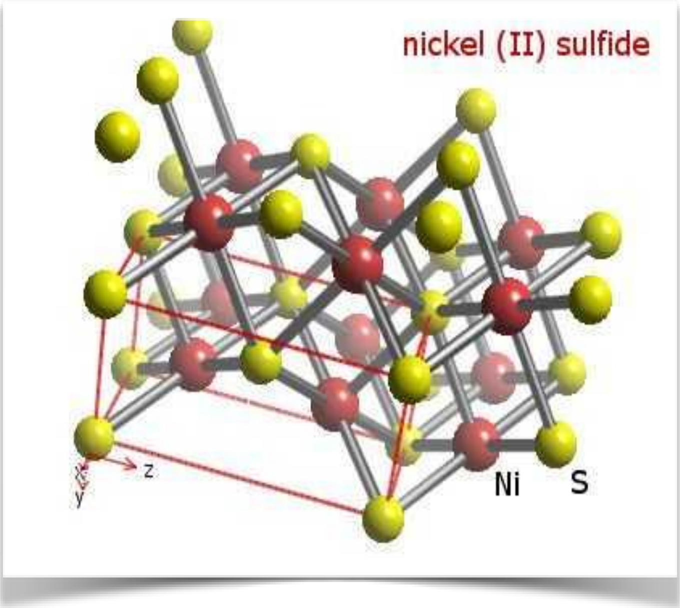
Spontaneous Breakage in Toughened Soda Lime Silicate Float Glass



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1.0 Introduction

Variously described as Spontaneous Fracture, Inexplicable Breakage and even Glass Cancer, the sudden, dramatic, and often complete collapse of a Toughened glass panel in a building, sometimes accompanied with a loud report, is more commonly known as Spontaneous Breakage.

This breakage phenomenon in Toughened glass is not new.

For the purposes of this Technical Publication the terms 'Toughened' glass and 'Fully Tempered' glass are interchangeable.

2.0 Background

Timeline

1962

Float Glass manufacturing was only introduced commercially in 1960 and yet by 1962 enough incidents of Spontaneous Breakage had occurred that Ballantyne of CSIRO (Commonwealth Scientific and Research Organisation, Melbourne Australia) published information concerning Nickel Sulphide (NiS) inclusions and the relationship to Spontaneous Breakage in Toughened Float Glass.

1972

By the early '70s the standards organisations in the USA had implemented DD-G-1403B which, described the parameters of Heat Strengthening glass. This is a method of thermal heat treatment for glass that eliminates thermally induced fracturing of glass in service, and provides substantively higher wind load resistance than ordinary annealed float glass. This standard was later superseded by, the still current, ASTM C-1048. Heat Strengthened glass is not a safety glass, and whilst there is a slim improvement in surface flatness over Fully Tempered glass, the principle reason for its' introduction was to reduce the instances of Spontaneous Breakage.

The USA standards organisations to date do not have a Heat Soak standard. That is because they extensively promote the use of Heat Strengthened glass which, because of its lower surface compressive strength, almost never has an issue with Spontaneous Breakage. Even on the rare occasion this happens, the Breakage does not have the cataclysmic failure characteristic of Fully Tempered glass and largely goes unreported.

1990

Although the USA adopted the use of Heat Strengthening to combat the issue of Spontaneous Breakage, Heat Strengthening was slow to take hold in Europe. Toughening was still the norm. Germany responded as the first European country to propose a Heat Soak practice to reduce Spontaneous Breakage in Toughened glass. This was prescribed in DIN 18516 and was first published in 1990. This standard however, principally covered Spandrel Glazing and the Heat Soak reference was very limited.

1999

In anticipating demand for the process, the first Heat Soak furnace in the GCC region was installed in Sharjah in 1999. Within ten years, almost every company in the region with a glass Tempering facility also had a Heat Soak oven.

2005

The German Standard, DIN 18516, was never adopted as European Standard as it was very ambiguous. Eventually, in 2005, the first European Standard was introduced exclusively covering the Heat Soak method which was EN 14179. The standard is still current. The latest update was released in 2016.

3.0 What is Spontaneous Breakage?

Toughened glass is designated as a Safety glass because of its Breakage characteristics. It will either not break, given a certain impact, or breaks into very small relatively harmless particles that cannot cause a piercing injury. The reason it fractures completely across the panel, in spite of the breakage point is because it has a deliberately set up stress regime throughout the panel. The outer surfaces are in compression and the inner mid-plate is under tension. If the mid-plate tensile area is compromised by a vent (small crack) the entire panel disintegrates as the opposing, balanced stressed areas are disconnected. The spread of further cracks is almost instantaneous.

Therefore, any introduction of a small vent into the glass, even if microscopic, with time, weather cycles, buffeting from wind gusts etc., may eventually open in size. If that vent interferes with the bond between the compressive stressed glass component and the tensile stressed glass component, the panel shatters completely.

Tiny vents can be introduced in many ways. These can be categorised under three main headings.

1. Surface damage
2. Edge damage
3. Inclusions

By far the most likely form of inclusion that will result in a Spontaneous Breakage is that of NiS.

4.0 How Does NiS cause Spontaneous Breakage?

NiS inclusions in float glass are found to change shape and reduce in volume by approximately 2% when heated to about 380°C. During the Toughening process the float glass is heated to its softening point. This is around 620°C. Once the glass has attained the softening point the NiS has reduced in volume.

In order to create the high surface compression levels desired in Toughened glass, the glass, following heating, is rapidly quenched. The outer surface hardens quickly and is at a slightly larger volume than the original glass pane introduced into the furnace. The inner mid-plate area hardens slightly slower and shrinks back to original volume; pulling the entire glass panel back to its original volume. As the outer skin hardened earlier, the inner mid-plate goes into tension whilst the outer surfaces are in compression.

Meanwhile, the NiS inclusion has been reduced back to ambient temperature but held, or 'frozen' in a smaller volume due to the rapidity of the quench and the stress regime around it. It will always try to grow back to its original size.

If the NiS inclusion has, or creates a microscopic vent from its surface which, is increased by heating cycles or flexion, the tensile stress area is compromised and collapse of the panel is inevitable.

5.0 Where does NiS come from?

NiS finds its way into float glass during manufacture. Sulphur derived compounds are unavoidable, but nickel can be reduced with careful control. Nickel can be introduced from the raw materials, fuels, various parts of the melting tank and the steel components of equipment in the melting tank. Glass manufacturers have taken action to reduce nickel contamination, over the 50 years or so, since NiS was demonstrated to be a cause of Spontaneous Breakage. The occurrence of NiS in float glass is now vastly lower than it was in the 1960's.

To date, due to the size of critical NiS inclusions in float glass, there is no commercial method of detecting these impurities at a float glass plant.

6.0 How can Spontaneous Breakage be avoided?

From the earlier section on Background, it is obvious that the Glass Industry has been working on this subject for over 50 years.

What practices are available to reduce or eliminate Spontaneous Breakage?

1. Avoid the use of Fully Tempered glass
2. Use Heat Strengthened glass
3. Heat Soak your Toughened glass

7.0 What is Heat Soaking?

- After toughening the glass is batched and stacked in a static oven. The temperature is gradually increased and then held at a high enough level to induce accelerated conditioning (250 - 260°C), but not so high as to affect the desired stress regime in the glass. Specifications may call for 8hr, 4hr or 2hr holding times. European Standard EN 14179 (2016) dictates 2hrs.
- The required conditioning is for three purposes:
- To increase the growth of any microscopic vents from the glass edge or surface sufficient to create a compromise of the tensile mid-plate and cause a subsequent glass breakage.
- To increase the growth of any microscopic vents around the surface of a microscopic foreign body within the glass and thereby cause a Spontaneous Breakage.
- To increase the growth rate of any Nickel Sulphide inclusions setting up a chain reaction, including the opening of microscopic vents surrounding the inclusion that may also cause a subsequent breakage.

Heat Soak Statistics

- Heat Soaking is expected to eliminate 98% of those tempered glass panels from production that may have otherwise sustained a Spontaneous Breakage
- 80% of Spontaneous Breakage in installed Toughened glass is found to be caused by NiS inclusions
- Heat soak testing statistically, and according to EN 14179, should provide for no more than one breakage, due to critical NiS inclusions in 400 tonnes of thermally Heat treated soda lime silicate safety glass

8.0 What is Heat Strengthening?

Heat Strengthening glass is undertaken in the same furnace as for Toughening the glass.

The difference is that the quench process is less rigorous. Blower pressures are reduced and the cycle time inside the quench area is increased. This creates less surface compressive and opposing mid-plate tensile stress in the glass. The fracture characteristics of the glass are ultimately more like annealed float glass.

Fracture characteristics for Heat Strengthened glass are examined in European Standard EN 1863 and surface compression regimes are specified under the USA standard ASTM C-1048.

9.0 Conclusion

Methods of avoiding Spontaneous Breakage in Toughened glass have been developed over many years. Although the Heat Soak discipline has been modified since first introduction in the early ’90s, the principle is the same. Heat Strengthening the glass has changed little since first implementation in the ’70s. By far, the best way to avoid Spontaneous Breakage is to avoid using Fully Tempered/Toughened glass wherever possible.

10.0 Recommendations

Spontaneous Breakage in Toughened architectural safety glass, its' causes and the methods of reducing and/or eliminating the phenomenon have been thoroughly documented over the years.

It is recommended that use of Tempered glass is carefully risk assessed at the time of design.

Questions to be asked are:

- Does the glass need to be Fully Tempered?
- Can the design be reconfigured to eliminate the need for Fully Tempered glass? i.e. cancel point fixing the glass, reduce sizes and therefore reduce impact of wind loads, etc..
- Will laminated safety glass work in the place of Fully Tempered safety glass?
- Does access to the glass, post breakage, present practical difficulties to the client post handover?
- Will Heat Soaking adversely affect the construction period?
- What is the increased cost to the project for Heat Soaking?
- What is the environmental impact of the additional energy required for Heat Soaking?

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