# GGF Data Sheet: Thermally Treated Soda Lime Silicate Glass Products - Spontaneous Breakage

4.4.2 May 2016

**Contents**



## Introduction

Thermally treated glasses may fracture from a variety of causes. These may be as follows:

- 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
- 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, 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

**NOTE: 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.**

## 1. Scope

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

Whilst breakage for other reasons can occur, these are not dealt with in this GGF Data Sheet.

Thermally toughened soda lime silicate safety glass is covered in GGF Data Sheet 4.4: Quality of Thermally Toughened Soda Lime Silicate Safety Glass for Building.

Other thermally treated soda lime silicate glasses are covered in GGF Data Sheet 4.4.1: Thermally Treated Soda Lime Silicate Glass Products - General.

## 2. Definitions and Descriptions

(See also GGF Data Sheet 4.4.1: Thermally Treated Soda Lime Silicate Glass Products - General)

Glass and Glazing Federation
40 Rushworth Street, London. SE1 0RB
Tel: 020 7939 9100 Fax: 0870 042 4266
www.ggf.org.uk



Glass and Glazing Federation

### 2.1 Heat strengthened soda lime silicate glass

Glass within which a permanent surface compressive stress, additionally to the basic mechanical strength, has been induced by a controlled heating and cooling process in order to give it resistance to mechanical and thermal stress and prescribed fracture characteristics.

### 2.2 Thermally toughened soda lime silicate safety glass

Glass within which a permanent surface compressive stress, additionally to the basic mechanical strength, has been induced by a controlled heating and cooling process in order to give it greatly increased resistance to mechanical and thermal stress and prescribed fragmentation characteristics

**NOTE: The mechanical properties, i.e. thermal durability and mechanical strength, and safety properties, i.e. fragmentation characteristics, are generated by the stress distribution through the glass. Mechanical properties are related to the level of surface compression. Fragmentation is dependent on the inner tensile stress. These properties are not size dependent.**

### 2.3 Heat soaked thermally toughened solda lime silicate safety glass

Glass within which a permanent surface compressive stress has been induced in order to give it greatly increased resistance to mechanical and thermal stress and prescribed fragmentation characteristics; and which has a reduced level of residual risk of spontaneous breakage due to the presence of critical nickel sulfide inclusions.

**NOTE: The mechanical properties, i.e. thermal durability and mechanical strength, and safety properties, i.e. fragmentation characteristics, are generated by the stress distribution through the glass. Mechanical properties are related to the level of surface compression. Fragmentation is dependent on the inner tensile stress. These properties are not size dependent.**

### 2.4 Spontaneous breakage (also referred to as spontaneous fracture)

An apparent unexplained fracture that can occur in heat treated glasses without an obvious external influence.

### 2.5 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.**

### 2.6 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.**

### 2.7 Nickel Sulfide inclusions

The most common type of critical inclusion found within thermally treated soda lime silicate glass is nickel sulfide.

### 2.8 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.

## 3. Heat Strengthened Soda Lime Silicate Safety Glass

### 3.1 The process

Heat strengthened glass is formed by heating annealed glass and then cooling it under controlled conditions. (More rapidly than during the annealing process, but not as rapidly as for toughened glass). Differential rates of cooling between the surface and the core of the glass causes differential contraction, the effect of which is to generate a compressive stress in the surface layer of the glass and a balancing tensile stress in the core.

Heat strengthened glass has a built-in stress as a result of this process, giving a surface compressive stress in the range of 25 N/mm² to 42 N/mm², i.e. 3,600 psi to 6,000 psi.

Heat strengthened glass offers some of the mechanical and thermal strength benefits of toughened glass but it still fails in a manner similar to that of annealed glass, but at higher loads.

### 3.2 Thermal characteristics

Heat strengthened glass will resist thermal stress and thermal shock at levels more than 2.5 times higher than annealed glass. The figure quoted in EN 1863-1 is 100K. It has a maximum operating temperature of 200 °C.

### 3.3 Rate of occurrence of fracture due to inclusions

Because the central tensile zone in heat strengthened glass has a reduced level of stress compared with that in thermally toughened safety glass, the size of the inclusion needed to propagate fracture is much larger

### 3.4 Residual risk

Spontaneous breakage is highly unlikely due to the low compressive stress level in this product and the size of critical inclusion necessary to initiate breakage. There are very few reported cases of spontaneous fractures of heat strengthened glass in Europe. The residual risk of fracture due to a critical inclusion is considered minimal.

## 4. Thermally Toughened Soda Lime Silicate Safety Glass

### 4.1 The process

Thermally toughened soda lime silicate safety glass is made from annealed glass which has been heated to a uniform temperature above 650 °C and cooled rapidly, usually by blowing cold air evenly at both surfaces. Toughened glass has a high built-in stress as a result of the rapid cooling, giving a surface compressive stress in the range of 80 N/mm² to 150 N/mm², i.e. 11,600 psi to 21,700 psi.

A thermally toughened glass suitable for safety glass applications, i.e. one that can be classified in accordance with EN 12600, is likely to have a surface compressive stress greater than 100 N/mm², i.e. 14,500 psi.

### 4.2 Thermal characteristics

Toughened glass will resist thermal stresses and thermal shock at levels equal to or greater than 5 times that of annealed glass. The figure quoted in EN 12150-1 is 200K. It has a maximum operating temperature of 250 °C.

### 4.3 Fracture characteristics

Due to the high levels of built-in stresses, once a fracture is initiated in toughened glass, it propagates rapidly due to the released energy. The effect is to disintegrate the glass into numerous small pieces, the edges of which are generally relatively harmless and are unlikely to cause cutting and piercing injuries like broken pieces of annealed glass.

A fractured vertical pane may remain in its frame unless dislodged by external actions such as wind, thermally induced bowing, human interference or freezing water.

Sloping panes and other types of glazing systems are highly likely to fall after fracture, even if framed.

### 4.4 Rate of occurrence of fracture due to 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.**

### 4.5 Residual risk

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.**

## 5. Nickel Sulfide Inclusions

### 5.1 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: Nickel sulfide is referenced as the critical inclusion. Actually the chemical composition will not be true $Ni_{(l)}S_{(l)}$ but a range. Generally the inclusion will also have other elements, e.g. iron, selenium, etc, incorporated. These multi component inclusions act at different temperatures and/or times when undergoing the 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.**

For further information, see Annex A.

## 6. Heat Soaked Thermally Toughened Soda Lime Silicate Safety Glass

### 6.1 The process

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.

**NOTE: With the publication of EN 14179-1: 2016, the holding temperature will change to 260 °C ± 10 °C**

### 6.2 Thermal Characteristics

Heat soaked thermally toughened soda lime silicate safety glass will resist thermal stress and thermal shock at levels equal to or greater than 5 times that of annealed glass. The figure quoted in EN 14179-1 is 200K. It has a maximum operating temperature of 250 °C

### 6.3 Rate of occurrence of fracture due to inclusions

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.

### 6.4 Residual risk

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. (See also 6.5)**

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.**

### 6.5 Batch occurrence of critical nickel sulfide inclusions

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.

## 7. Assessment of Fracture Pattern Characteristics of Thermally Treated Soda Lime Silicate Glass

The statistical information, risk data and conclusions contained within this document have been determined by and therefore refer to heat soaked thermally toughened soda lime silicate safety glass products that have been produced from soda lime silicate annealed float glass supplied by mainline manufacturers who continuously operate systems and safeguards that minimise the inclusion of Nickel Sulfide and similar contaminants in their product.

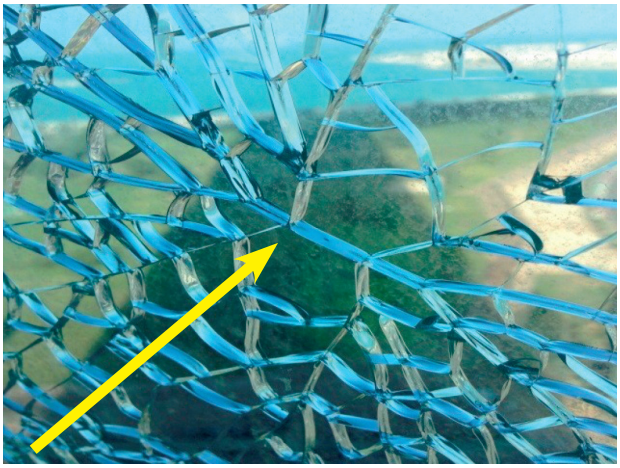

**Figure 1:** Butterfly pattern at origin

The characteristic fracture pattern associated with thermally toughened glass has at its origin a butterfly shape. See Figure 1.

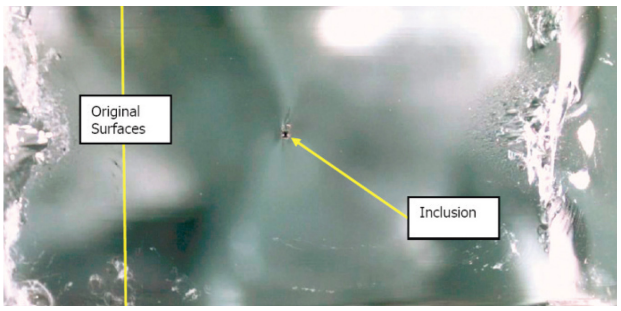


**Figure 2:** Fracture surface showing inclusion

If there is a visible dot on the primary fracture face, it is likely that the cause of fracture is an inclusion. See Figure 2.

The causes of fracture, which always produce such a fracture pattern are wind, snow, soft body impact, centre punch, surface chips and any type of particle inclusion.

To determine the cause of the fracture, it is necessary to send the inclusion particle for laboratory analysis.

**Annex A**

In 1962, Ballantyne of the CSIRO (Building Research, Melbourne) published a report indicating that the cause of many of the spontaneous breakages was nickel sulfide (NiS). NiS is a complex material that undergoes a phase change (a change in crystalline structure) at 290 °C, which is accompanied by a volume change. The **α**NiS, which is stable above 290 °C, has a smaller volume than the **β**NiS, which is stable below 290 °C.

The glass manufacturing process melts the batch mix and then allows the glass to set on cooling. The glass moves into the annealing lehr, at around 600 °C, in which it is cooled to room temperature over a period of about 20 minutes. Any NiS in the glass is converted to the **α** phase at the high temperatures during melting, but the rapid cooling does not allow time for the conversion to the **β** phase. The NiS is thus "frozen" into the glass in an unstable form.

Over a period of time the **α** phase slowly converts back to the **β** phase, the conversion being accompanied by an increase in volume of 2%-4%. In annealed (ordinary, untreated) glass this is not a practical problem. However, if a particle (inclusion) of NiS is sufficiently large and is in the central (tensile stress) zone of toughened glass, then the expansion caused by the conversion can exert sufficient excess stress, in this already pre-stressed product, to cause a crack to propagate and result in disintegration of the pane.

The most common cause of spontaneous breakage is due to critical particles of nickel sulfide; however, silicon particles have also been identified as another cause.

**Bibliography**

**European Standards**

**EN 1863-1** Glass in building - Heat strengthened soda lime silicate glass - Part 1: Definition and description

**EN 1863-2** Glass in building - Heat strengthened soda lime silicate glass - Part 2: Evaluation of conformity/Product standard

**EN 12150-1** Glass in building - Thermally toughened soda lime silicate safety glass - Part 1: Definition and description

**EN 12150-2** Glass in building - Thermally toughened soda lime silicate safety glass - Part 2: Evaluation of conformity/Product standard

**EN 12600** Glass in building - Pendulum test - Impact test method and classification for flat glass

**EN 14179-1** Glass in building - Heat soaked thermally toughened soda lime silicate safety glass - Part 1: Definition and description

**EN 14179-2** Glass in building - Heat soaked thermally toughened soda lime silicate safety glass - Part 2: Evaluation of conformity/Product standard

**GGF Data Sheets**

**GGF Data Sheet 4.4** Quality of Thermally Toughened Soda Lime Silicate Safety Glass for Building

**GGF Data Sheet 4.4.1** Thermally Treated Soda Lime Silicate Glass Products - General