GLASS TYPES

Glass is routinely used by architects in contemporary building design in order to create a sense of space and light. It would be unusual to work on any new commercial or public building that did not feature the use of architectural glass and as such it is essential to understand how to incorporate it into constructions.

On many projects the architect's design will go to tender, a main contractor is appointed who will then split off the various sub-contracts. Right at the end, the contracts for items such as balustrades and canopies are awarded. The lucky recipient may have little, if any scope to influence the design and will rarely be provided with sensible guidance. The architect's drawing of a balustrade may include a specification of glass type and thickness which may or may not be suitable. It is rare for instance for a canopy design to have calculated wind and snow loads. Many factors add complications to the contractor's job of accurately pricing the work and ensuring the completed project complies with relevant design codes.

On both small and large projects the subcontractor often has responsibility for specifying the appropriate glass type and thickness to be incorporated into the architects design, and also to demonstrate to the Building Control officer that the completed works comply with Building Regulations and British Standards.

The contractor who lacks the knowledge and experience to recognise the pit-falls will at best struggle and could at worst suffer big losses. As with all aspects of life, it is better to 'get it right first time'.

The nature of the glazing infill will determine its:

- potential for breakage
- breakage characteristics
- post-breakage behaviour.

Each will be significant in determining the risk associated with using glass at height. For instance, some glazing infill materials may be more likely to break in particular circumstances and may therefore have an increased risk of causing injury. Breakage characteristics will determine the potential for cutting and piercing injuries. Post breakage behaviour determines if the glass has sufficient residual strength to resist loads that are applied without glass falling from height and potentially causing injury. It also determines whether the glass will fall as a single object, clumps of glass fragments or separate glass fragments, which affects the potential for causing serious injury

Annealed glass

This is 'ordinary' glass used in many applications. It can be cut, sawn, edge worked, curved and drilled. Common thicknesses are 4, 6, 8, 10, 12, 15, 19 and 25mm. Annealed glass has a characteristic mechanical strength of 45 N/mm2, as defined in BS EN 572-1 and is therefore one of the weakest glazing infill materials. On breakage it forms sharp-edged, pointed shards. These sharp edges have a high potential for causing cutting injuries, while pointed shards can cause piercing injuries. For these reasons monolithic annealed glass is not normally considered to be a safety glass. If breakage occurs the glass may crack sufficiently to form isolated unsupported island fragments that do not extend to the glass edge.

Annealed glass may break as a result of mechanical loads and thermal stresses. The glass can be made more resistant to mechanical loads by increasing glass thickness. Improved edge finishing may also increase mechanical strength. Resistance to thermal stress breakage may be increased by decreasing glass thickness and by improved edge finishing.

The small amount of residual strength and rigidity of the broken glass means that it has the potential to remain in place, depending on the glazing method used and provided that no island fragments are formed and that no significant forces, such as impact or strong winds, are applied to dislodge the glass. Should island fragments form, they are likely to fall out, even if fragments extending to the edge stay in place. In a sloping orientation, gravity will increase the potential to fall. Should annealed glass fall from height the consequences may be serious, because of the breakage characteristics of the glass, the weight of the glass falling and the distance the glass falls.

Heat strengthened glass

Heat-strengthened glass has a characteristic mechanical strength of 70 N/mm2, as defined in BS EN 1863-1. It is stronger than annealed glass and breaks in a similar manner, producing sharp-edged pointed shards. Its broken glass edges have the potential to cause cutting or piercing injuries. For these reasons it is not normally considered to be a safety glass. Like annealed glass, it may crack sufficiently to form isolated unsupported island fragments.

The heat-strengthening process induces a compressive surface stress and a tensile internal stress in the glass. Should the compressive surface layer be penetrated by impact or damage, the tensile stresses present are sufficient to initiate cracks that will cause localised glass breakage. The compressive surface layer does not have to be completely penetrated since the application of loads or other stresses to the glass may be sufficient to overcome the remaining compressive stress and cause breakage.

The strength of heat-strengthened glass is sufficiently high that it is unlikely to fail as a result of thermal stresses encountered during normal building operation. The glass can be made more resistant to mechanical loads by increasing glass thickness.

The small amount of residual strength and rigidity of the broken glass means that it has the potential to remain in place, depending on the glazing method used and provided that no island fragments are formed and no significant forces, such as impact or strong winds are applied to dislodge the glass. Should island fragments form they are likely to fall out even if any fragments extend to the edge stay in place. In a sloping orientation there will be a greater potential to fall due to the effect of gravity. Should heat strengthened glass fall from height the consequences may be serious, due to the breakage characteristics of the glass, the weight of the glass falling and the distance the glass falls.

Toughened glass

Toughened glass has a characteristic mechanical strength of 120 N/mm2, as defined in BS EN 12150-1. It is stronger than both annealed and heat-strengthened glass. On breakage it disintegrates into comparatively small, blunt, rounded glass fragments, known as dice, as opposed to sharp shards. These fragments clump together and may fall en masse. If the glass pane is relatively thin and small in surface area, when it falls the associated clumps are less likely to cause severe cutting and piercing injuries than sharp shards of broken annealed or heat-strengthened glass. Nevertheless, victims may still be lacerated and require stitches or other hospital treatment. Upon breakage, some of the toughened glass also forms small glass flecks and splinters that may cut. With monolithic glass, toughened glass generally presents fewer safety risks than broken annealed or heat-strengthened glass. Toughened glass has high impact strength and its safer breakage characteristics mean it is considered a safety glass.

The toughening process induces a compressive surface stress and a tensile internal stress in the glass. Should the compressive surface layer be penetrated by impact or other damage the tensile stresses present are sufficient to initiate cracks that will cause complete breakage of the glass pane.

The compressive surface layer does not have to be completely penetrated since the application of loads or other stresses to the glass may be sufficient to overcome the remaining compressive stress and cause breakage. There is also a small risk that toughened glass will fail as a result of nickel sulfide inclusions within the glass. Heat-soaking toughened glass will greatly reduce, but not eliminate, the risk of breakage due to the presence of these inclusions.

The strength of toughened glass is sufficiently high that it is unlikely to fail as a direct result of thermal stresses encountered during normal building operation. In design its use is often controlled by deflection limits. The glass can be made more resistant to mechanical loads by increasing its thickness.

Once broken, monolithic toughened glass has a high likelihood of falling from height because of its low residual strength. This is particularly true if the glass is in a sloping or horizontal orientation due to the effect of gravity. Vertically oriented glass may also fall if dislodged by loads applied to the glass, such as impact or strong winds. This is most likely to occur for single glazing. If toughened glass in barriers breaks it will have no residual strength to resist penetration and contain an impacting body.

When the glass does fall, the greatest hazard with toughened glass is if the fragments stay together, forming clumps that fall en masse. The size of the clumps increases with glass thickness because of the increased interlock of the glass fragments. With glass 10–12 mm thick, clumps may be 300–400 mm long or more. The clumps have a tendency to fall edgeways and only break up or disintegrate on second impact such as contact with a person or a floor. The clumps may weigh several kilogrammes each and when falling from height may have considerable energy. The risk of injury will increase with the weight of the glass falling and the distance the glass falls. For these reasons the pane size and glass thickness of sloping toughened glass used overhead may be limited by industry guidance, such as CWCT TU10 Use of glass overhead.

Whilst toughened monolithic glass has been used for a number of years in overhead glazing applications by all contractors and specifiers. The industry is moving away from using such and are instead favouring toughened laminated glass. This is to design out the risks associated with the use of monolithic toughened glass.

Heat soaked toughened glass

The heat-soaking process does not change the properties of the toughened glass. Heat soaked toughened glass will therefore have the same strength, breakage characteristics and post-breakage behaviour as toughened glass. It will however have the advantage of a significantly reduced likelihood of nickel sulfide-induced breakage.

The science of heat-soaking has not yet been perfected and all the commercially available heat-soak regimes limit the risk of breakage statistically over very large volumes of production. Individual projects use relatively small volumes of glass compared to the volumes over which nickel sulfide breakage rates are calculated statistically. In practice, lower rates of breakage tend to occur on most projects than the overall statistics would suggest, while a few unfortunate projects incur higher rates of breakage. Where the latter occurs, it is then a matter of debate as to whether the increased incidence results from a greater degree of NiS contamination of the glass used for toughening or whether the heat-soaking was ineffective.

Wired glass

Wired glass is one of the weakest glazing infill materials, because the presence of wire mesh weakens the glass. The mesh is normally 0.42 mm diameter. The presence of wire also increases stress concentrations within the glass. Wired glass breaks in a similar manner to annealed glass, but the mesh may hold together the broken glass fragments. This reduces the potential for cutting injuries from exposed glass edges, but is insufficient to allow the glass to be classified as a safety glass. Wired glasses with wire thickness of 0.7 mm or above may have sufficiently high impact strength that the glass can be considered a safety glass. However, under extreme impact where wired glass is broken and penetrated, or if it is dislodged from its frame, sharp glass edges, pointed glass shards and wires that have the potential to cause cutting and piercing injuries may be exposed. Wired glass may also be susceptible to thermal stress breakage due to the presence of vents where the wire intersects the pane edge.

Where glazing is at height, it is current practice to use safety wired glass instead of ordinary wired glass. Safety wired glass has been available only since around 1992 and so is unlikely to be present in older buildings. Should a pane of wired glass be broken it is unlikely to fall from height because of the presence of the wires, which provide a degree of integrity or residual strength. However, the ability of wired glass to remain in place once broken diminishes if water penetration induces rusting of the wire mesh. Also, should the broken glass pane be

subject to a significant load there is a potential for the glass to sag, come out of its frame and fall from height as a single object. The weight of the glass and the distance it falls mean that the consequence of this may be serious. As a result, it is important that any broken panes of wired glass in roof glazing are replaced as soon as practicable after breakage. Finally, where the glass is broken by sufficient force that the wires are also broken, glass fragments with sharp edges may fall.

Film backed glass

The presence of a well-adhered film on monolithic annealed or monolithic heat strengthened glass will hold the glass fragments together on breakage, reducing the potential for cutting injuries and for broken monolithic glass to fall from height. The film, if sufficiently strong, may also prevent penetration, thereby preventing people from falling through the glass.

For film-backed glass to perform satisfactorily on breakage care should be taken to ensure that the film selected has sufficient strength to hold the fragments together on breakage. For this purpose only safety/security films are normally used. These come in a variety of strengths and in some cases are capable of holding fragments together under extreme conditions, such as during earthquakes, heavy storms and hurricanes. The method of anchoring the film-backed glass in place may influence behaviour on breakage. For example, deglazing and applying the film on to the glass so that it extends into the rebate is more likely to hold the glass in place on breakage than alternative methods. The use of film should be justified by reference to breakage test reports or testing to verify that the performance is appropriate for a given situation. This should include carrying out film tests at pre-determined intervals in the years following application because the film has a limited life.

Films may increase the heat absorption of the glass causing the glass to get hotter. This may present the following problems:

- an increased risk of breakage due to increased thermal stresses. This should not be a problem for toughened glass that is filmed although it may accelerate the occurrence of nickel sulphide-induced breakages. For annealed glass, which has a lower resistance to thermal stresses, thermal calculations should be carried out to ensure the glass can withstand the increased stresses without breaking
- an increased risk of breakage through greater thermal expansion. Care should therefore be taken to ensure that the glazing system can tolerate any additional thermal expansion that occurs.

The film will also need to be applied in accordance with manufacturer's instructions to ensure it adheres properly to the glass and the expected performance is achieved. In addition, where film-backed glass is used at height the glazed product should stay in position when broken for sufficient time to allow glass replacement to take place.

Applying film to monolithic toughened glass that has a little residual strength on breakage will increase the potential for sagging, particularly when in sloping orientations. If sagging is significant the film-backed glass may come out of its frame or fixings and fall from height as a single object. The film may also need to be resistant to tearing after glass breakage especially if it is subject to load, such as on bolted glass. Film manufacturers or suppliers should always be consulted when selecting film to ensure the film is appropriate for the situation.

Manufacturers may guarantee films for five to 20 years when used internally. Films have a limited life expectancy, therefore, which may markedly increase whole-life-cycle costs.

Laminated glass

The strength, breakage characteristics and post-breakage characteristics of laminated glass are dependent upon the component layers, glass thickness, the number of glass plies, interlayer type and interlayer thickness. Laminated glass may therefore show a wide range of performance.

The mechanical strength of laminated glass can be increased by using stronger glass, increasing glass ply thickness, increasing the number of plies and improving edge finish. Resistance to thermal stresses can be increased by using stronger glass that is more resistant to thermal stresses and by improving edge finish.

The normal breakage characteristic of laminated glass is that the broken glass will remain adhered to the interlayer, reducing the potential for glass edges to become exposed and for glass fragments to fall from height, both of which may cause injury.

Post-breakage behaviour will be influenced by the properties of the materials used in construction of the laminated glass and by the number of glass plies that break. This could lead to the following situations:

- one ply breaks
- one ply breaks and the remaining plies break because of the residual load
- all plies break.

The strength of the laminated glass will decrease if any ply is broken.

Post-breakage behaviour, particularly for sloping glazing, can also be influenced by the potential for the plastic interlayer to creep or deform at elevated temperatures. This may allow the laminated glass to sag and come out of its frame or fixing and cause serious injury to anyone below. Consequently, if sloping laminated glass is to be used in a situation outside normal design parameters, the post-breakage behaviour is often investigated at a realistic service temperature and stability demonstrated for a period of time acceptable to all interested parties. It should be noted that the properties of interlayer plastics vary according to a number of factors, including time, temperature and composition.

Laminated annealed glass

Laminated annealed glass is widely used in situations where the thermal stresses induced in the glass will not exceed safe limits. Due to the benefits of annealed glass such as an absence of roller wave distortion, anisotropy and breakage due to NiS inclusions, use of such glass is preferable to the alternatives in situations where the thermal stresses can be controlled by appropriate design.

Thin laminated glasses, such as those with a thickness of 6.4 mm using plies of 3 mm glass, may appear fairly robust, but the plies will have no more resistance to impact on their edges than the glass plies of which they are composed. Such laminated glass may therefore be more susceptible to breakage during handling than either monolithic glass of the same thickness or laminated glass with thicker glass plies. Laminated annealed glass is also susceptible to thermal stress breakage if the safe working limits for annealed glass are exceeded.

Should all plies of the laminated annealed glass break and it is supported on all four edges, the laminate will typically have sufficient residual strength to prevent the pane from being displaced from the frame and falling from height as a single object, provided that excessive loads are not applied. If the broken laminated annealed glass is supported on only two edges, there is the possibility of it folding and sliding out of the frame unless the glazing material is an adhesive sealant.

Laminated annealed glass that falls will tend to hold together but will fold, exposing sharp edges.

Laminated heat-strengthened glass

Laminated heat-strengthened glass breaks in a similar pattern to annealed glass. Such glass is stronger than annealed glass and will be unlikely to break from thermal stresses during normal building operation. Following breakage, the post-breakage behaviour is similar to that of laminated annealed glass.

Laminated toughened glass

Laminated toughened glass is strong enough to accommodate high mechanical stresses so it is used where the laminate is expected to have high strength, such as in bolted fixings. The laminate is also resistant to breakage from thermal stresses.

The glass should remain rigid and in place, provided at least one ply is unbroken. Where all plies of the laminate break, it will have little strength and its post-breakage behaviour will be dominated by the tensile strength, stiffness and tear resistance of the interlayer. In sloping situations, there is a risk that a laminate will sag and fall as a single object from the rebate. Bolted laminated panes comprising only toughened glass may also be at risk of falling if the interlayer tears around bolt holes once the glass has broken. Potential solutions to this have included use of special interlayer materials or the use of a laminate comprising a toughened glass ply and a non-toughened glass ply. The latter ply provides more residual strength on breakage than a second toughened glass pane, but it reduces the strength of the laminated glass in its intact state.

Care is needed if a laminate incorporates glasses of different thicknesses or strengths. If their differing properties are not taken into account there may be an additional risk of breakage. These issues also require careful consideration on curved glass.

Interlayer type for laminated glass

The post-breakage behaviour of laminated glass will depend upon the nature and thickness of the interlayer material. The interlayer may need to be sufficiently stiff that the laminated glass does not sag and come out of its frame or fixing on breakage. The properties of the interlayer may vary with temperature. Polyvinyl butyral (PVB), the most common interlayer, typically has a maximum working temperature of around 40°C, but this can be higher depending upon the formulation of the specific PVB material used. Where PVB interlayers are used on heat-treated glasses that exhibit roller wave, it is normal practice to increase the thickness of the interlayers to accommodate the roller wave. This generally overcomes the potential for delamination; as a result, delamination is very rare.

Other interlayer types have been developed and may have performance benefits. They are only used for a small proportion of the laminated glass market and include:

- intumescent interlayers, which expand in a fire to provide heat insulation and become opaque to prevent the transmission of heat by radiation
- cast-in-place (CIP) interlayers using polyester, polymethyl methacrylate or other resins for applications ranging from overhead glazing to acoustic glazing products. The resins may have specific advantages over PVB, such as increased acoustic insulation or higher temperature stability. They may not however give the same degree of safety on breakage as PVB
- polyurethane interlayers, which behave similarly to PVB, but have superior mechanical properties above 40°C