

# Glass Breakage Analysis: The Impact of Nickel Sulfide Inclusions in Building Glazing

## Part Two: Manufacturing, Prevention, and Case Studies

By Misael Rojas, RRO, AIA, NCARB

**BUILDING UPON THE** foundational concepts established in Part One<sup>1</sup>—which examined the material science, formation mechanisms, and fracture behavior of nickel sulfide (NiS) inclusions—this article advances the discussion toward the systemic, industrywide challenges associated with preventing, detecting, and mitigating these defects within architectural glazing. While the sections in Part One detailed how the phase transformation of NiS inclusions precipitates spontaneous breakage in thermally toughened glass, this part shifts focus to the upstream manufacturing variables, quality assurance constraints, and post-installation evaluation methods that shape the practical management of NiS-related risk. By exploring the technological limitations of current detection techniques, the absence of universal standards governing inclusion thresholds, and the implications of case-study failures in real-world facade systems, this segment provides a comprehensive framework for understanding how NiS contamination persists across the glass supply chain—and what strategies are emerging to address it.

### **ADVANCING DETECTION TECHNIQUES AND ESTABLISHING INDUSTRY BENCHMARKS FOR NiS INCLUSION PREVENTION**

While quality control efforts are primarily directed toward preventing inclusions during the production phase, a growing need exists for the development of post-installation detection technologies to assess NiS-related risks in extant structures. Furthermore, the establishment of comprehensive industry benchmarks for acceptable inclusion rates and effective failure mitigation strategies is anticipated to enhance overall quality assurance and clarify liability standards.

### **POST-INSTALLATION DETECTION TECHNIQUES: EVALUATING PRACTICAL SOLUTIONS**

The capability to detect NiS inclusions in fully installed glass represents a significant advancement in preventative maintenance and risk assessment for high-rise buildings. While these nondestructive testing methods—comprising ultrasound imaging, laser scanning, and refined photometric analysis—offer efficacious means to identify potential defects, they are not devoid of challenges. Each approach has limitations concerning accuracy, environmental sensitivity, and implementation feasibility, thereby necessitating meticulous consideration prior to widespread adoption. Industry professionals continue to evaluate their practicality, with the objective of refining detection techniques and integrating them into comprehensive glass assessment protocols. A review of the advantages and disadvantages of each of these NiS analysis methods for in-place construction is presented below.

#### **Ultrasound Imaging**

Ultrasound imaging sends high-frequency acoustic waves through glass and analyzes reflections from discontinuities to infer internal defects. While it can penetrate the full thickness and detect larger flaws (for example, voids or delaminations), typical NiS inclusions are near or below practical resolution limits, yielding weak, indistinct signals.

*Interface* articles may cite trade, brand, or product names to specify or describe adequately materials, experimental procedures, and/or equipment. In no case does such identification imply recommendation or endorsement by the International Institute of Building Enclosure Consultants (IIBEC).

Pros of ultrasound imaging include the following:

- Provides depth analysis, facilitating the identification of inclusions embedded within glass layers.
- Proves effective for internal structural assessments without necessitating glass removal.
- Offers a noninvasive approach applicable to dense materials.

Cons of ultrasound imaging include the following:

- Exhibits limited resolution for microscopic inclusions, rendering detection unreliable for submillimeter defects.
- Laminated glass interlayers may interfere with ultrasound wave penetration, potentially compromising data integrity.
- Requires specialized operators and equipment, consequently increasing both cost and logistical complexity.
- The application of this technique across an entire building to identify near-microscopic particles may render the exercise impractical.

### **Laser Scanning**

Laser scanning for NiS inclusion detection is a nondestructive optical technique that projects a controlled laser beam across the glass surface to identify microstructural irregularities that may correspond to embedded defects. As the laser interacts with the glass, variations in reflection, refraction, or surface scatter can reveal localized distortions associated with inclusions or stress concentrations.

Pros of laser scanning include the following:

- Characterized by speed, efficiency, and the capacity to scan large glass surfaces within a brief time frame.
- Demonstrates high sensitivity to microstructural irregularities that may correlate with NiS inclusions.
- Proves effective in surveying expansive glass facades.

Cons of laser scanning include the following:

- Possesses limited penetration depth, making deeply embedded inclusions more challenging to detect.
- Inconsistencies in reflection and refraction stemming from coatings and ambient environmental lighting may distort readings.
- Necessitates precise calibration and reference data for accurate defect identification.
- The application of this technique across an entire building to identify near-microscopic particles may render the exercise impractical.

### **Refined Photometric Analysis**

Refined photometric analysis is a nondestructive optical technique that utilizes light scattering and total internal reflection (TIR) to detect the NiS inclusions. A coupled light source propagates through the glass via TIR, and when it encounters an NiS inclusion, the light scatters. A sensor captures these scattered photons, allowing for the precise in-place localization of the inclusion without destructive testing.

Pros of refined photometric analysis include the following:

- Represents a passive, nondestructive approach employing light-based detection principles.
- Offers the potential for integration into building maintenance systems for long-term monitoring.
- Proves valuable for identifying stress points and fracture precursors associated with inclusions.

Cons of refined photometric analysis include the following:

- Incapable of directly detecting NiS inclusions; instead, it relies on inferred stress pattern analysis.
- Subject to environmental variables, such as ambient light conditions, which can impact detection accuracy.
- Requires sophisticated computational data interpretation to differentiate genuine inclusions from normal optical distortions.

Considering the unique strengths and limitations inherent in each technique, a synergistic approach may yield optimal results. For instance, laser scanning can efficiently identify surface and near-surface irregularities, while refined photometric analysis can monitor stress patterns over time to predict potential failure risks. The overarching challenge lies in adapting these technologies for practical, cost-effective implementation across large-scale building projects. The feasibility of such extensive investigative efforts must be thoroughly vetted, as the sheer scale of the search may indeed present a considerable challenge.

### **ESTABLISHING INDUSTRY BENCHMARKS FOR NiS INCLUSION PREVENTION**

Despite several decades of research into spontaneous glass breakage, the glass industry currently lacks universally accepted benchmarks for NiS inclusion prevention and detection. Collaborative efforts among manufacturers, forensic engineers, building-science-based architects, and regulatory bodies possess the

potential to enhance transparency, standardize quality control measures, and minimize liability risks through the following initiatives.

### **Defining Acceptable NiS Inclusion Rates**

- Establish quantifiable thresholds for allowable inclusion size and frequency in tempered glass production.
- Develop robust statistical models for risk assessment predicated upon inclusion concentration per unit of glass tonnage. This may involve advanced technology like artificial intelligence (AI).

### **Mandating Advanced Testing Protocols**

- Implement universal heat soak testing (HST) standards to eliminate defective glass prior to installation wherever feasible and integrate these requirements into project specifications at the early stages of the design process. HST is a destructive post-production treatment that effectively accelerates the phase change of critical NiS inclusions, thereby inducing their breakage in a controlled environment. Due to the nature of cost implications for projects, these standards should be properly vetted through all stakeholders of the project from the incipient stage.
- Require manufacturers to conduct enhanced screening processes specifically targeting NiS contamination. While it is mentioned in this article that some manufacturers are employing these stringent strategies, it is not mandated.
- Propose fabrication visitation as an integral component of the quality assurance and quality control (QA/QC) process and submittal review. This is another cost implication for most projects and should be discussed as early as possible within the design or implementation phases.

### **Developing Predictive Failure Models**

- Utilize advanced computational simulations to forecast spontaneous breakage probabilities.
- Introduce AI-driven defect tracking systems for large-scale glazing installations.
- Integrate this methodology into building information modeling software and coordinate effectively with fabricators.

### **Encouraging Proactive Inspection Requirements**

- Establish systematic inspection and monitoring protocols for high-risk installations.

- Integrate automated stress analysis technology into contemporary glazing maintenance strategies.

### Clarifying Manufacturer Liability and Warranty Standards

- Strengthen existing legal frameworks that delineate manufacturer responsibility for spontaneous glass breakage. This is a circular standard that will likely lead to manufacturers pushing more stringent in-house QA/QC efforts at their facilities.
- Standardize contractual obligations pertaining to the replacement or financial compensation for defective glass.

## CASE STUDIES AND LESSONS LEARNED

### HISTORICAL AND RECENT INCIDENTS

The issue of spontaneous glass breakage attributable to NiS inclusions possesses a substantial historical trajectory, with incidents documented globally. One of the earliest and most prominent cases transpired in the 1960s at ICI House (presently Orica House—see **Fig. 1**) in Melbourne, Australia,<sup>2</sup> which was the nation's inaugural skyscraper, where 71 glass panels spontaneously shattered. This event catalyzed pioneering research by Ron Ballantyne in 1961, which was one of the first research projects of its type to formally describe the NiS breakage mechanism. This discovery led to the development of HST, thereby bringing the NiS phenomenon to international prominence. Decades later, similar dramatic failures have persisted, as evidenced by incidents at Waterloo Station in London, with its iconic glass-and-steel roof, completed in 1994. In 1999, it became apparent that numerous glass panels in the roof were spontaneously shattering and, in some cases, falling onto the platforms below.<sup>3</sup> The investigations into the failures found that the breakage was indeed caused by NiS inclusions.

More recent occurrences underscore the ongoing nature of this challenge. For example, International House, situated near Tower Bridge in London, encountered significant issues with its glass facade due to a batch of glass affected by NiS inclusions. In Sydney, Australia, a high-rise apartment building experienced multiple glass pane explosions between 2010 and 2012, with broken glass descending numerous stories, fortunately without causing injury. These incidents collectively highlight that NiS-induced breakage represents a global concern, not confined to specific import origins or “inexpensive” glass, as all flat glass produced



**Figure 1.** View of ICI House when constructed in 1958. Photo courtesy of [pursuit.unimelb.edu](http://pursuit.unimelb.edu).

via the float process inherently carries this potential risk.

### NASHVILLE INCIDENT: INVESTIGATION AND FINDINGS

An analysis of spontaneous glass breakage within a Nashville, Tennessee, mixed-use property was executed through a comprehensive, multi-stage process (**Fig. 2**). This investigation was commissioned by the client to scrutinize a series of glass breakage incidents that transpired over a 15-month period in an office building component. By reviewing project documentation, conducting on-site examinations, and correlating data with independent laboratory analyses, the investigation sought to ascertain the root cause of these failures.

#### Investigation Approach

- Site inspections: Visual examinations were systematically conducted on both exterior and interior elements across various levels of the building. This process included detailed photographic documentation to capture the physical manifestations of breakage.
- Document review: The investigation encompassed a thorough review of pertinent project documents, including specifications, installation instructions, prior inspection reports, and manufacturer warranty information.
- Technical testing correlation: An independent laboratory report, which employed scanning electron microscopy with energy-dispersive X-ray spectroscopy analysis, definitively



**Figure 2.** Curtainwall on eastern exposure.

confirmed the presence of NiS inclusions in the submitted glass samples.

- Environmental documentation: Conditions prevailing at the time of each breakage event (including temperature, humidity, and ambient lighting) were meticulously recorded to develop a comprehensive contextual understanding of the failure occurrences.

#### Key Observations and Analysis

- Multiple locations of breakage: The investigation identified numerous glass breakage incidents distributed across several floors and on all four exposures within the office component of the multi-use building. Each occurrence consistently presented similar failure patterns, most notably the characteristic “butterfly” fracture originating from within the panel.
- Glass specifications and defects: The affected facades are composed of unitized curtainwall systems incorporating laminated insulated glass units (IGUs). These IGUs are formed by dual layers of float glass bonded with a polyvinyl butyral interlayer and feature a low-emissivity coating applied to the second surface from the exterior of the glass assembly. Observations further revealed the presence of mild to moderate optical distortions along the facade, in addition to the discrete breakages.
- Crack patterns indicative of internal stress: The crack patterns observed consistently displayed “butterfly” or web-like features, conspicuously lacking any signs of physical impact or handling damage (**Fig. 3**). In several instances, minute particles were identified at the origin of the fracture pattern, strongly suggesting a defect-triggered mechanism rather than external trauma.
- One instance of edge-related damage was observed on a glass unit that was removed from the building and stored for analysis.



**Figure 3.** Close-up view of butterfly pattern of origin point within cracked glass.

- Glass type utilized: Multiple types of glass were employed in this project, with both tempered and heat-strengthened (HS) glass integrated into the assembly. It is noteworthy that HS glass exhibits a significantly lower failure rate attributable to inclusions.
- Historical information: The property owner disclosed that the design team did not mandate HST. This omission was attributed to value engineering decisions made during the design process, wherein the scope for such testing was removed for cost-saving considerations.

### Cause of Failure (Laboratory Findings and Material Considerations)

The collective evidence for the Nashville project indicated that NiS inclusions constituted the primary cause of the observed spontaneous glass breakage. NiS particles, typically ranging from 0.002 in. to 0.004 in. (0.05 mm to 0.10 mm) in size, are inadvertently incorporated during glass manufacture. Under conditions of thermal fluctuation, these inclusions undergo expansion when the glass experiences significant temperature changes. Due to the constrained flexibility of the glass core, the expanding NiS inclusion generates sufficient internal stress to initiate cracking from within, thereby producing the distinctive “butterfly” fracture pattern.

The report provided by the glass testing laboratory confirmed NiS inclusion as the cause of the breakage. It was pertinent to point out to the client that NiS inclusion-based breakage occurring in HS glass is exceedingly rare, if indeed possible. This observation supports the inference that the installed glass was not HS but rather tempered glass, which was subjected to higher thermal stress than HS glass and facilitates the NiS phase transformation, leading to particle size increase and subsequent cracking of the glass from within.

### Industry Context and Other Notable Factors from the Case Study

While the occurrence of NiS-induced breakage at the time of the investigation was statistically rare, the consequences in terms of safety and maintenance remained substantial to the owner as well as the occupants of the building. Cost implications also represented a major concern for spontaneous breakage in the buildings for the remainder of the complex that were not only occupied but also featured multiple systems integrated into their exterior cladding, such as mechanical vents, steel accessories, or other adjacent construction elements.

It was explicitly explained to the client and owners of the complex that estimating the potential breakage of NiS inclusions is a probabilistic calculation and is not intended to serve as an accurate prediction of future glass breakage on any given building. Although frequencies of breakage on projects globally may fall within a similar range, the industry has yet to establish an agreed-upon average against which breakage can be precisely quantified. Furthermore, not all breakages can be quantified with ease, given that these events often result in a multitude of shattered glass pieces, rendering cause analysis challenging.

### Conclusion: Investigation (Specific to Nashville Case Study)

The investigation into the spontaneous glass breakage in Nashville underscored the complex nature of glass performance within modern architectural systems. Evidence derived from on-site inspections and laboratory analysis strongly supported NiS inclusions in the tempered glass as the root cause of these failures within this particular glass facade. In the case of the Nashville project, the removal of HST played a crucial part in the presence of the NiS throughout the exposures of the building. The time elapsed between each of the breakage occurrences indicated that the phase changes were not just attributable to the thermal differences, as the south, west, and north facades all experienced breakage at varied times.

Given the unpredictable nature of NiS inclusion breakage, the following proactive steps were recommended to the Nashville development team and client:

- Immediate stabilization: Secure any compromised glass units using heavy-duty film or reinforced tape to mitigate public hazard until a permanent fix is applied.
- Detailed documentation: Record the exact date, time, and ambient conditions (both interior and exterior) at the time of each

breakage to better understand potential triggering factors.

- Glass replacement strategy: (1) Promptly remove and replace affected units. (2) Preserve broken samples for ongoing technical analysis to further validate the root cause.
- Manufacturer engagement: (1) Notify the glass manufacturer regarding the confirmed defect and discuss potential revisions in their production process to reduce the risk of NiS inclusions. (2) Where possible, consider additional HST or enhanced screening methods before installation.
- Long-term monitoring and maintenance: (1) Implement a regular inspection regime that includes detailed documentation of environmental conditions to track any subsequent occurrences. (2) Adopt updated industry best practices to minimize the likelihood of future incidents.

Furthermore, breakage also occurred on the ground-floor atrium glass, which is largely shaded by the adjacent buildings, reducing the possibility of causality to a primarily solar-exposed condition. In general, although such breakages are statistically rare when compared to the sheer number of glass-clad buildings, the impact of glass breakage on safety and property maintenance unequivocally warrants proactive intervention. By incorporating immediate stabilization measures, the suggestions of maintaining thorough documentation, engaging manufacturers, and planning for long-term monitoring offer the stakeholders of the development the ability to effectively manage risks and uphold building safety standards. HST should be given due consideration by project teams at the early stages of the design process. While ensuring proper fabrication and minimizing the risk of spontaneous breakage can entail significant expense, early awareness of these potential risks enables owners and clients to plan accordingly. By addressing these costs up front, they can be integrated into the overall project budget or offset through strategic adjustments in other areas, thereby ensuring a more judicious allocation of resources.

### IMPLICATIONS FOR BUILDING OWNERS AND DESIGNERS

The unpredictable and delayed nature of NiS-induced spontaneous breakage presents significant implications for building owners and designers. For building owners, these failures can lead to substantial liabilities, pose safety concerns for occupants and the public, negatively impact asset value, and potentially damage

reputation. The risk is particularly acute in overhead glazing and public areas where falling glass fragments, even small ones from tempered glass, can cause serious injury.

A critical lesson derived from these incidents is the imperative for proactive risk management, rather than merely reactive replacement of broken panes. Designers and specifiers must acknowledge that while NiS inclusions are rare, their unpredictable manifestation and potential for high-impact consequences in critical applications necessitate stringent mitigation strategies. This includes a careful selection of glass types and treatments based on the specific application and perceived risk.

For instance, while heat soaking significantly reduces the risk of in-service breakage, it does not guarantee 100% elimination of the issue. Therefore, for applications where glass fallout is a severe concern (for example, high-rise facades, overhead canopies), specifying laminated glass, often in conjunction with heat soaking, is a prudent measure. Laminated glass ensures that even if an NiS-induced fracture occurs, the fragments are retained by the interlayer, thereby preventing their descent. Additionally, for existing installations of tempered glass, the application of security films with anchoring systems can provide a post-breakage retention solution, holding shattered glass in place.

Beyond material specifications, proper installation practices are also critical. Edge damage during handling or installation, or improper framing that introduces excessive stress, can also lead to spontaneous breakage—sometimes erroneously attributed to NiS. Therefore, comprehensive quality control throughout the entire project life cycle, from glass manufacturing and processing to installation and maintenance, is essential to minimize all forms of spontaneous glass failure.

## CONCLUSION


NiS inclusions persist as a complex and enduring challenge within the field of architectural glass, particularly for toughened window and curtainwall applications. The phenomenon is rooted in a subtle material science characteristic: the protracted, delayed volumetric expansion of the NiS inclusion as it undergoes a phase transformation, a process that is “frozen” during the rapid cooling phase of glass tempering. This inherent, unpredictable “delay-action bomb” mechanism possesses the capacity to precipitate spontaneous glass breakage years subsequent to installation, notwithstanding that the initial impurities

are microscopic and virtually undetectable in intact glass.

While statistically rare, the potential for high-impact consequences—especially in high-rise facades and overhead glazing, where falling glass poses a significant public safety risk—mandates robust prevention and mitigation strategies. The industry’s primary response has been the widespread adoption of HST. Nevertheless, HST is not a panacea; its efficacy is not 100%, and it contributes to both project cost and lead time.

For enhanced safety, particularly in critical applications, laminated glass offers a vital layer of protection by retaining glass fragments after breakage, even in the event of an NiS-induced fracture. HS glass, while not susceptible to NiS-induced breakage due to its more gradual cooling process, is frequently laminated to fulfill safety glazing requirements.

The persistent nature of NiS inclusions underscores the formidable challenge of achieving complete elimination at the manufacturing source, given the extreme sensitivity of the float glass process to minute contaminants. This reality drives ongoing research into advanced nondestructive detection methods and the development of novel glass compositions, such as borosilicate glass, that inherently prevent NiS formation.

Ultimately, the comprehensive management of risks associated with NiS inclusions necessitates a multifaceted approach. This encompasses informed design decisions, rigorous specification of heat-soaked and/or laminated glass for high-risk applications, adherence to evolving international standards (for example, EN 14179-1, *Glass in Building—Heat Soaked Thermally Toughened Soda Lime Silicate Safety Glass*),<sup>4</sup> and meticulous quality control throughout the entire supply chain and installation process. By fostering a thorough understanding of the fundamental science of NiS and its architectural implications, the industry can continue to enhance the safety and reliability of modern glass structures. 

*This article is intended as both a detailed technical analysis of glass breakage phenomena and a guide for improving quality assurance in glazing installations based on information available at the time of its creation. For inquiries regarding this analysis, further discussion on advancing testing methodologies, or additional technical insights, please contact the author at [mrojas0377@gmail.com](mailto:mrojas0377@gmail.com).*

## REFERENCES

1. Rojas, Misael. 2026. “Glass Breakage Analysis: The Impact of Nickel Sulfide

Inclusions in Building Glazing. Part One: Understanding and Identifying NiS.” *IIBEC Interface* XLIV (3): 10–18.

2. Marfella, Giorgio. 2017. “When Building Glass Breaks Dangerously It Is a Design Problem.” University of Melbourne. <https://pursuit.unimelb.edu.au/articles/when-building-glass-breaks-dangerously-it-is-a-design-problem>.
3. Harper, Keith. 1999. “Eurostar Firm Demands Millions.” *The Guardian*. <https://www.theguardian.com/business/1999/dec/11/5>.
4. European Committee for Standardization (CEN). 2016. *Glass in Building—Heat Soaked Thermally Toughened Soda Lime Silicate Safety Glass*. EN 14179-1. Brussels Belgium: CEN.

## ABOUT THE AUTHOR



MISAEAL ROJAS, RRO,  
AIA, NCARB

**Misael Rojas** is a senior forensic architect with over 23 years of experience in architectural design, forensic investigations, construction, and building enclosure systems. As a leader in the industry, he has contributed to the construction, investigation,

and design of many buildings throughout the United States, as well as large-scale international projects. His deep expertise in building enclosures allows him to collaborate effectively with architects, clients, and contractors, ensuring well-integrated solutions from design through construction and into complex investigations. Currently, he serves as a managing architect at Exponent and as an executive director on the board of IIBEC’s Metro New York Chapter. Licensed in multiple states, Misael operates nationally as a leading forensic architect while residing in northern New Jersey.

Please address reader comments to [chamaker@iibec.org](mailto:chamaker@iibec.org), including “Letter to Editor” in the subject line, or IIBEC, *IIBEC Interface* Journal, 434 Fayetteville St., Suite 2400, Raleigh, NC 27601

