Volume 33, Number 4, April 1998
1998 Archives Series
A Page from the USGlass Archives

Temper Temper

Managing the Problems Inherent in Tempered Glass

by Regina R. Johnson

The waves were the first thing the architect noticed when the shipment of 500 lites of tinted tempered glass was installed in a curtainwall project. A heavy roll-wave distortion was apparent on the glass, and what was worse, glass delivered on the same truck had distortion in each direction. The architect rejected the shipment.

"That creates a checkerboard pattern (on a building) that sticks out like a sore thumb," explained the job's glazing contractor, who wished to remain anonymous. Evidently, the fabricator that had provided the glass order requires customers to specifically request that the distortion be in the same direction, and charges a premium for the service.

"I got stuck holding the bag and it cost me another $15,000, including labor, to replace several thousand square feet of glass," the midwest contractor said. "My biggest irritation is the lack of industry standards that allowed this to happen."

In another scenario, *Washington Post* food critic Phyllis Richman rushed to investigate the sound of crashing glass in her home to find that the tempered glass door of her oven had shattered into small glass particles without number on her kitchen floor. When she could not get it replaced for free, she wrote an irate article describing her experience for the *Washington Post*. The decade-old oven had not been used in weeks and had not been subjected to temperature or shock trauma of any kind. Conditions of the incident suggest a tempering stress or point defect as the cause, but more than a year later, Richman has no conclusive explanation. "I don't really have any idea," she said.

The same process that strengthens tempered glass also creates some inherent problems. Through the tempering process, a system of residual stresses is introduced to convert normal flat glass to safety glass when the stress level is high enough. Glass is tempered by heating sized, edged glass in a tempering furnace to approximately 1,200 degrees Fahrenheit, then rapidly cooling, or quenching, the glass to approximately 400 to 600 degrees Fahrenheit. In quenching, air jets quickly cool and set the surfaces, leaving the inner portion of the glass thickness relatively hot and cooling at a slower rate. The surfaces become rigid, but the center is still pliable and contracting as it cools, thus compressing the surface. Compressive residual stresses imposed on the glass surface,

The same process that strengthens tempered glass also creates some inherent problems. Here, shattered glass is held in place with the glassLock window film system from Western Glass Restraint Systems of San Jose, CA.

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>
> —John Colapietro
> Tempglass, Inc.

which close up any cracks, are balanced by residual tensile stress in the center of the glass.

These stresses make tempered glass approximately four times stronger than annealed glass, making it ideal for applications where maximum resistance to thermal and cyclic wind loading pressures is required. In addition, if broken, fully tempered glass breaks into relatively safe, small pieces, rather than shards.

However, distortion and point inclusions, touched on in the incidents above, are a natural part of the tempering process. Potential problems with these phenomena raise important questions for professionals industry-wide, whether directly involved in the manufacturing or tempering process or dealing with products that use tempered glass.

Dealing With Distortion

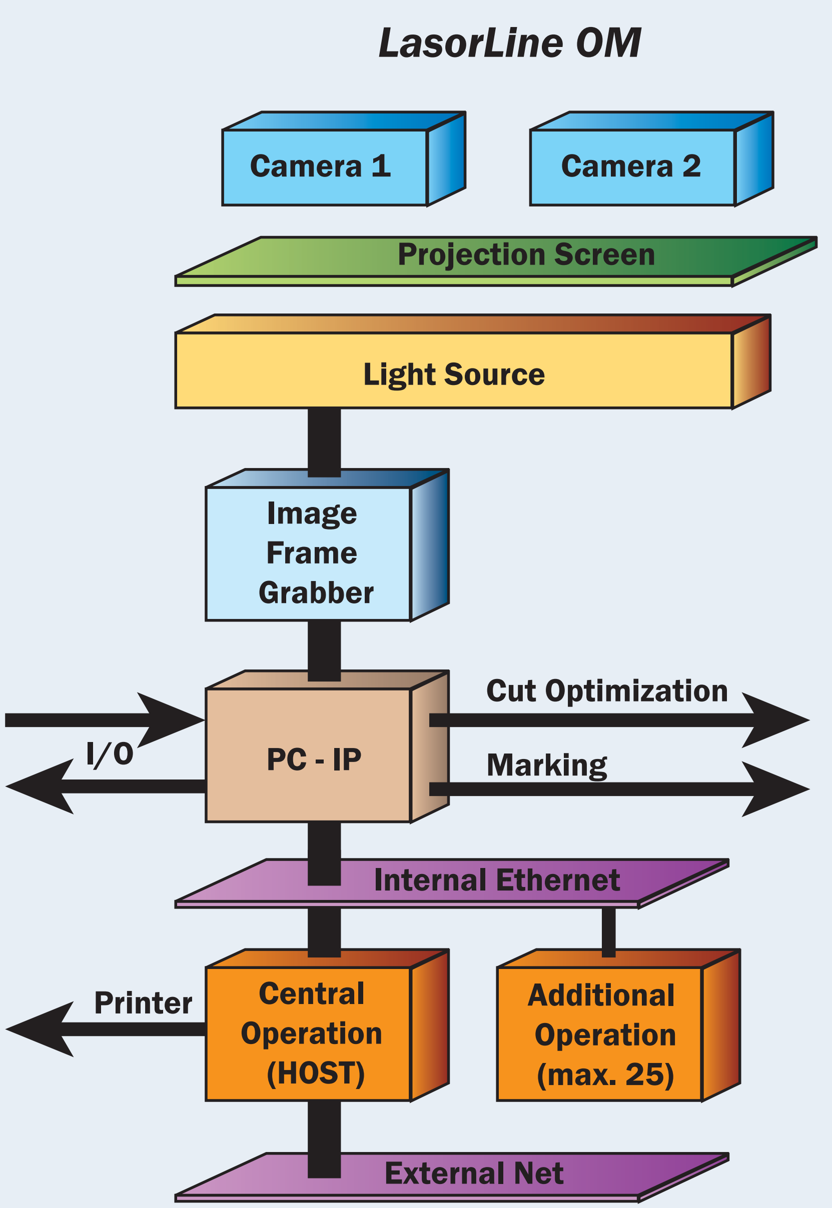
By its very nature of heating sheet glass to a level of soft pliability, the tempering process always causes distortion to some degree. Its severity is largely a function of the furnace and tempering conditions. Though usually imperceptible to the consumer, optical distortion can be unacceptable for architectural applications, especially those with tinted or coated products. Distortion is also a critical problem when glass is to be treated (e.g., with lamination) after tempering. Therefore, optimization of the tempering process to minimize distortion represents a constant challenge for manufacturers.

In tempering, glass is heated by radiation, convection or a combination of both. Through this heating, glass enters a transition range, during which typical transition problems such as roll-wave distortion or bow and warp can occur.

“During the heating, glass will sag very slightly between the carrier rolls (in a roller hearth or gas hearth furnace), or from the tongs in a vertical furnace,” explained Harry Miles, industry expert and consultant to the Glass Association of North America (GANA). “The result is a slight deviation from optically flat glass, usually seen as ripples or roller wave.” Miles added that glass thickness and size affect the amount of distortion: generally, the thicker the glass, the less deviation from perfect flatness, while larger glass sizes tend to have more deviation.

Distortion is particularly problematic with auto glass, due to higher quality demands. According to Catita Edward, executive vice president of Atlanta-based Lasor Laser Sorter, “The gravity of optical distortion on automotive glass is, of course, considerably more serious, resulting in a large number of

Temper Temper continued



The Lasorline OM detection system from Lasor Laser Sorter is designed to inspect the etire flo9at glass ribbon with two cameras.

rejects due to higher quality demands."

To minimize distortion, many issues must be considered in optimizing the tempering process. According to Doug Canfield, president of Casso-Solar Corp. in Pomona, N.Y., the three most important considerations in optimizing the process involve the conveyor system, temperature uniformity throughout the furnace and the quench design.

"Distortion will vary depending on how flat the conveyor bed is maintained and how precisely motion is controlled via conveying rollers," he explained. "Flatness is a function of roll spacing and roll speed, and sometimes it's best to have a lot of small rollers close together. However, this does increase the cost of the system." Canfield added that a multiple-zoned flat-roof furnace or an elliptical- or domed-roof furnace can greatly increase temperature uniformity in the furnace, resulting in a more uniform glass surface. "It also depends on where the furnace is positioned in the plant," he added, noting that location next to an outside wall can affect the temperature regulation on that side of the furnace. Finally, Canfield says roll spacing and line speed should be optimized to avoid distortion during the quenching process.

Mauri Leponen, director of architectural glass industry for the Tamglass Group, a glass machinery manufacturer from Finland, agrees that temperature uniformity is critical. "Most important is focusing and controlling heat according to the glass type and loading," he explained. "Our systems use an optimized heating control method whereby sensors detect where the glass is located and only that area is heated." This is an improvement over the more common open-type heating system that heats the entire furnace, said Leponen.

It is also important to monitor the tempering process to minimize distortion, he added. "We have to know what is coming out of the system, and feedback on the temperature and pressure is most critical," explained Leponen. Tamglass Group's Quality Monitoring System (QMS™) monitors and compares tempering conditions so that changes can be effected to optimize the process.

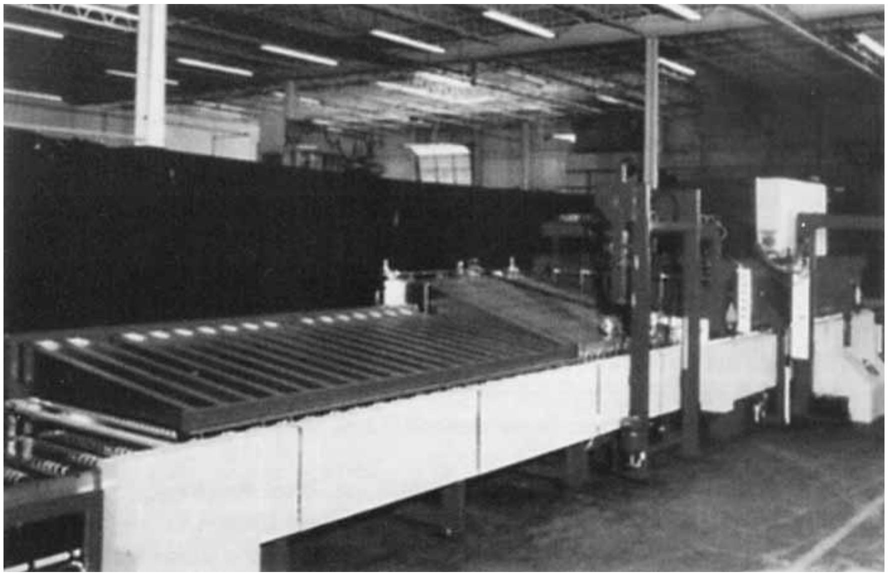
John Colapietro, quality control manager for Tempglass, Inc. in Perrysburg, Ohio, noted that in addition to factors such as the condition of the furnace, size of the glass and conditions under which the tempered glass will finally be viewed, the experience level of the operator certainly contributes to the level of distortion apparent in tempered glass. "It's part art, part science," he said. "There is some skill that the operator develops over time, which helps in making adjustments to optimize the process."

Many machinery manufacturers also produce equipment designed to detect tempered glass problems such as distortion. Edward states that Lasor Laser produces a defect detection system for online quality control. "We also supply off-line equipment to detect any remaining defects and check on the optical quality of the glass after it has been tempered," she said. "Tempering can cause additional reject-causing defects that are not perceivable prior to tempering."

Common industry practice and MasterSpec®, a compendium of specifications produced by the American Institute of Architects, require that roll-wave distortion be parallel with the bottom edge of glass as installed. However, this is only possible if the width of lites falls within the widths that can be handled by the tempering furnace (typical maximum width is 84 inches). Further, loading capabilities through the furnace often make it inefficient to produce a large quantity of glass with distortion in the same direction.

For this reason, some temperers charge a premium for providing distortion in the same direction throughout an order. Opinions vary regarding how warranted this practice is, however. "Charging for uniformity or specifying which direction the roller wave must run may be justified on production inefficiencies caused by having to run lites of glass in a certain direction," remarked Miles. "I am sure that some temperers must either turn down orders with that sort of problem, charge extra or take a loss."

Tom Sugano, general manager of Milgard Tempering Inc. in Tacoma, Wash., sees it differently. "I think any good tempering company probably tries to run all glass the same way, anyway. Otherwise, your customer could have a checkerboard pattern and (they) will be mad," he said. "We don't charge for it, and we don't even mention it."



Continuous horizontal flat glass tempering system from Tamglass Group of Finland.

Work Toward a Distortion Standard

ASTM C 1048 *Standard Specification for Heat-Treated Glass* includes limitations for bow and warp distortion, but the current requirements for flatness do not limit the kind of visually unacceptable roll-wave distortion produced by the horizontal tempering process. However, according to Roscoe Reeves, Jr. FAIA, CSI, director of architectural specifications for ARCOM Master Systems in Alexandria, Va., "The ASTM committee responsible for standards for heat treating glass is considering adding roll-wave distortion limits in the next edition."

Though the tempering industry has worked for years to devise a standard for optical distortion, Miles explained that it has been difficult "to arrive at an honest, repeatable and meaningful method to quantify distortion and then, based on such a measurement, establish limits." He added that the different optical effects caused by varying temper furnace roll spacing and roll diameter complicate the task, and while the industry continues to try to devise such a standard, "it knows that an inadequate or invalid standard is worse than none."

In the meantime, a great number of float glass manufacturers and temperers have developed in-house standards for distortion tailored to meet the needs of their markets. According to Colapietro, "We use different quality control measures including the visual 'zebra board' method, which reflects lines off of the glass surface. We also use a small roll-wave gauge that measures distortion." Colapietro explained that with the objective roll-wave gauge method, a small dial caliper detects any high or low points on the glass surface.

Viracon is another company that has adopted in-house standards for controlling distortion. As Roger Skluzacek, technical services manager, explained, "We measure roller wave distortion periodically, and use visual zebra boards to inspect all heat-treated glass." He added, "It's always been our position that we like to see any roller-wave distortion parallel to base."

Milgard also compares tempered glass against the zebra board, according to Sugano, who noted that because of the subjectivity of the test, "the operator must be well-trained to recognize acceptable levels."

Darrell Aldrich, general manager of Northwestern Industries, Inc. in Seattle, Wash., explained that in order to produce the flattest glass possible, his company developed high standards internally using inspection with the zebra board. "When we added laminating to our manufacturing capabilities, flatness became even more important. We then implemented measuring instruments to quantify the distortion. This removed much of the subjectivity of what is acceptable distortion." Aldrich added, "With good equipment and properly trained operators, we believe we can and do produce tempered glass with minimal distortion."

"PPG uses an in-house standard for controlling distortion, as well as various measurements for flatness, bow and warp and edge kink," said Albert F. Lutz, Jr., director of technical services and product development for PPG Industries in Pittsburgh. "We use both visual inspection and measurement in absolute units."

Because the appearance of distortion is influenced to some degree by the application and conditions under which the tempered glass is viewed, industry authorities advise the use of mockups for all building projects. "Construct a full-size mockup, view it in the context(s) for the planned building and retain the mockup for comparison to the final products," advised Miles. "Without it, what you see is what you get."

MasterSpec® also advises users to consult manufacturers and view mockups that simulate project conditions to evaluate the degree of distortion present.

Thermal Stress Breakage: Whose Responsibility?

by John E. Ponder

Thermal stress is a problem for which each participant in the construction process may have some level of responsibility. The extent of responsibility will have to be determined on a case-by-case basis depending upon the express terms of each participant's contract (i.e., who is to specify the material to be used), what express and/or implied representations were made, and what is the professional standard of care regarding compliance with industry standards. In attempting to limit legal liability, there are four basic prevention measures: *avoid, minimize, shift* or *insure* for liabilities.

Liability can be *avoided* by employing due diligence techniques such as investigation of the job site; becoming educated on product criteria propensities and limitations; and adequate design and quality control through careful inspection for edge damage.

Liability can be *minimized* by including protective provisions in contracts and purchase orders limiting liability for thermal stress breakage; excluding thermal stress breakage from express warranties; disclosures and bulletins warning of the potential for thermal stress breakage and means of reducing thermal stress development such as avoiding shading patterns and heat traps.

Liability can be *shifted* by provisions in contracts regarding scope of work and performance standards; responsibility for specifying materials; and indemnification obligations for claims arising from thermal stress breakage.

Liability can be *insured* by requiring a broad form of comprehensive general liability insurance policy including products/completed operations; obtaining certificates of insurance; and insisting upon additional insured endorsements.

By becoming educated about thermal stress, acting to prevent it and following these steps to limit legal liability from it, thermal stress breakage should cease to be a significant problem for the glass industry.

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Avoiding Inclusions

Approximately 50 different types of dirt or other inclusions found in glass have been identified, according to GANA. Most of these are blemishes that do not in any way affect performance of the glass. However, much has been made of very rare but harmful glass inclusions such as nickel sulfide stones, which are contaminants that may cause spontaneous breakage at some point after tempering—even years later.

Boston's John Hancock Tower is perhaps the most famous case allegedly involving harmful inclusions. In 1973, when the 60-story, 790-foot reflective glass tower was still under construction, huge window panels weighing 500 pounds each began shattering in place, particles raining down below. Nearly half of the windows shattered over time, and eventually all 10,344 of the Hancock's double-pane windows were replaced with single sheets of tempered glass at a cost of $7 million. Experts have speculated that harmful glass inclusions or foundational problems were to blame in the Hancock disaster. Another theory suggests that the lead solder bond between the reflective chromium and the window frame was too rigid, prohibiting the joint from absorbing slight movements of the tower.

Despite all the publicity generated by cases of apparently spontaneous breakage such as the Hancock Tower or a consumer's shattered oven door, such incidences have become increasingly rare. "The industry has found ways to significantly reduce this potential," said Bob Spindler, director of the product development group for Cardinal IG in Minnetonka, Minn.

"Our experience has been that nickel sulfide stones are very rare," agreed Aldrich. "But this is difficult to really know. The nature of tempered glass breakage is that the evidence will become a large pile of small glass pellets."

"Inclusions large enough to be detected visually on the float production line are cut out. Most other harmful inclusions that get through will cause breakage at the tempering facility or none at all," according to Miles. "The exception is nickel sulfide." He added that incidences of the contaminant are exceptionally uncommon because just one type, or phase, of nickel sulfide causes breakage, and only if the stone is located in or near the tension zone of fully tempered glass. According to A.A. "Sak" Sakhnovsky, Ph.D., president of the Construction Research Laboratory Inc. in Miami, nickel sulfide may be introduced during the manufacturing process in several ways. Nickel-rich contaminants, such as stainless-steel from stirring sticks, may inject nickel, while sulfide may be in the furnace fuel or batch materials. During tempering, the nickel sulfide inclusions are transformed into a state wherein they will expand with time and temperature. Nickel sulfide stones typically range in size from three to 15 thousandths of an

Shattered Perceptions for Consumers

When she was startled by the crash of glass on the lower floor of her home one morning in 1996, Phyllis Richman, restaurant reviewer for the *Washington Post*, first suspected burglars. Instead, she found her kitchen floor paved with small pieces of glass—the remnants of her Thermador oven door, which had spontaneously shattered.

As she shared with her readers, she was shocked, baffled and outraged by what appeared to be a manufacturing defect. The oven was a decade old and had not been used in weeks. To compound Richman's frustration, instead of replacing the door without question as she had expected, the oven manufacturer accepted no responsibility for the loss. Thermador's customer service representative suggested that on the rare occasions when the glass doors break, the customer is at fault, having caused a situation such as a blow to the door or a cold shock to a hot door.

Her investigation with an appliance parts retailer, Underwriters Laboratories, the Association of Home Appliance Manufacturers (AHAM) and the U.S. Consumer Product Safety Commission revealed that such reports of glass oven doors breaking without apparent cause do arise from time to time. A representative of the AHAM explained that the door was made of tempered glass, which "can have internal stresses."

Eventually, Thermador did replace Richman's oven door, though not accepting responsibility for the incident. Her indignant article about the experience generated many letters from readers, some of whom informed Richman that the incident was likely caused by a nickel sulfide inclusion.

Conservator Bruno Pouliot of the McCord Museum of Canadian History in Montreal faced bewilderment similar to Richman's when a large tempered glass lite from an exhibit case suddenly shattered during the museum's staff Christmas party in 1996. Environmental records for the day showed no significant fluctuation in temperature of relative humidity. The incident was unsettling—though it caused little damage to artifacts in the case, it raised concerns for the safety of visitors, staff and artifacts on display.

Pouliot took his dilemma to the internet with a plea for information on what might have caused the incident. His final solution: to install clear acrylic shatterproof-resistant safety films on all tempered glass lites used in exhibition cases.

inch, making online detection of every tiny inclusion impractical. ASTM C 1036-90 *Standard Specification for Flat Glass* permits stone inclusions from less than 16 up to 125 thousandths of an inch in float glass.

The practice of cutting visible blemishes from glass before it ever reaches the tempering furnace is usually motivated by the desire to produce the most aesthetically perfect glass possible, rather than because the inclusion might cause spontaneous breakage. According to Sugano, "If we see an inclusion, we take it out because it's objectionable for the customer to view."

Temperers say their best defense against inclusions of all types is inspection. At Milgard, glass is inspected at several stations. "It is visually inspected when it is taken out of the manufacturer's pack and placed on the cutting line, during the breakout procedure, after it is washed, when it is loaded into the furnace and again when it comes out of the furnace," said Sugano. "We have a final inspection for picky customers where the glass is examined on a light rack."

Sugano added that the most common defects found are scratches, but any kind of defect glass is rejected.

"We're governed by the ASTM spec for point defects for float glass, as well as internal documents," said Lutz. In addition to visual inspection techniques, he said, "PPG also uses a sensor system to measure point defects."

Because very tiny inclusions are difficult to detect visually, detection systems using laser scanning or other sensors are available. In addition, some companies use heat soak testing, which causes fully tempered glass with inclusions to shatter. The process involves exposing the tempered lites to one or more cycle of heating to temperatures based on their thickness and quantity, with cooling between each heating cycle. However, it adds to production costs and, according to industry experts, is not always effective.

Sakhnovsky noted that heat soaking is used with great success in Europe, but is less effective as used in the United States. He said temperers claim to eliminate all stones in Europe. "U.S. manufacturers heat soak with the temperature too low and for too short a time," he said. "Few U.S. companies use heat soaking at all because it's not cost effective."

PPG Industries argues against the practice on its internet website, which states, "Heat soaking of fully tempered glass is a significant waste of energy, is not completely effective, and therefore, provides little additional information for estimating the probability of breakage caused by nickel sulfide stone inclusions."

It should be emphasized that apparently spontaneous breakage is not always caused by an inclusion. Surface or edge damage, for example, can eventually result in breakage for no apparent cause. "We have rarely heard of customers experiencing spontaneous breakage," commented Aldrich. "I believe physical damage which weakens the glass and/or mechanical stress is responsible for most tempered glass breakage."

Miles reminded, "Glass is glass and it can be broken by a number of causes, some of them not readily detected."

"We All Wash Our Glass and Our Hands"

Washing flat glass prior to tempering is another issue. Encouraged by experts to avoid the scratched, pockmarked and dented glass that can result from tempering unwashed glass, washing also serves the basic purpose of keeping the tempering furnace clean. Once dirt or particles from the edging process are introduced into the furnace, it can build up on the conveyance rollers, eventually damaging glass as it flows through the system. Other times, particles such as glass fines from the cutting or edging process and handling smudges that are not washed off the surface of glass before tempering will bake onto the surface, causing blemishes.

Whether from dirty rollers or debris on the glass surface, unclean furnace conditions can cause small "pimples" on the surface not visible to the casual viewer. This pimpling condition is described throughout the industry by various names, including "orange peel," "heat prickling," "seeds," "bubbles," or just plain "garbage" that was not washed off prior to the glass entering

Detection System For NiS Stones Developed

A new method for detecting glass inclusions may be on the horizon. A research team at the University of Queensland in Australia has developed a technique that it says detects 0.1 to 0.5 mm stones in glass panels both before they leave the factory and in existing applications.

"The advantage of our technique is that we can differentiate between harmless air bubbles trapped in the glass and potentially dangerous stones," said John Barry, Ph.D., a member of the team.

The group is now working on developing an imaging technique that will automatically detect nickel sulfide stones in glass on the production line.

the tempering furnace. During normal window cleaning after building construction, the pimples can be scraped off and then dragged across the glass surface, causing scratches.

Dan Fields, a third-generation window cleaner and owner of Fields Window Cleaning in Livermore, Calif., said he first became aware of the problem more than three years ago when he was consulted in an insurance lawsuit. Since learning about the causes of tempered glass with these pimples, Fields has become an outspoken advocate of glass washing, writing articles and traveling to industry conferences to spread the word.

He named several West Coast temperers whose glass is regularly found to be pimpled during window cleaning—companies whose windows he refuses to clean.

"I've lost jobs when I've refused to wash (blemished) glass," he said, "but I end up getting them back."

Though no standard for washing tempered glass exists, most tempering facilities do wash all glass prior to tempering as a matter of good practice. "Glass comes to the temperer with interleaving powder, sometimes a carbon-dioxide film and some handling smudges. Cutting and edging adds a little oil, chips and other smudges," explained Miles. "While there might be a reason for not washing the glass prior to tempering, I cannot imagine what it might be."

Lutz remarked, "PPG has a proprietary coating and surface protection, so washing removes this coating and any residue from the edge seaming process, as well as any cutting chips and marks left by handling."

"Foreign matter on the glass can become fused to the glass during tempering," added Aldrich. "If you don't wash the glass, you cannot control this."

Still, some resistance to washing glass before tempering remains, especially in cases where the application does not demand high-quality tempered glass or due to the expense of the glass washing system.

In particular, washing glass before tempering is imperative if there is to be any treatment after tempering. As Lyle Hill, president of MTH Industries in Chicago observed, in the case of glass to be laminated, etched or sandblasted, "If not washed first, the glass will be virtually useless." He added, "I know there is an additional cost for washing, but there needs to be some discernment as to where and how the glass will be used."

Further, evidence does not support the cost argument for not washing glass prior to tempering. According to Bob Lang, sales manager for Zelionople, Pa.-based Billco Manufacturing, a manufacturer of glass washers, "The cost of a glass washer is often less than ten percent of the cost of a tempering furnace. It's minuscule compared to the furnace investment and the potential cost of customer rejects."

"The tempering companies that don't wash prior to tempering just say there is no ASTM standard that requires them to, even though they should know it's bad practice not to," noted Fields.

In addition to washing glass prior to tempering, many temperers also regularly clean the surface of the rollers in the tempering furnace, a process called honing. "We clean our furnace rollers every week to prevent a buildup of contamination," said Aldrich. This practice also extends the life of the rollers, which are expensive to replace.

Despite the fact that no standard for washing tempered glass exists, most temperers do not believe the industry should adopt one.

"We don't need more regulation, especially regarding washing," said Sugano. "I can't believe there would be a temperer who wouldn't wash glass. You're ruining your most expensive piece of equipment."

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>
> —Darrell Aldrich
> Northwestern Industries, Inc.

"I think it's so obvious people should do it, there is no need (for standardization)," said Lutz. Miles compared it to the most basic act of cleanliness: "We all wash our glass and our hands . . ."

Quality Control is Paying Off

Glass manufacturers and temperers are to be commended for their extraordinary efforts to eliminate the problems inherent in tempered glass. Through quality control measures including furnace design improvements, tempering optimization and detection efforts, the industry has come a long way toward this goal. ■

the author

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