a smaller scale. The sheet thus rolled is roughly trimmed while hot and soft, so as to remove those portions of glass which have been spoilt by immediate contact with the ladle, and the sheet, still soft, is pushed into the open mouth of an annealing tunnel or lehr, down which it is carried by a system of rollers.

Polished plate glass

The **plate glass** process starts with sheet or rolled plate glass. This glass is dimensionally inaccurate and often created visual distortions. These rough panes were ground flat then polished clear. This was a fairly expensive process.

Before the float process, mirrors were plate glass as sheet glass had visual distortions that were akin to those seen in amusement park or fun-fair mirrors.

Float glass

90% of the world's flat glass is produced by the **float glass** process invented in the 1950s by Sir Alastair Pilkington of Pilkington Glass, in which molten glass is poured onto one end of a molten tin bath. The glass floats on the tin, and levels out as it spreads along the bath, giving a smooth face to both sides. The glass cools and slowly solidifies as it travels over the molten tin and leaves the tin bath in a continuous ribbon. The glass is then annealed by cooling in a temperature controlled oven called a "lehr". The finished product has near-perfect parallel surfaces.

A very small amount of the tin is embedded into the glass on the side it touched. The tin side is easier to make into a mirror. This "feature" quickened the switch from plate to float glass. The tin side of glass is also softer and easier to scratch.

Glass is produced in standard metric thicknesses of 2, 3, 4, 5, 6, 8, 10, 12, 15, 19 and 22 mm. Molten glass floating on tin in a nitrogen/hydrogen atmosphere will spread out to a thickness of about 6 mm and stop due to surface tension. Thinner glass is made by stretching the glass while it floats on the tin and cools. Similarly, thicker glass is pushed back and not permitted to expand as it cools on the tin.

Annealed glass

Annealed glass is glass without internal stresses caused by heat treatment (ie toughening or heat strengthening). Glass becomes annealed if it becomes heated above a transition point, then allowed to cool slowly, through not being quenched. Thus glass made using the float glass process is annealed by the process of manufacture. Because of this, where glass is simply described or specified as "float glass", this usually means annealed float glass, although in fact most toughened glass is strictly float glass, as it has been made using the float glass process.

Annealed glass is the common glass that breaks into large, jagged shards that can cause serious injury, hence annealed glass is considered a hazard in architectural applications. Building codes in many parts of the world restrict the use of annealed glass in areas where there is a high risk of breakage and injury, for example in bathrooms, in door panels, fire exits and at low heights in schools.

Figure rolled glass

The elaborate patterns found on figure rolled glass are produced by in a similar fashion to the rolled plate glass process except that the plate is cast between two moving rollers. The pattern is impressed upon the sheet by a printing roller which is brought down upon the glass as it leaves the main rolls while still soft. This glass shows a pattern in high relief. The glass is then annealed in a lehr.

The glass used for this purpose is typically whiter in colour than the clear glasses used for other applications.

This glass can be laminated or toughened depending on the depth of the pattern to produce a safety glass.

Laminated glass

Laminated glass is a type of safety glass that holds together when shattered. In the event of breakage, it is held in place by an interlayer, typically of PVB, between its two or more layers of glass. The interlayer keeps the layers of glass bonded even when broken, and its high strength prevents the glass from breaking up into large sharp pieces. This produces a characteristic "spider web" cracking pattern when the impact is not enough to completely pierce the glass.

Laminated glass is normally used when there is a possibility of human impact or where the glass could fall if shattered. Shopfront glazing and windshields are typically laminated glasses. The PVB interlayer also gives the glass a much higher sound insulation rating, due to the damping effect, and also blocks 99% of transmitted UV light. Using toughened glass on windshields would be a problem when a small stone hits the windshield at speed, if it were toughened and the stone hit with enough force the whole windshield would shatter into the small squares making visibility difficult and it would also be likely that the wind would blow the small squares into the driver and passengers.

Toughened glass (tempered glass)

Toughened glass in a vandalized phone booth in Britain

Toughened glass (also known as **tempered glass**) is a type of safety glass that has increased strength and will usually shatter in small, square pieces when broken. It is used when strength, thermal resistance and safety are important considerations.

At home you are likely to find toughened glass in shower and sliding glass patio doors. In commercial structures it is used in unframed assemblies such as frameless doors, structurally loaded applications and any glass where there is a danger of human impact.

Toughened glass is typically four to six times the strength of annealed glass. Although toughened glass is most susceptible to breakage via edge damage, breakage can also occur from impacts in the centre of the glass pane.

Heat-strengthened glass

Heat-strengthened glass is glass that has been heat treated to induce surface compression, but not to the extent of causing it to "dice" on breaking in the manner of tempered glass. On breaking, heat-strengthened glass breaks into sharp pieces that are typically somewhat smaller than those found on breaking annealed glass, and is intermediate in strength between annealed and toughened glasses.

Chemically strengthened glass

Chemically strengthened glass is a type of glass that has increased strength. When broken it still shatters in long pointed splinters similar to float (annealed) glass. For this reason, it is not considered a safety glass and must be laminated if a safety glass is required.

Chemically strengthened glass is typically six to eight times the strength of annealed glass.

The glass is chemically strengthened by submersing the glass in a bath containing a potassium salt (typically potassium nitrate) at 450 °C. This causes sodium ions in the glass surface to be replaced by potassium ions from the bath solution.

These potassium ions are larger than the sodium ions and therefore *wedge* into the gaps left by the smaller sodium ions when they migrate to the potassium nitrate solution. This replacement of ions causes the surface of the glass to be in a state of compression and the core in compensating tension. The surface compression of chemically strengthened glass may reach up to 690 MPa.

There also exists a more advanced two-stage process for making chemically strengthened glass, in which the glass article is first immersed in a sodium nitrate bath at 450 °C, which enriches the surface with sodium ions. This leaves more sodium ions on the glass for the immersion in potassium nitrate to replace with potassium ions. In this way, the use of a sodium nitrate bath increases the potential for surface compression in the finished article.

Chemical strengthening results in a strengthening similar to toughened glass, however the process does not use extreme variations of temperature and therefore chemically strengthened glass has little or no bow or warp, optical distortion or strain pattern. This differs from toughened glass, in which slender pieces can often be significantly bowed.

Also unlike toughened glass, chemically strengthened glass may be cut after strengthening, but loses its added strength within the region of approximately 20 mm of the cut. Similarly, when the surface of chemically strengthened glass is deeply scratched, this area loses its additional strength.

Chemically strengthened glass was used on some fighter aircraft canopies.

Self-cleaning glass

A recent innovation is so-called **self-cleaning glass**, aimed at building, automotive and other technical applications. A 50 nanometre coating of titanium dioxide on the outer surface of glass introduces two mechanisms which lead to the self-cleaning property. The first is a photo-catalytic effect, in which ultra-violet rays catalyse the breakdown of organic compounds on the window surface; the second is a hydrophilic effect in which water is attracted to the surface of the glass, forming a thin sheet which washes away the broken-down organic compounds.

Insulated glazing

Insulated glazing, or **double glazing** is a piece of glazing consisting of two or more layers of glazing separated by a spacer along the edge and sealed to create a dead air space between the layers. This type of glazing has functions of thermal insulation and noise mitigation.

Evacuated glazing

Another recent innovation for insulated glazing is **evacuated glass**, which as yet is produced commercially only in Japan. The extreme thinness of evacuated glazing offers many new architectural possibilities, particularly in building conservation and historicist architecture, where evacuated glazing can replace traditional (much less energy-efficient) single glazing.

An evacuated glazing unit is made by sealing the edges of two glass sheets, typically by using a solder glass, and evacuating the space inside with a vacuum pump. The evacuated space between the two sheets can be very shallow and yet be a good insulator, yielding insulative window glass with nominal thicknesses as low as 6 mm overall. The reasons for this low thickness are deceptively complex, but the potential insulation is good essentially because there can be no convection or gaseous conduction in a vacuum.

Unfortunately, evacuated glazing does have some disadvantages; its manufacture is complicated and difficult. For example, a necessary stage in the manufacture of evacuated glazing is outgassing; that is, heating it to liberate any gases adsorbed on the inner surfaces, which could otherwise later escape and destroy the vacuum. This heating process currently means that evacuated glazing cannot be toughened or heat-strengthened. If an evacuated safety glass is required, the glass must be laminated. The high temperatures necessary for outgassing also tend to destroy the highly effective "soft" low-emissivity coatings that are often applied to one or both of the internal surfaces (i.e. the ones facing the air gap) of other forms of modern insulative glazing, in order to prevent loss of heat through infrared radiation. Slightly less effective "hard" coatings are still suitable for evacuated glazing, however.

Furthermore, because of the atmospheric pressure present on the outside of an evacuated glazing unit, its two glass sheets must somehow be held apart in order to prevent them flexing together and touching each other, which would defeat the object of evacuating the unit. The task of holding the panes apart is performed by a grid of spacers, which typically consist of small stainless steel discs that are placed around 20 mm apart. The spacers are small enough that they are visible only at very close distances, typically up to 1 m. However, the fact that the spacers will conduct some heat often leads in cold weather to the formation of temporary, grid-shaped patterns on the surface of an evacuated window, consisting either of small circles of interior condensation centred around the spacers, where the glass is slightly colder than average, or, when there is dew outside, small circles on the exterior face of the glass, in which the dew is absent because the spacers make the glass near them slightly warmer.

The conduction of heat between the panes, caused by the spacers, tends to limit evacuated glazing’s overall insulative effectiveness. Nevertheless, evacuated glazing is still as insulative as much thicker conventional double glazing and tends to be stronger, since the two constituent glass sheets are pressed together by the atmosphere, and hence react practically as one thick sheet to bending forces. Evacuated glazing also offers very good sound insulation in comparison with other popular types of window glazing.