Spontaneous Breakage of Thermally Toughened Glass

by Ben Wallace, Glass and Glazing Federation

With construction products in the spotlight more than ever it is important to have the right products installed in the right places. A common glazing industry issue that we regularly experience, both throughout the UK and internationally, is the seemingly random spontaneous fracture of thermally toughened soda lime silicate safety glass. This is where the installed glass shatters into thousands of pieces. Thermally toughened soda lime silicate glass was first manufactured in 1931.

Fractured thermally toughened glass may remain in place, or it may fall out. The design of this product means that the internal stress obtained during the toughening process causes the glass to get the shattering effect. Whilst thermally toughened glass has many benefits regarding additional strength when thinking about wind loadings, impact, and safe breakage behaviours, it also carries risk. If fractured, glass falling from height and/or acting as a barrier, can have significant safety implications.

In addition, large projects with multiple spontaneous fractures could have significant financial implications. This may involve multiple Expert Witnesses acting on behalf of their clients trying to ascertain the cause of fracture.

It was in 1961 that E R Ballantyne issued a report on the breakage of thermally toughened cladding panels from a building in Melbourne, Australia. This report showed that an inclusion of 'nickel sulphide' was at the origin of the fracture. Further work explained that the inclusion experienced a phase change that caused the toughened glass to fracture.

Thermally treated glasses may fracture from a variety of causes. These in order of occurrence are:

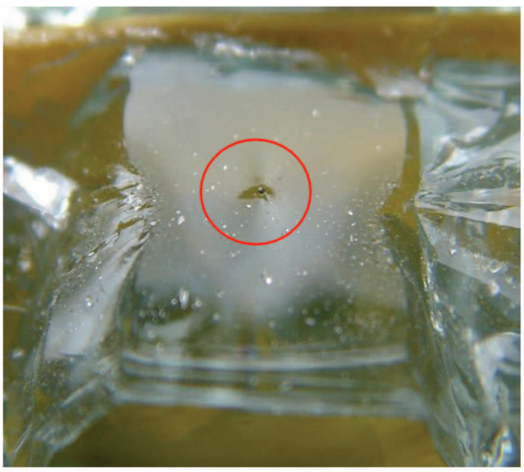
- Edge damage (e.g. caused during manufacture, transportation, installation, service conditions)
- Sharp body impact, either accidental or malicious
- Poor glazing design (e.g. glass to metal contact)
- Poor workmanship (e.g. incorrect installation, inappropriate assembly of fittings, unskilled labour)
- Inferior glazing materials (e.g. use of incorrect gaskets, bushes, etc)
- Excessive loads either mechanical or thermal
- Incorrect processing of glass
- Inclusions in the glass

1 Ballantyne E.R.: Report 061-5: Fracture of toughened glass wall cladding, I.C.I. House, Melbourne, CSIRO, Division of Building Research, Melbourne: 1961

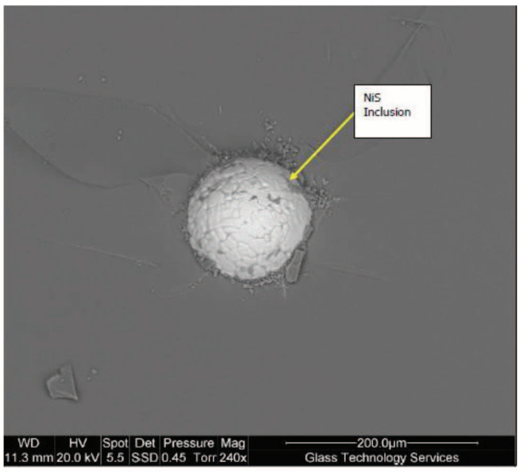
Thermally treated glass therefore becomes associated with unexplained, but noticeable, breakages and these have been labelled "spontaneous fractures", whereas breakages from similar causes in other types of glass are frequently referred to as "cracks". In fact, thermally treated glass is less susceptible to breakages than any other form of glass, but the fracture propagates with a loud noise which may be accompanied by falling particles and is therefore much more obvious.

In addition, with toughened glass, the origin of the fracture, which is a source of information as to the cause, is often lost. Of the various causes of "spontaneous fracture", only that associated with the presence of foreign particles in the glass is more likely to cause fracture in thermally treated glass than in other forms of glass, because they can disturb the very high built-in stresses in thermally treated glass. Spontaneous breakage due to inclusions is possible in any of the three different types of thermally treated glass products available:

- Heat strengthened soda lime silicate glass – EN 18632



Above, example of an inclusion in a toughened glass origin.



Above, Magnified NiS Inclusion.

• Thermally toughened soda lime silicate safety glass – EN 12150

• Heat soaked thermally toughened soda lime silicate safety glass – EN 14179

The presence of an inclusion within annealed glass is not a problem. It is only of concern when in the tensile stress zone of a thermally treated product.

This article covers the spontaneous breakage of thermally treated glasses, together with types of inclusions, the rate of occurrence and associated risks.

For the purpose of this article the following definitions apply:

• Spontaneous breakage (also referred to as spontaneous fracture) - An apparent unexplained fracture that can occur in heat treated glasses without an obvious external influence.

• Inclusions - An inclusion that by virtue of its size and position in the thermally treated glass can cause failure.

• NOTE: These can be of various materials that are either critical (e.g. nickel sulphide) or non-critical (e.g. refractory stone, un-melted frit)

• Critical inclusions - An inclusion or small impurity in the glass that can undergo a phase change which may lead to fracture of thermally toughened soda lime silicate glass sometime after toughening.

• NOTE: Failure is also possible in heat strengthened soda lime silicate glass.

• Nickel Sulphide inclusions -The most common type of critical inclusion found within thermally treated soda lime silicate glass.

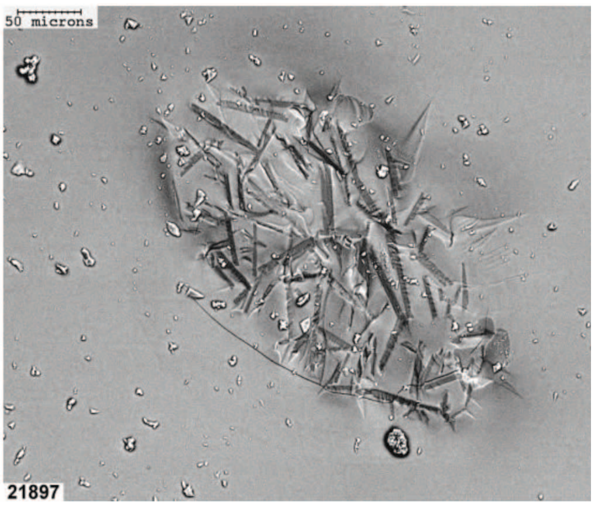
• Level of associated risk - Risk of spontaneous breakage of thermally treated soda lime silicate glass on a statistical basis due to the presence of critical inclusions.

Types of Inclusions- **Non – Critical**
These can be one of the following:

• Un-melted frit

• Fragments of refractory block

• Inclusion that does not undergo phase change



Above, example of un-melted frit

If these are sufficiently large and in the tensile stress zone (towards the centre of the glass thickness), they can disrupt the stresses built into toughened glass to an extent that the glass fractures from around the inclusion. Often this will occur during manufacture, but it can also occur sometime after manufacture, usually fairly quickly, but it may be a matter of months. Toughened glass containing a non-critical inclusion which survives longer than a few months is very unlikely to fracture from the inclusion in service.

Types of Inclusions- **Critical**
Nickel Sulphide
Background nickel sulphide has two main states, one of which is stable at high temperatures and one which is stable at lower temperatures. When glass is thermally treated the nickel sulphide transforms to the high temperature state during the heating process, but the glass is cooled rapidly which does not allow the reverse transformation to the low temperature state. This reverse transformation occurs over a period of time, accompanied by an increase in volume.

Therefore if:

• The nickel sulphide inclusion is large enough, and

• Within the tensile (central) portion of the thermally treated glass, it can cause fracture at some time after manufacture.

All types of thermally treated glass, i.e. heat strengthened, thermally toughened, can be subject to spontaneous breakage as the result of the presence of critical nickel sulphide inclusions. However, the risk of spontaneous breakage due to the presence of a critical nickel sulphide inclusion can be significantly reduced by using heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179.

Rate of Occurrence of Fracture Due to Critical Inclusions
There are no definitive and proven concentration levels for critical inclusions in any manufacturers thermally toughened soda lime silicate safety glass.

NOTE: Glass manufacturers have taken action to reduce nickel contamination of the annealed glass since NiS was shown to be a cause of spontaneous fracture of toughened glass.

Consequently, the incidence of NiS in glass has now been reduced.

Spontaneous breakage of thermally toughened soda lime silicate safety glass due to critical inclusions remains statistically unlikely for the large quantities of glass supplied and installed in buildings.

Reducing Spontaneous Breakage due to Critical Inclusions
Heat soaked thermally toughened soda lime silicate safety glass is manufactured by taking thermally toughened panes and subjecting them to the heat soak process cycle. The heat soak process cycle consists of a heating phase, a holding phase and a cooling phase. This process encourages unstable α phase to convert to the β stable phase and force the glass to fracture within the heat soaking oven. The heat soak process

cycle in EN 14179-1 requires the glass to be heated to a temperature greater than 280 °C, held at a temperature of 290 °C ± 10 °C for a period of 2 hours before controlled cooling to an ambient temperature.

This process is used to reveal the presence of critical inclusions in glass panes. It is a destructive test that is designed to break glass that is at risk.

Heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179-1 has a reduced rate of fracture due to the presence of critical inclusions. Heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179-1 will have a residual risk of occurrence of critical inclusions of 1 in 400 tonnes.

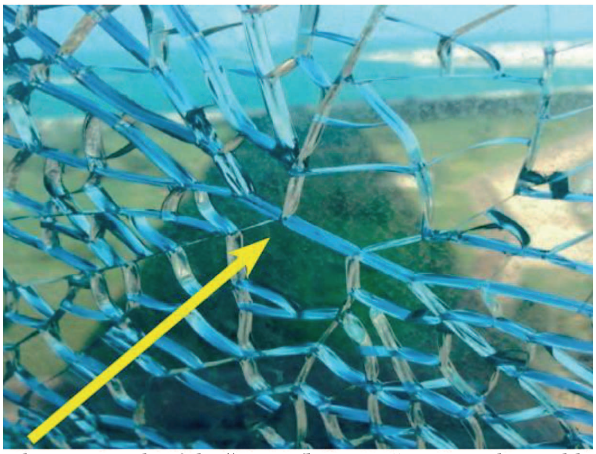
The heat soak process cycle itself is not fail safe. Other types of non-critical inclusions that may not be removed during the heat soak process cycle, and smaller sized critical inclusions that do not necessarily fracture in the heat soak oven, may cause fracture in use.

It is not possible to provide a specific definitive quantifiable residual risk of fracture due to critical inclusions in any specific batch of heat soaked thermally toughened soda lime silicate safety glass.

Heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179 is deemed to be the best product for reducing spontaneous fractures as a result of critical inclusions.

The statistical analysis which provides the level of risk of critical nickel sulphide inclusions remaining in heat soaked thermally toughened soda lime silicate glass is valid for large volumes of production, but does not necessarily relate to individual projects.

Contamination of the float glass occurs in batches leading to periods of glass containing no critical nickel sulphide inclusions followed by "spikes" when a number of inclusions are present in a particular batch of float glass. It is for this reason that there appear to be batches of glass supplied for specific projects that have been selected "by chance" from a contaminated batch of float glass and others that appear to be free from contamination. Residual risk analysis is indicative only and over the life of a building. Nickel sulphide induced failures may occur despite heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179-1 being installed.



Above, example of the "Butterfly Wings" pattern observed by myself in Abu Dhabi.

Assessment of Fracture Pattern Characteristics of Thermally Treated Soda Lime Silicate Glass

The fracture pattern of Thermally Treated Glasses is characterised by a pair of particles commonly referred to as the "Butterfly Wings".

This fracture pattern can occur with other glass types. In the case of Thermally Treated Glass the fracture, which produces such a fracture pattern can be the result of wind, snow, soft/hard body impact, centre punch, surface chips and any type of particle inclusion.

To determine the specific cause of the fracture, the origin must be examined in detail by a qualified expert. To determine if it is the result of an inclusion, it may be necessary to send the inclusion particle, if present, for laboratory analysis.

The orientation of the façade can play a part in the timing of fractures. Typically South, East and West facades will show spontaneous fractures first followed by the North façade sometime later. It is simply a function of time / temperature / stress in the glass all combining to form a pattern of breakages on a building.

The above three images show an example of the incorrect glazing in the overhead position that has suffered Spontaneous Fractures due to Critical Inclusions. The images effectively demonstrate the safety implications of these fractures.

There are many instances of spontaneous breakages occuring on buildings in commercial and domestic installations all over the world. All of which are different but all will look to portion liability and many of which end up in a legal dispute. It is crucial that the correct and suitably qualified industry expert witness is appointed.

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After leaving the military, Ben worked for a UPVC Manufacturer as a technical advisor to the trade. Upon joining the GGF in 2012 as a trainee Technical Officer, he carried out a two-year training programme to become a full Technical Officer after shadowing some of the industry's leading experts. Since then Ben has been involved in all elements of the glazing industry and worked on some extremely high profile glazing projects internationally.

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