Technical Note No. 61
GLASS TYPES

This Technical Note replaces TN11. It describes the different types of architectural flat glass. It also describes the physical characteristics of each glass type, performance classes of different glasses and relevant Standards.

This Technical Note is one of eight describing the use and performance of glass. They are:

TN61 Glass types
TN62 Specification of insulating glass units
TN63 Glass breakage
TN65 Thermal fracture of glass
TN66 Safety and fragility of glazed roofing: guidance on specification
TN67 Safety and fragility of glazed roofing: testing and assessment
TN68 Overhead glazing
TN69 Selection of glass to prevent falls from height

This Technical Note should also be read in conjunction with:

TN7 Threat resistant fenestration
TN35 Assessing the appearance of glass
TN48 Energy loss through windows

Introduction

Glass can be used to provide a durable, transparent enclosure to a building. However, basic annealed glass can be treated in a number of ways to improve:

- Appearance - clear, reflective, coloured, patterned, printed;
- Environmental properties - heat loss, solar gain, acoustic isolation;
- Integrity - safety (e.g. human impact or fire resistance), security (e.g. resistance to bandits, blasts or bullets) and strength (e.g. wind or snow loads).

The performance of glass is often dependent on the frame or fixings used to hold it in place. The performance of the whole glazed system needs to be considered when assessing thermal performance and fire performance. The glazing system may also influence the performance of glass when considering security applications, acoustic performance and safety performance.

Glass products are often asymmetric in their construction and performance. Glazing the glass in the correct orientation is imperative for asymmetric products.

Glass and the Building Regulations

The use of glass types, which provide enhanced levels of environmental performance or integrity, is mandatory for particular glazing situations in the UK.

Thermal insulation

Building Regulations AD L1A, AD L1B, AD L2A and AD L2B set limits for carbon emissions from buildings. Carbon emissions are affected by, amongst other things, the area of glass, solar control properties of the glass, light transmission of the glass and the U-value of windows (glass, spacer bar and frame). CWCT TN48 gives advice on U-values of glazing and windows.

Safety (impact)

Approved Document N and BS 6262-4 contain guidance on glazing locations where accidental impact is likely, and selection of appropriate safety glass types. Safety glass should reduce the risk of injury by resisting breakage, breaking safely or breaking with no significant penetration (i.e. by containment). BS EN 12600 gives...
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impact test requirements for three classes of safety glass increasing in severity from 3 to 1.

BS 6206 is the earlier method of test and gives three classes of safety glass increasing in severity from C to A. Following the publication of BS EN 12600; BS 6206 should only be applied to plastic glazing materials. However Building Regulations AD N (1998), as amended in 2000, uses BS 6206 to categorise glass performance.

The classification system of BS 12600 gives greater information than that from BS 6206 and includes breakage mode. The equivalence of the classes of performance given in the two standards has been determined by the Building Research Establishment (2005) and is shown below:

<table>
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<tr>
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Glass tested to BS EN 12600 will have a full classification in the form $\alpha(\beta)\varphi$. $\alpha$ is the class referred to in the table above and is the classification digit required on finished sizes of glass.

**Safety (falling)**

Glass may be required to act as a barrier and provide containment to prevent falls from buildings or where there is a change in floor level (greater than 600mm). Building Regulations AD K gives details of the requirements for protection from falling. BS 6180 is the Code of Practice that gives recommendations for the design and construction of temporary and permanent barriers in and about buildings. CWCT TN69 gives further guidance on the use of glass in barriers.

**Safety (fire)**

Areas next to escape routes must have a limited area of glazing or incorporate special glass types to allow the safe passage of occupants from a fire (Building Regulations AD B). Fire resistance performance is classified using two ratings:

**Integrity (E)** is the ability of the element of construction, that has a separating function, to withstand fire exposure on one side without transmission of the fire to the unexposed side as a result of the passage of flames or hot gases which may cause ignition either of the unexposed surface or of any material adjacent to that surface.

**Insulation (I)** is the ability of an element of construction to withstand fire exposure on one side without significant transfer of heat from the exposed side to the unexposed side. Transmission of heat shall be limited so that neither the unexposed surface nor any material in close proximity to that surface is ignited. The element shall also provide a barrier to heat, sufficient to protect people near to it.

**Radiation (W)** is not a requirement for glasses used in the UK.

For all transparent glazings, sufficient infra-red radiation may be transmitted to cause ignition of materials on the other side. Fire (insulation) performance may be provided by the use of laminated glass with an intumescent interlayer(s), which on exposure to fire becomes opaque and limits or resists the transmission of conductive and radiative heat.

All fire resistant glass and glazing systems must be supported with fire test evidence to the appropriate standard. Some glass and glazing systems are resistant to fire from only one side but some are fire resistant from either side.

BS EN 357 and BS EN 13501-2 give methods of classifying fire performance of glass and BS 476-22 describes methods of test and classification of glazed areas of construction. European Standards for testing fire performance are:

- General requirements (BS EN 1363-1)
- Alternative and additional procedures (BS EN 1363-2)
- Non-loadbearing walls including glazing (BS EN 1364-1)
- Doors, including glazed doors (BS EN 1634-1)
- Floors and roofs, including glass floors (BS EN 1365-2)
Glass types

For sloping overhead glazing systems it should be noted that:

- Glass will perform differently when sloping and is more likely to sag. Glass should have been fire tested at the correct orientation.

- The glazing system carries the weight of the glass and its own weight and will be required to do so during a fire.

The safety of overhead glazing is particularly important where falling broken or heat-softened glass may prevent safe escape of the occupants or limit safe access for firefighters.

Security

Security requirements are not covered by the Building Regulations but may be important and will vary according to the type, location and usage of the building. Security glass should reduce the risk of breakage or penetration during criminal attack in order to delay access to premises or protect personnel against attack.

BS 5544 and BS EN 356 give test methods and performance requirements for bandit resistant glazing.

BS EN 1063 gives test methods and performance requirements for bullet-resistant glazing. BS 5051, the earlier standard for bullet-resistant glazing is only partially replaced by BS EN 1063 and BS 5051 now applies only to glazing materials other than glass.

CWCT TN7 gives advice on blast resistant glazing.

Glass types

Basic glass

Basic (annealed) glass is untreated glass manufactured from soda lime silicates, which can be cut or scored with a wheel and snapped. It is the least expensive and most readily available type of glass. The term includes float glass, sheet glass and patterned glass manufactured as follows:

- **Float glass** is manufactured by pouring molten glass continuously from a furnace onto a large shallow bath of molten tin, where it floats, spreads out and forms a level surface (over ninety five per cent of glass is manufactured by the float process);

- **Sheet glass** is manufactured by the flat drawn process and has a natural fire-finished surfaces but, because the two surfaces are never perfectly flat and parallel, there is always some distortion of vision and reflection;

- **Patterned glass** products are manufactured by the rolling process in which semi-molten glass is squeezed between metal rollers (polished plate glass is produced by grinding, smoothing and polishing the surfaces of rolled glass. However, the use of plate glass has been largely displaced by the availability of float glass).

Basic (annealed) glass breaks into sharp-edged shards, although these may remain in the frame, depending on the glazing method, orientation and loads applied.

Basic (annealed) glass may not be able to resist the stresses caused by expansion that occurs when it is heated. Differential heating (resulting from shading or the cooling effect of the frame) may result in thermal fracture. It may occur in the event of fire or as a result of solar heating. Basic (annealed) glass is unsuitable in all fire situations requiring fire resistant glass. Thermal fracture is discussed in greater detail in CWCT TN65; other breakage of glass is discussed in CWCT TN63.

Patterned glass

Patterned glass transmits light with varying degrees of diffusion so that vision through the glass is not clear; usually the deeper the pattern the greater the diffusion and obscuration. Patterned glass is manufactured by the rolling process and can be toughened (depending on the pattern so the manufacturer should be consulted), laminated or made into insulating glass units. It is available in clear and, for some products, tinted forms.

Wired glass

Wired glass is made by positioning an electrically welded steel wire mesh within the molten glass in a continuous rolling process; it is supplied in textured (obscured) or polished (transparent) form.

Wired glass breaks into shards which are held together by the wire mesh, but sharp glass edges may be exposed, and the wire will corrode if the glass is not replaced. The wire
may also corrode if the edge of the glass is exposed to damp conditions, which may ultimately lead to fracture of the glass. Wired glass cannot be toughened or heat-strengthened. It is weaker than an equal thickness of monolithic glass and is more susceptible to thermal fracture. It is not a security glass.

Wired glass is designed to give integrity only fire resistance and test certification will be available for suitable types. The performance obtained depends upon the manufacturer, area of the glass, the type of framing and the glazing details. Fire-resisting wired glasses - like all fire glasses - should be specified carefully. Evidence should be sought for the performance of a specific glass tested in a specific frame. Wired glass is available with an impact classification to BS EN 12600 Class 3(B)3. Impact resistant wired glass usually has a thicker gauge of wire.

**Heat treated glass**

Basic (annealed) glass may be reheated and chilled to produce:

- Thermally toughened glass
- Heat soaked thermally toughened glass
- Heat strengthened glass
- Bent glass

Reheating the glass causes it to be less flat than when produced on the float line and this will affect the appearance of the glass. CWCT TN35 gives advice on the appearance of glass.

**Thermally toughened glass**

Thermally toughened glass is formed by heating and then rapidly cooling (quenching), basic (annealed) glass. Differential cooling, and the rate of hardening, through its thickness generates a compressive stress in the surface of the glass, which is balanced by a tensile stress in its core. This produces a stronger glass and also modifies the failure mode of the glass.

Toughened glass to BS EN 12150 achieves Class ‘1’ impact resistant glass to BS EN 12600. Compared with annealed glass a four to five times greater load can be applied before the compressive surface stresses are overcome (e.g. by bending of the glass under impact) and the glass fractures. This glass is tougher because the flaws which are present on the surface of the glass are held in compression and prevented from developing into fractures.

Toughened glass shatters into small, relatively harmless fragments. A vertical pane may remain in its frame, but sloping panes are likely to fall out when they break. There is a risk with toughened glass that the fragments may clump together and fall *en masse*, see CWCT TN68.

BS EN 12150 requires that, within 5 minutes of breakage, a 6mm thick pane of toughened float glass shall have fractured to form at least 40 glass fragments within a 50mm square; this suggests a mean fragment size of 8mm. Each falling fragment therefore represents a small projectile, but even a small clump of fragments may cause significant damage if falling from a height. For thicker panes of toughened glass the fragments will be at least as long as the glass is thick, and have significant mass and energy when falling from height.

The manufacturer should be consulted for details of what glass types can be toughened because not all coated glass products can be toughened. Glass having a hard (pyrolytic) coating (e.g. some low-E coatings) can be toughened after coating. Some soft (sputtered) coatings can also be toughened after coating but others must be applied to the glass after the toughening process. Different glass processors may give different answers depending on the toughening oven they use.

**Heat soaked toughened glass**

Any pane of basic (annealed) glass has a small risk of containing nickel sulfide impurities, in the form of small crystals. As glass is heated during the toughening process these impurities change state. When the glass is quenched the impurities may be locked into the high temperature \( \alpha \)-state and recovery to the low temperature \( \beta \)-state may then take some years. Spontaneous breakage of the glass may occur, if the particles are present in the right size and position within the glass, as the low temperature \( \beta \)-state of a nickel sulfide crystal occupies a slightly greater volume and generates a local stress concentration. Impurities larger than 50\( \mu \)m may cause failure, but only if they are in the core (tensile zone) of the glass.
Nickel sulfide failures can start to appear immediately after production, with a peak failure rate within a few years after production, but failures may occur for 20 to 30 years.

The best protection against nickel sulfide induced failures is to avoid the use of toughened glass where alternatives are appropriate. If using toughened glass, ensure that the basic (annealed) glass that is toughened is obtained from a quality float glass manufacturer. A further safeguard is to head-soak the glass to BS EN 14179 using duly calibrated equipment.

The failure rate of toughened glass in service can be reduced by heat soaking - the toughened glass is heated to encourage reversion of the impurities to the low temperature \( \beta \)-state. Panes of glass with large impurities should shatter during this process. Heat soaked glass should be manufactured and marked to BS EN 14179 which describes the heat soaking process. Heat-soaking will not cause all panes containing nickel sulfide to shatter and there will be a residual risk of glass falling once installed.

Further guidance on nickel sulfide failure and heat soaking is given in ‘Glass in buildings, Breakage-the influence of nickel sulfide’, CWCT.

Poor design and careless handling (e.g. edge damage) or glazing (e.g. wrong or no setting blocks) are much more common reasons for spontaneous breakage of toughened glass than nickel sulfide inclusions. Nevertheless, heat soaking should be specified for toughened glass if a risk analysis shows this to be prudent. Risk should take account of safety from falling glass and the cost of replacing broken glass. Designers are responsible for ensuring that the glass specification is appropriate.

Guidance on the need to heat soak is given in CWCT TN68.

**Heat-strengthened glass**

Heat-strengthened glass is formed by heating basic (annealed) glass and then cooling it in a controlled way, more slowly than when making toughened glass. This increases the strength of the basic glass but does not modify its failure mode. The process is used to make glass safe from thermal fracture or to make glass for laminating more resistant to stress.

Heat-strengthening gives a smaller increase in strength than toughening (described above) but with a much reduced risk of failure due to nickel sulfide inclusions because of the reduced tensile stresses in the glass. Heat-strengthened glass fails in large shards in the same way as basic (annealed) glass. Heat-strengthened glass is generally flatter than toughened glass.

Heat-strengthened glass could also be called ‘partly toughened’; by varying the strengthening process it is possible to produce glass with fracture properties anywhere between those of annealed and toughened glass.

BS EN 1863 defines heat-strengthened glass. It requires heat-strengthened glass to exhibit fracture properties similar to those of annealed glass, but with a limited size and number of separated fragments. Heat-strengthened glass does not achieve an impact classification to BS EN 12600.

**Laminated glass**

Laminated glass is formed by bonding together two or more panes of glass using a variety of interlayers. Any of the glass types described above may be used in many combinations.

Glass is laminated for the purpose of:

- Maintaining integrity should a pane of glass break,
- Reducing the likelihood of penetration (for security or safety reasons),
- Improving acoustic properties;
- Giving decorative effects.

The following materials are used as interlayers to modify the post-failure behaviour of glass:

**Polyvinylbutyral** (PVB) is a flexible material used primarily to produce glass with one or more of the following characteristics:

- An impact classification
- Containment on impact
- Retention post failure
- Resistance to intruders (anti-bandit)
- Blast resistance
- Noise attenuation
Polyvinylbutyral (PVB) is used in multiples of 0.38mm thickness. A thicker interlayer may help to reduce the risk of debris penetration on impact.

**Polyester** is a liquid that is poured between the glass panes to be laminated. It is a difficult process compared with the use of PVB but unlike PVB may be used to laminate curved glass and panes of glass with deep relief on their surface, for instance some patterned glasses. In these cases it is used instead of PVB but the laminated glass will not have the same impact performance as if PVB where used.

**Ionoplasts** are supplied in rigid sheet form and are less easy to use than PVB. They are stiffer than PVB and creep less. As a result laminates made with ionoplast interlayers are stiffer but they are less good at absorbing energy and do not perform as well when subjected to blast and some impact loads.

**Polymethylmethacrylate** (PMMA) is a soft interlayer and is used to give acoustic performance by decoupling the two laminated panes.

Glass may be laminated to achieve decorative effects and these take many forms. Interlayers may be coloured and objects may be embedded in the interlayer, for instance a wire mesh.

Laminating to improve acoustic performance or modify the appearance may not give improved post failure behaviour, although some interlayers do. Laminated glasses should be checked to ascertain whether they are classified as safety and/or security laminated glass products.

Laminated annealed glass breaks into shards, creating sharp edges, but these are held together by the interlayer. Different interlayer materials and thicknesses have different effects upon performance.

Laminated glass may include one or more panes of toughened glass. If all panes are of toughened glass then the broken glazing will lose all structural integrity and may pull free from the frame, unless properly secured, see CWCT TN68.

PVB and other interlayer materials may degrade in the long-term presence of water so the edges of laminated glass should be permanently protected from immersion in liquid. However, exposure to intermittent wetting, for example in rebates, is not generally considered to be problematic. Note that although laminated glass is only slightly weaker than a single pane of the same thickness it will deflect more under long-term loads, and the interlayer may soften at higher temperatures; PVB is not suitable for sustained high temperature exposure (in excess of 70°C).

In the event of fire, PVB laminated glass may break and hang loosely from its frame. Softening of the plastic interlayer may allow such broken laminated glass to continue to fall from a slope glazing system for a significant period of time after a fire has been brought under control, and as such presents a serious hazard to fire-fighters.

**Tinted and coated glass**

Glass may be produced with an inherent colour tint (bronze, green, blue, grey, amber etc) by adding small amounts of metal oxides to the glass composition during manufacture. The colour is achieved by the selective absorption of some of the incident radiation which in turn reduces solar heat gain inside the building but increases the temperature of the glass.

Alternatively, or additionally, surface coatings may be applied that modify some or all of the solar energy transmission, colour and thermal insulation properties. It is also possible to introduce colours into laminated glass interlayers.

Coatings may be applied to the hot glass as part of the float manufacturing process or as a separate operation once the glass has been manufactured. The former are referred to as hard, pyrolitic or on-line coatings and have greater hardness and durability. The latter are referred to as soft, sputtered or off-line coatings. Most off-line coated glasses have to be used as a pane in an insulating glass unit.

Most solar control and obscured glasses need to be checked for the risk of thermal breakage. The manufacturer can advise on the requirements for toughened or heat strengthened glass if thermal fracture is a problem and the risk cannot be designed out of the glazing system and its surroundings see CWCT TN65.
Glass types

CWCT TN51 gives further advice on tinted and coated glasses for solar control.

**Low emissivity glass**

Low emissivity (Low-E) coatings reduce the radiation of long-wave infra-red from the surfaces of single glazing and within the glazing cavity. They may also reflect long-wave thermal radiation. However, the coatings are transparent to short-wave solar radiation and so allow solar radiation to pass into the building. In this way beneficial winter solar radiation can be trapped within a room, which reduces the need for heating. However, summer heating can also occur and so low-E glass needs to be used in conjunction with adequate provision for cooling ventilation when used for large glazed areas. It should be noted that low-E coatings will also reduce night-time heat loss.

Low-E glass may be used in conjunction with solar control (i.e. tinted or reflective) glasses to provide an energy management solution balancing heat gain during warm periods and heat loss during cool periods. Some glazing products provide both features in one coating. The need for solar control glazings and appropriate glass combinations should always be assessed on a project-by-project basis and can reduce or eliminate the need for air-conditioning.

Many low-E glasses can be laminated. When laminated, the non-coated face has to be against the interlayer because the coating has to be on an exposed surface to limit radiation or increase reflection of long-wave radiation. The coating is also normally glazed towards the cavity of an insulating glazing unit to protect it from abrasion and sometimes oxidation. Some hard-coated glasses can be glazed with the coating on the outside of the IGU or as a single pane, but the effectiveness of the coating is severely reduced by surface dirt or moisture. Glass manufacturers can advise on the most suitable coating position.

**Borosilicate glass**

Borosilicate glasses, although more expensive than ordinary annealed glass, offer the advantage that under similar temperature variations their expansion is less than that for soda lime silicate glass. They also possess a higher viscosity at elevated temperatures. This means that they can withstand the high temperatures of a fire for longer periods. These glasses can now be manufactured by the float process, and are generally supplied as a heat-strengthened or toughened glass. They remain transparent during a fire situation and do not:

- Protect passers-by from the effects of heat from excessive infra-red radiation.
- Prevent the spread of fire by radiation through the glass.

The fire resistance performance depends on the glazing system as well as the glass type.

**Intumescent glass**

Intumescent glass is a laminated glass in which the interlayer(s) is a material which swells and becomes opaque when subjected to excessive heat. This opacity may be accompanied by fracture of the glazing, but the glazing remains in place. Intumescent glazing thereby protects passers-by from the effects of intense heat to some degree.

Intumescent glass is available with different numbers of intumescent interlayers, depending upon the level of fire protection required.

**Plastics glazing materials**

A number of sheet plastics glazing materials exist, including polymethylmethacrylate (PMMA, acrylic) and polycarbonate (PC). Plastic materials may be produced in multi-walled form in addition to plain sheet.

These materials are usually better at resisting impact than glass, and when broken tend to remain in place. However, they are also more flexible (deflect more under load), and the designer should check that rebate depths are sufficient to ensure that the deflected glazing cannot pull free from the framing system. Note that BS 5516 bases design charts for selection of plastics glazing materials on a standard edge cover of 15mm, compared to a minimum edge cover of 10mm for glass.

Plastics glazing materials are easily scratched and discolour over time. They may be surface treated to resist the effects of ultraviolet radiation, although the treatment is often limited to one side of the sheet and the materials must be installed the right way around. Many rigid plastics materials also have high rates of water vapour transmission, and cannot be used as part of an IGU.
Some plastics glazing materials are prone to stress cracking the presence of certain chemicals used in other polymer products. The compatibility of plastics glazing materials with sealants, rubbers and polymer coatings should be carefully assessed. In particular it should be noted that certain sealants may evolve chemicals during cure that can attack plastics glazing materials even if there is no direct physical contact.

In a fire situation some plastics may burn and fall and/or release particulate contaminants or noxious gases. The use of the building may need to be considered. For example, the use of plastics glazing materials may be excluded in areas used for food or pharmaceutical preparation on the grounds of the high cost of replacing contaminated stock, should a small, localised fire occur.

**Insulating glass units**

Insulating glass units incorporate two or more panes separated by spacers, which are attached and sealed by one or more perimeter seals. The gap between the panes can be filled with air, which is dried by desiccant within the spacer, or a low conductivity gas such as argon, krypton or even xenon for improved thermal insulation. Insulating glass units should comply with the requirements of BS EN 1279. CWCT TN62 gives further information on insulating glass units.

**Summary**

There are many glass types now available. Although basic (annealed) glass forms the basis of most of these, their physical and mechanical characteristics can differ greatly. Careful design, with knowledge of manufacturer’s products and their availability, is necessary to achieve satisfactory performance.

**References**

BS 476-22:1987 *Fire tests on building materials and structures. Methods for determination of the fire resistance of non-loadbearing elements of construction*


BS 5544, 1978, *Specification for anti-bandit glazing (glazing resistant to manual attack).*


BS 6262: *Glazing for buildings,*

Part 1, 2005, *General methodology for the selection of glazing,*

Part 2, 2005, *Code of practice for energy, light and sound,*


BS EN 357, 2004, *Glass in building - Fire resistant glazed elements with transparent or translucent glass products - Classification of fire resistance*

BS EN 572, *Glass in buildings – Soda lime silicate glass products.*


BS EN 12150-1, 2000, *Glass in building - thermally toughened soda lime silicate safety glass – Definition and description.*


BS EN13501-2, 2007, *Fire classification of construction products and building elements. Classification using data from fire resistance tests, excluding ventilation services*

BS EN 1279-1, 2004 *Glass in buildings – Insulating glass units – Generalities, dimensional tolerances and rules for the system description.*

BS EN 1863-1, 2000, Glass in building - Heat strengthened soda lime silicate glass – Definition and description


The following Building Regulations Approved Documents may be accessed at:

Building Regulations (Scotland) may be downloaded from:  http://www.sbsa.gov.uk

Building Regulations (Northern Ireland) may be downloaded from: http://www.dfpni.gov.uk/index/buildings-energy-efficiency-buildings/building-regulations/br-technical-booklets.htm

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