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Characteristics of Window Glass

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Although it was known before 2,000 B.C., glass found little use as a window material until Roman time. By the tenth century there was fairly high production of window glass in northern Europe, probably encouraged by the dictates of the climate. Through modern glass technology it is now used extensively in buildings for cladding and windows, not to mention a myriad of other applications.

Glass is used in windows because it admits light and permits vision through it, while satisfying most of the requirements of an element in an exterior wall. Furthermore, it is durable in most environments, readily available at relatively low cost and has adequate strength when properly used.

Basically, glass is a product of the fusion of silica. Fusion of pure silica is difficult to achieve, however, and a fluxing agent is commonly added to simplify the action. The product may be lacking in durability, but other oxides can be added to overcome this problem. The glass used for most window material is the cheapest to make and handle and is called *Soda-Lime Glass*, because these are the predominant compounds combined with silica for its manufacture. Other oxides in varying proportions can be introduced into the melt to modify many of the properties of the finished product. Flat glass is also known by its process of manufacture as sheet, polished plate, float or rolled glass.

Sheet Glass is made by drawing the glass vertically out of the liquid mass, with the sheet so formed being fire polished and annealed. The drawing process produces waves and surface distortions that vary throughout the draw. Selection of cut sheets is made and classified AA, A, B, or Greenhouse solely on the optical qualities of the sheet. "A" quality is the highest standard grade for commercial glazing purposes, but "B" quality is quite satisfactory for most window glazing.

Polished Plate Glass is produced by rolling a continuous sheet or by casting and rolling large sheets separately. After annealing and cooling, the surfaces are made flat, parallel and bright by mechanical grinding and polishing. Plate glass is available in three grades, also based on optical properties. Glazing Quality is the standard grade for window glazing; Mirror Glazing Quality is used for high-quality glazing and mirrors; Silvering Quality is used for top grade mirrors and very special glazing applications.

In the *Float Glass* process the molten glass floats on the dead flat surface of molten metal where it flows to a uniform thickness. When the sheet is drawn off, both surfaces are flat, parallel, fire polished and sufficiently cooled to remain undamaged by the rollers used to transport it through subsequent operations. This glass combines the optical quality of polished plate glass with the surface advantages of sheet glass.

Rolled Glass includes patterned, corrugated plate glass blanks and wired glass. As the glass is drawn horizontally from the tank, figured, textured or plain rolls impress the desired pattern on one or both surfaces, regulating at the same time the thickness of the sheet. Patterned glasses diffuse transmitted light, afford varying degrees of obscurity and are often used for decorative purposes. Any flat glass can be rendered*Obscure* through surface treatments of glue chipping, acid etching or sand blasting.

Transparency

The transparency of glass to visible radiation is the primary reason for its use in windows. As an element in an exterior wall, however, a window must also control heat flow. All radiant energy, both visible and invisible, produces heat when absorbed, so that the transmission characteristics of glass to all radiation striking it should be known. Solar radiation is short-wave (0.3 to 4.5 microns), and made up of visible light (0.4 to 0.7 micron), accounting for 43 per cent of the total energy, ultra-violet (below 0.4 micron) 3 per cent, and infra-red (over 0.7 micron) 54 per cent. Radiation emitted by ground and building surfaces is entirely infra-red (5 to 50 microns) and of lower intensity. The smoothed curves of Figure 1A show the rate of energy received, at different wave lengths, from the sun and from terrestrial objects.

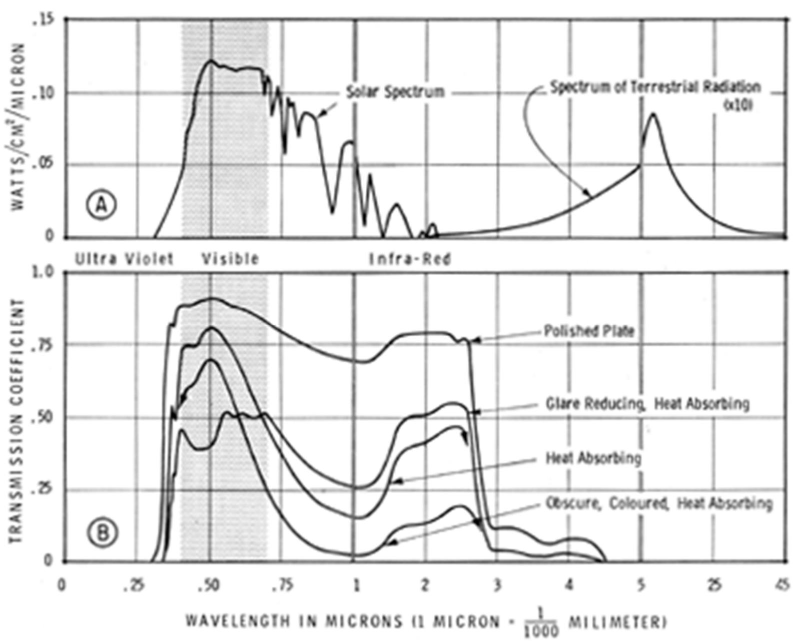

Figure 1. Radiation from sun and from terrestrial body with transmission curves for several glasses (¼ in. thick).

Glass is not completely transparent to radiant energy; some is reflected, some absorbed and only the remainder transmitted. The ratio of these factors is dependent upon the wave length and incident angle of the radiation, and upon the characteristics of the glass.

Maximum transmission for any flat-surfaced glass occurs when the radiation is perpendicular to the plane of the glass (zero angle of incidence) when the reflection from the two surfaces is at a minimum and the transmission path is the shortest. As the angle of incidence increases both the surface reflection and the length of the transmission path increase, with a resultant reduction in the energy transmitted. This reduction, however, is negligible from O to 50 deg incidence, but increases rapidly to total reflection at 90 deg. Figure 1 of **CBD 39** shows the variation with incident angle of the reflection, absorption and transmission factors for a single sheet of ordinary window glass.

Absorption of radiant energy by glass varies with the wave length of the radiation and the absorption characteristics of the glass. It may be seen in Figure 1B that ¼-inch plate glass is essentially transparent to all of the solar spectrum except the short-wave ultra-violet. It is less transparent, however, to wave lengths over about 3 microns and opaque to wave lengths over 4.5 microns. This means that solar radiation can pass through glass to heat surfaces inside a building, but longer wave length radiation from objects in the building is absorbed by the glass. This accounts in part for the common "greenhouse effect," or the ability of an unheated glass-enclosed space to experience a rapid temperature rise during hours of sunshine and retain its heat during the night. It should be noted that absorption of radiation causes the glass temperature to rise, and transmitted radiation causes a heat gain in the building interior.

Transmission Reduction

Transmission through glass can be modified by adjusting the angle of incidence, by increasing the surface reflection of the glass, or by modifying the chemical make-up of the glass to increase the absorption factor. When glass is inclined outward at the top an appreciable reduction in heat transmission through south windows can be accomplished during the summer months (**CBD 39**). Reflection of radiation can be increased with special high-reflectance coatings on glass, but many of them are non-durable and require protection.

Heat Absorbing Glasses are designed to absorb as much of the solar infra-red radiation as possible while maintaining high transmission in the visible region. Some are also designed to absorb visible radiation to reduce glare, which further reduces heat transmission. Typical transmission curves for heat-absorbing and glare-reducing glasses are shown in Figure 1B. Under development are photochromic glasses which alter their absorption in harmony with radiation intensity, but these are not yet perfected or available for general use.

Reduction of solar heat gain through glass is accompanied by a reduction in the natural light entering a room. Reducing transmission by increased absorption causes the glass to heat, whereas the same reduction achieved by increased reflection does not. The reduction of light transmission in both cases depends upon the characteristics of the glass used.

Strength of Glass

Glass is a brittle material and does not deform plastically before failure. It fails in tension regardless of the nature of loading. The potential tensile strength of glass is about 1,000,000 psi, but failure occurs at average stresses far below this value because of the stress-raising effect of surface imperfections both inherent in the glass and mechanically created. Glass is most vulnerable at its edges, with surface imperfections from cutting and handling adding to the risk of failure. The grinding and polishing of plate glass affects the surface condition of the glass, so that its usable strength is considerably less than that for firepolished sheet glass. Because the effect of stress raisers is indeterminate the allowable tensile strength of glass is determined statistically and a sizable safety factor included. By using the value thus established breakage can be reduced to an insignificant level but not eliminated.

Glass can be greatly strengthened by development of a "stressed skin" sandwich, where both surfaces are in compression and the middle is in tension. This can be accomplished by heating the glass to near its melting point and rapidly cooling both surfaces. The contraction of the middle (of the thickness) of the sheet develops the desired stress on final cooling. *Safety Toughened Glass*, as it is called, is three to five times more resistant to failure by bending, impact or thermal shock than annealed glass of the same thickness, although other properties such as durability, transparency (except for polarized light), elasticity, flexibility or coefficient of expansion are not changed. The "Achilles Heel" of safety toughened glass is its edges; even a relatively light impact with a sharp object can cause failure. Exterior doors of safety toughened glass are normally protected by metal at the sill because of this. Toughening of glass must be done after it has been cut to size, because any cut or failure results in complete disintegration of the sheet into many small cubes.

Wired glass is often assumed to be stronger than plain glass of the same dimensions because of the reinforcing action of the wire. This is incorrect. Wired glass is actually weaker owing to edge flaws inherent in the material after cutting and the internal stresses from differing rates of contraction on cooling. The wire serves one purpose only: to hold the pieces of glass together after fracture has occurred. This, however, is particularly important for fire separation endurance, a limited burglar protection, and the prevention of flying glass splinters. As a fire separation or burglar protection, it is well to know that a pane of wired glass has only from 1/5 to 1/10 its original strength once the glass fractures.

Thermal Conductivity

The thermal conductivity (k) of soda-lime glass at between 5 and 7 Btu/hr sq ft °F/in. is higher than that of insulating materials, but much lower than that of most metals. Glass of normal thickness offers negligible resistance to heat transfer between the inside and outside of a building and the thermal resistance of a pane is predominantly due to the surface films. This thermal conductivity is sufficiently low, however, to allow significant temperature gradients to occur in the plane of the glass. These develop because of variations in heat exchange at the surfaces, with the added complication of heat transfer between the glass edge and the window sash or frame. Shading by the frame and heat loss from the glass when the frame is cold can cause the edges of a pane of glass to be considerably colder than the central area. The severe temperature gradient produces differential thermal expansion that causes tensile stress in the edge and may cause a fracture to develop. Heat-absorbing glasses and the inner pane of sealed double-glazing units are vulnerable to thermal fracture.

Thermal Expansion

The coefficient of expansion for soda-lime glass is 4.5×10^{-6} and the modulus of elasticity is 10,000,000 psi. Thermal expansion and contraction of glass is of importance in the design of glazing details, but it is even more important with respect to the development of stresses within the glass from temperature differentials in a pane. Where fracture due to thermal stressing cannot be handled with safety toughened glass, borosilicate glass rather than soda-lime glass might be considered. Borosilicate glass with a coefficient of expansion of approximately 2×10^{-6} is common in kitchenware designed to resist severe thermal shock.

Durability of Glass

Glass is a durable material when exposed to normal atmospheric conditions, but it does suffer some surface deterioration. The most aggressive element of the atmosphere is water. An adsorbed layer of water attacks the surface of glass, dissolving or releasing certain elements that cause the water to become alkaline. Other than hydrofluoric acid, alkaline solutions are the most aggressive in their attack on glass. If an alkaline solution remains on the surface, the attack can become severe; consequently, frequent cleaning is quite important. The effect of the attack is to reduce the brilliance of the surface, but severe conditions can obscure visibility. With repeated wetting and drying without washing, the dissolved products will appear as a whitish scum, again acting to obscure vision. This latter condition is a common failing where condensation is permitted to occur inside hermetically sealed multiple glazing units.

The requirements of window glass as an element in an exterior wall are determined by the differences in the environments being separated. With proper consideration of the characteristics of glass available, selection and design to satisfy these requirements can be achieved.