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# GLASS in GLAZING from brittleness to brilliance

What makes glass ideally suited to glazing, and what can go wrong.

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**S**taring out of a window on a dreary winter's day it is easy to forget that only some thin panes of glass separate you from the biting elements. As a fabric of our built environment glass is easily hidden in plain sight, owing to one of its key properties - transparency. However, the invisible nature of this material is somewhat shattered when problems arise. Glass is well known for its brittleness and apparent weakness.

Materials science and engineering has invented other transparent materials to rival glass. Some of these are not brittle and can replace or be combined with glass in numerous applications. These include polymers, such as perspex and other plastics. Nevertheless, glass still reigns supreme in glazing and has done since its inception in the Roman era. With today's technical advances, there are some very good reasons why glass remains the principal glazing material, despite its weaknesses.

## Unique properties

Beyond its excellent optical properties, one of the main factors for its continued use is the chemical inertness of glass. It is why you are still able to enjoy the stained glass windows of Canterbury Cathedral, some 800 years or more after they were installed. It is also why you will find glass used for food and beverage containers – not to mention the relative ease with which it can be

recycled. The hardness of glass also provides a level of scratch resistance beyond polymer-based materials. This allows repeated cleaning without impinging on its optical properties.

The apparent weakness of glass and its fracture behaviour arise from it being a brittle material; its lack of ductility. When a load, such as a bending load or impact is applied to a material, tensile stresses are generated. These stresses are concentrated at the surface of the material and at small imperfections, or other discontinuities, such as surface notches or scratches or foreign material

(inclusions). All materials contain such flaws to some degree, which act to locally concentrate these stresses. Materials also have a maximum level of stress they can support (the yield stress) until (in ductile materials) permanent deformation occurs.

Unlike ductile materials, the brittle nature of glass means it reacts differently. In glass, once the tensile stress at a stress concentrator exceeds the yield stress, an unstable crack can form and propagate through the material, unimpeded by the energy sapping processes of deformation. Hence, even if the overall load applied to the glass produces bulk tensile stresses below the theoretical yield stress, cracking and complete fracture can occur from a localised site of concentrated stress.



Temperature variations across a pane give rise to differential expansion and/or contraction.



Stained glass window at Canterbury Cathedral

resulting in internal stresses and associated cracking. For example, on exposure to sunlight, the perimeter zone of a pane of glass (shaded by the frame) can remain cooler than the central area, which expands. This expansion imparts a tensile stress in the perimeter zone, which can form thermal cracks. Unlike high energy impact events, thermal cracks are usually slow growing and are frequently unnoticed in the initial stages. Once initiated, the growth of the cracks usually cannot be stopped, and they often propagate in distinct stages, in a meandering fashion, with cycles of temperature variation.

Many potential factors can cause or contribute to the risk of thermal cracking, by increasing temperatures and/or variations in temperature experienced by the glass. These include; locations more exposed to sunlight, deep window frames that cause shading, installation of close-fitting blinds or curtains, or the application of films, decals or posters to the glass surface. Some manufacturers provide online calculators that give an indication of a windows

This trait is useful when cutting glass. By scoring the surface (to generate a sharp notch to concentrate stress) and then applying a small bending load, the glass can be made to snap precisely along the desired line. But this brittle trait of glass is less useful when the cricket ball becomes acquainted with the greenhouse.

### The impact of heat

Even where no impact or other external loading of the glass has occurred, cracks can still form from thermal stresses arising from thermal expansion and/or contraction. Temperature variations across a pane give rise to differential expansion and/or contraction,

thermal cracking risk. Where this risk is high, glass that is stronger and more resistant to thermal cracking can be specified.

### Stronger, safer glass

In the modern era materials science has stepped in to soften the blow when it comes to glass' poor resistance to impacts and thermal stresses. Toughened glass, used extensively in modern glazing, counters tensile stresses with locked-in compressive stresses, imparted into the glass pane during a specific heat treatment at manufacture. Any tensile stresses subsequently generated that would ordinarily result ➤

in cracks from the surface of the glass must first overcome the compressive stress introduced from heat treatment. Consequently, toughened glass is normally immune to thermal stress cracking. In fact, the overall strength of toughened glass can be up to around four times that of un-toughened glass.

Still, accidents happen, and if the fracture of toughened glass does occur, the residual strain introduced from the heat treatment drives a rapid propagation of numerous cracks, that spread out through the entire pane (usually accompanied by a sharp bang). This creates a web of fractures that transforms the pane into countless small cuboidal fragments. Unlike the large shards produced in the fracture of un-toughened glass, these small relatively blunt fragments are less likely to cause injury, which is why toughened glass is referred to as 'safety glass'. Such glass can be specified where there is a risk of thermal stress cracking but also for critical areas. These is where people are likely to come into contact with glazing, such as near, or in, doors. Using safety glass can meet Building Regulation<sup>1</sup> requirements to avoid injury from impact with glazing.

Laminated glass, in which two or more panes of toughened and/or non-toughened glass are bonded together using a thin polymer interlayer, provides additional strength to the pane. If a pane of laminated glass fractures for any reason, the shards and fragments of the pane remain in place.

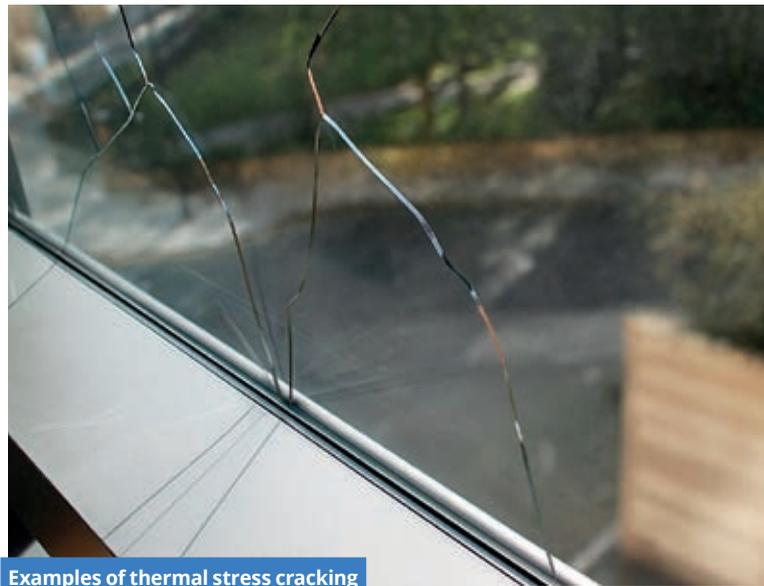
This further reduces the risk of injury, particularly in situations where the glass is intended to form a barrier, such as glass panels in a balcony balustrade.

Unfortunately, the strengthening heat treatment for toughened glass can cause a change in the atomic structure of a type of inclusion, specifically nickel sulphide (NiS) inclusions. These inclusions can be present in the glass as a contaminant from the manufacturing process and, over time, can result in crack formation. If the crack forms in the tensile core of the pane, a sudden and seemingly spontaneous fracture of the entire pane can occur, even years after installation.

The sudden noise and fracture, which can result in the entire collapse of a pane, can be startling and inconvenient, particularly if the pane happens to be a shower screen. When used in fenestration, replacements can be costly. This is especially true in tall buildings, where specialist and expensive access equipment and difficult arrangements, such as road closures, may be required. NiS inclusions, while not always present, are a difficult contaminant to eliminate from mass produced glazing. These inclusions can



An NiS inclusion at the origin of cracking in a fractured toughened glass panel



Examples of thermal stress cracking

be concentrated in a batch of glass, meaning that a particular building can be the subject of repeated NiS inclusion induced fractures.

Manufacturers are aware of the risks of NiS inclusions, so such causes of fracture are often omitted from product guarantees. However, the risks of such costly events are substantially reduced by specifying toughened glass that has been heat soaked, in accordance with *BS EN 14179-1*<sup>2</sup>. Toughened glass manufactured to this standard undergoes a heat soak test (HST) after the initial toughening heat treatment. The intention of this test is to cause fracture from any NiS inclusions during the HST, rather than after installation.

The HST does increase the costs of the glass and the test is not 100% effective, but consideration should be given to this treatment, particularly in buildings or

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**The overall strength of toughened glass can be up to around four times that of un-toughened glass.**

areas of a building in which the cost to replace the glazing (due to access arrangements for, example) might be substantial. It is not possible to determine from inspection or testing whether a pane of glass has been subject to HST. Therefore, it is important to obtain and retain the glass specifications and declarations of conformity, which can be referred to if issues arise.

Any glazing fractures that do occur can be inspected to determine the cause of the fracture. However, it is important that all (or as much as possible), of the glass is retained for inspection in its as-found condition. It is then usually possible to determine whether the cause of fracture was from an external event (such as impact, wind loading or building movement), manufacturing defect (such as NiS inclusions or other flaws at the edge of the pane) or was caused or contributed to by other factors, such as inappropriate specification of the glass. Such investigations can prove important in any claims process and in the development of proactive measures to mitigate against future occurrences. ●

## References

<sup>1</sup>The *Building Regulations 2010, Protection from falling, collision and impact, Approved Document K*, gov.uk

<sup>2</sup>*BS EN 14149-1:2016 Glass in building – Heat soaked thermally toughened soda lime silicate safety glass. Part 1: Definition and description*, BSI Group

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