Spontaneous Breakage of Thermally Toughened Glass

Thermally toughened soda lime silicate glass was first manufactured in 1931. Since that time breakages of thermally toughened glass have occurred. It was in 1961 that E R Ballantyne issued a report on the breakage of thermally toughened cladding panels from a building in Melbourne, Australia¹. This report showed that an inclusion of 'nickel sulfide' was at the origin of the fracture. Further work explained that the inclusion experienced a phase change that caused the toughened glass to fracture.

Example of an inclusion in a toughened glass origin

Magnified NiS Inclusion

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

- Edge damage, caused during e.g. 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


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Inclusions in the glass

Thermally treated glass thus 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 1863
- 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 sulfide, 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 Sulfide inclusions** - The most common type of critical inclusion found within thermally treated soda lime silicate glass.

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2 EN 1863: *Glass in building – Heat strengthened soda lime silicate glass*
3 EN 12150: *Glass in building – Thermally toughened soda lime silicate safety glass*
4 EN 14179: *Glass in building – Heat soaked thermally toughened soda lime silicate safety 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

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.

Critical

Nickel sulfide

Background nickel sulfide 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 sulfide 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 sulfide inclusion is large enough, and
• Within the tensile (central) portion of the thermally treated glass, it can cause fracture at some time after manufacture.

NOTE 1: Nickel sulfide is referenced as the "critical inclusion". Actually the chemical composition will not be true Ni$_2$S$_2$ but a range. Generally the inclusion will also incorporate other elements, e.g. iron, selenium, etc. These multi component inclusions act at different temperatures and/or times when undergoing the phase change.

NOTE 2: There are chemical compositions of nickel sulfide that are non-critical inclusions, i.e. they do not undergo a phase change.

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 sulfide inclusions. However, the risk of spontaneous breakage due to the presence of a critical nickel sulfide inclusion can be significantly reduced by using heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179.

NOTE: In service conditions the conversion of critical inclusions is affected by glass temperature. The higher the temperature, the rate of conversion is greater therefore increasing the risk of fracture.

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.

NOTE: A residual risk of fracture due to critical inclusions in thermally toughened soda lime silicate safety glass still remains.

Reducing Spontaneous Breakage due to critical inclusions

Heat Soaked Thermally Toughened Soda Lime Silicate Safety Glass

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.

NOTE: This residual risk is on a statistical basis and does not necessarily refer to any specific batch. Reliance on other published predictions can give a false impression of the probability of contaminations within float glass.

The heat soak process cycle itself is not failsafe. 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.

NOTE: Expectations and claims that no fracture due to critical inclusions are allowed are erroneous.

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.

NOTE: Heat soaked thermally toughened soda lime silicate safety glass is recommended for all situations where:

• The stability of the structure,
• The maintenance of the barrier,
• The safety of users may be at risk from breakage.

The statistical analysis which provides the level of risk of critical nickel sulfide 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 sulfide 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 sulfide induced failures may occur despite heat soaked thermally toughened soda lime silicate safety glass in accordance with EN 14179-1 being installed.

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.

To determine if it is the result of an inclusion it will be necessary to send the inclusion particle, if present, for laboratory analysis.

Example of the “Butterfly Wings” pattern

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