Poster 10

A Review of the Nickel Sulphide Induced Fracture in Tempered Glass

Dr. Leon Jacob
Jacob & Associates Pty Ltd

Keywords

Abstract

A brief review of the magnitude of the nickel sulphide problem is discussed. The need for heat soaking of all tempered glass is questioned given that the total volume of NiS inclusions in glass is extremely low and so not warranted given the cost.

A new technique for the prediction of the fracture rate of NiS induced failures is offered for discussion.

Introduction

Even though Mr. Ballantyne [1] was the first to bring the nickel sulphide (NiS) phenomenon to the world in his outstanding 1961 report on "Fracture of toughened glass wall cladding", the glass industry was well aware of the problem a lot earlier. For instance PPG industries (a major US glass manufacturer) was aware of the problem, as early as the late 1940's.

In recent years significant research has been undertaken in an attempt to develop a cost-effective method of heat soaking tempered glass [2,3]. The limitation of this technique is that it addresses only the transformation of the NiS inclusion from its a to b phases. Furthermore, not all NiS inclusions will be transformed and thus eliminate the problem of spontaneous fracture in tempered glass.

An attempt to predict the failure rate of NiS contaminated tempered glass panels is investigated and proposed.

Problem Definition

The presence of nickel sulphide is adventitious in most glass. It has been estimated that in normal float glass production NiS inclusions occur at a frequency of about one per 8 tonnes of raw glass [4].

It has been estimated that 1 gram of nickel sulphide can produce approximately 1000 inclusions of 0.15 mm diameter. Consequently, it does not require too much contamination to produce a serious problem.

NiS induced fracture in tempered glass has generally been found to be restricted to a batch of glass rather than all tempered glass. Numerous large high rise glass facades around the world have experienced NiS induced fracture. Yet in comparison there are literally thousands of high rise glass facades that have not reported any fracture of tempered glass. A recent survey in Sydney showed that out of the 45 high rise buildings glazed with tempered glass only 1 had a NiS induced fracture problem.

A local toughening plant monitored its production over a 5 year period. All the reported NiS induced failures were recorded and it was found that they had a total of 1 NiS induced failure for every 450 tonnes of tempered glass produced. None of the tempered glass was heat soaked. It could be stated that this manufacturer was fortunate not to have suffered a bad batch of glass. It is also generally considered that the NiS problem occurs in batches of glass. It appears that the problem is limited to glass in a few buildings rather than all tempered glass.

A review of 8 proven NiS problem buildings in Australia with a total of 17,760 panels of tempered glass showed that there have been only 306 reported NiS induced panel failures over a 12 year period. This equates to a failure rate of 1.73 %.

The failure pattern is unique to each building. Some batches of NiS contaminated tempered glass experience glass breakage from the installation stage of the façade while others have an incubation period before failure commences. Furthermore, failures have been known to occur up to 20 years after manufacture.

Studies as to the factors that induce

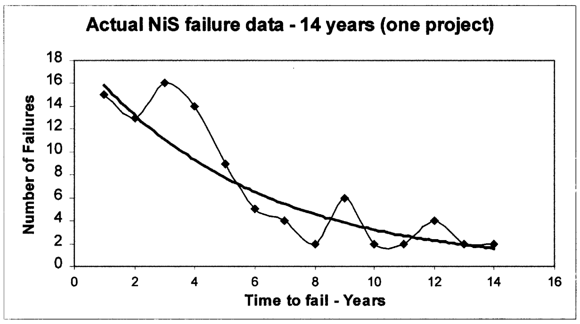
spontaneous fracture do not show any positive correlation between:

- The size of the inclusion and time to fracture.
- The location of the inclusion within the body of the glass and time to fracture
- The purity of the inclusion and time to fracture

The only positive relationship is that with time there is a tendency for the rate and number of failures to decrease.

Nickel Sulphide inclusions often contain other metals such as iron, copper and cobalt. These impurities generally influence the fracture behaviour of the NiS inclusion. Recent studies have also shown that there is a relationship between the amount of iron (Fe) in the inclusion and the time to fracture.

Figure 1 below shows a decline in the failure rate from NiS inclusions in 1 major building monitored.



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Fracture Mechanism

Jacob [5] identified various factors that influence the fracture rate of tempered glass with NiS inclusions. The time to fracture is dependent on numerous factors such as:

- Purity of the inclusion
- Location of the inclusion within the tensile zone of the tempered glass
- Magnitude of the tensile stress within the body of the glass
- Size of vent associated with the inclusion
- Environmental conditions – temperature and lateral wind pressure
- Panel size – membrane stress developed in the window

Analysis of the fracture surfaces obtained from the failure of a tempered glass panel clearly show the relationship between the mirror radius and the stress at fracture is as shown in equation 1.

$$\sigma_f = K_{Ic} / \{c\ .\pi\}^{1/2}$$

Equation 1

Using this fundamental equation for NiS induced fracture in tempered glass it can be seen that spontaneous fracture will occur when the vent associated with the inclusion approaches about 4.5 mm in depth. This has been observed after measuring numerous fracture origins.

Stress and Stress Intensities

Swain [6] estimated the hydrostatic stress at the inclusion glass interface to be 835 MPa for a completely pure and totally transformed inclusion. This stress can nucleate crack growth when the float glass is initially cooled in the annealing chamber. It is these vents that ultimately cause the spontaneous fracture in tempered glass.

However, this stress decreases dramatically as the distance from the surface of the inclusion is increased. Contamination in the inclusion will also reduce this hydrostatic pressure and so requiring additional stress to effect crack growth and ultimate fracture.

The in – built tensile stress of tempered glass adds to the stress at the crack tip. A tempered glass with a residual surface compression of say 110 MPa will have a balancing tensile stress equal to 55 MPa. Finally, the membrane stresses developed within the panel as a consequence of externally induced lateral loads will assist in crack growth.

It is possible that flaws emanating from a NiS inclusion are a product of a slow crack growth. One explanation is that, on cooling through the 379^0 C NiS phase - transition temperature, a part of the NiS in the inclusion transforms and nucleates a flaw at the glass - inclusion interface. This flaw will grow under the action of:

- the tempering stress - tensile
- stresses developed from temperature variation – the differences in the coefficient of expansion between glass and the inclusion
- the environmental induced stresses such as membrane stresses – wind induced.

This gradual crack growth can take several years and is dependant on the various factors discussed earlier.

Elimination of NiS inclusions

The heat soaking process is one method of reducing the incidence of NiS induced failure in tempered glass by causing the phase change to occur before the glass panel is installed in the building. Numerous heat soak criteria have been developed with different levels of success. In any event the heat soaking process is not 100 % effective and failures have known to occur with heat soaked tempered glass.

An alternative to heat soaking is to eliminate the formation of NiS in the raw glass manufacturing process. Brungs [4] suggested a method by controlling the glass oxidation state in the batch.

Nickel Sulphide failure rate – Prediction

The failure rate of NiS inclusions in installed tempered glass panels is difficult to predict because of the numerous variables that influence its behaviour. Data from a major building collected over a period of 12 years has been used to develop a predictive technique. Figure 2 shows a Weibull distribution of the fracture data as a function of time. There appears to be good fit between the raw data and the prediction curve.

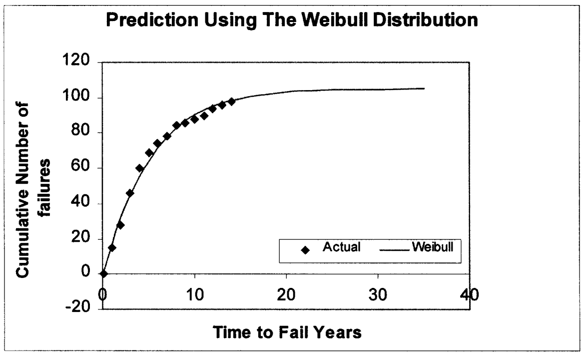

Figure 2. Weibull distribution used to predict future NiS induced failure in tempered glass. It could be predicted that a further 6 to 7 failures could occur over the next 25 years.

Limitation of this predictive technique can be listed as follows:

- Adequate fracture data – number of failures and time – a few years of data
- The curve fitting is a function of the estimate as to the number of anticipated future failures
- The total number of tempered glass panels in the batch is not included in the prediction technique

This method has been verified on numerous other projects with NiS induced failure.

Conclusion

NiS inclusions have historically manifests itself in batches of tempered glass. Not all tempered glass has NiS inclusions. The quantity of glass with NiS induced failure is only a very small fraction of the total volume of tempered glass manufactured and used.

The quantification of the risk associated with NiS induced failure in tempered glass is difficult given the added cost of heat soaking and the relatively small proportion of NiS inclusions found in tempered glass.

Total failure rates of 1.73 % should not be considered catastrophic. Yet the elimination of this type of failure is essential. Tempered glass when used in overhead applications poses a significantly different risk from failure. Heat soaking would be essential for such applications.

Finally the need for heat soaking of all tempered glass is not warranted. It ought to be used selectively dependant on the application and the perceived risk associated with NiS induced spontaneous fracture of tempered glass.

References

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