Trends and Challenges of Tempered Laminated Glass

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4=Curved Glass 5=Overhead glazing 6=Point Fixed Glazing Systems

Abstract

The tempered laminated glass market has been growing fast in the last decade, mainly in high-rise buildings. The question arises: why use tempered laminated glass? The answer is straightforward: for safety reasons and potential liability issues. Other types of glasses such as annealed float glass and heat-strengthened glass are not accepted by the building codes as "safety glass". Tempered glass is a safety glass but it may break spontaneously. Application of the heat soaked treatment (HST) may strongly reduce this risk but does not eliminate it fully. This raises the critical question of the post breakage behavior of so-called "safety glass". Equally important, the new architectural trend toward lighter structures imposes the use of thinner or lighter glazing while keeping the same structural and mechanical strength of the glass construction. Finally, the need to avoid the risk of thermal breakage associated to the use of thermal Low-e glass and solar absorbing glazing do influence the choice and specification of tempered laminated glass.

The architect's demand for toughened laminated glass has pushed the laminators to overcome their reluctance to produce this type of laminate. This reluctance was due to the complexity of the manufacturing process, the low production yield and the overall manufacturer responsibility in case of failure once installed in the building. Major process and product improvements have been worked out between involved laminators and 首诺 Inc., the world's leading provider of interlayers for the automotive and architectural laminated glass market. This paper presents the different reasons leading to the specification of tempered laminated glass based on 首诺 Inc. interlayers (Product trade names Saflex® and Vanceva®).

Introduction

Products made by laminating tempered glass are getting increasing foothold in buildings. Tempered Laminated Safety Glass provides the best structural strength and integrity even in case of breakage. However, the production process is difficult and very demanding. Lamination of tempered glass may become a nightmare (1) for a manufacturer because it depends not only on the lamination process by itself but also, and mainly, on the quality of tempered glass used to make the laminates. A laminator should be able to control all these parameters in order to maximize production yield and to supply top quality products that will remain durable after several years of use. Several significant trends have emerged in the toughened laminated glass market:

- the reinforcement of the Building Codes in Europe is paving the road worldwide
- the weakness of the fully tempered glass (NiS inclusions)
- the post breakage behavior of glass
- the availability of multi-directional curved glass
- the color breakthrough thanks to Vanceva product offering
- the improved tempering machine technology has led to the use of heat-strengthened glass in architectural glazing

Safety-in-Use: European Regulations

The Construction Products Directive (CPD - 89/106/EEC - Official Journal L40, 11/02/94) and the Interpretative Documents (id's - Official Journal C 62, 28/02/94) specify, in the context of the essential requirement for "safety-in- use", the performance values for construction works and the essential characteristics of product construction in the face of risk of injuries associated with:

- Direct impact of occupants against fixed or moving parts of the (glass) work
- The danger of falling infill materials (glass) or objects from overhead glazing
- The danger of falling through the glazing (protecting a change in level)

Subject to normal maintenance, construction products described herein must be satisfied for an economically reasonable working life. The requirements generally concern actions that are foreseeable. The European norm EN 12600 (Safety impact test) covers most of the impact situations and allows ranking of the glazing products based on their impact resistance and mode of breakage. However, this norm does not predict either the risk of spontaneous breakage of toughened glass (or heat-strengthened glass) or the risk of thermal breakage of annealed glass and subsequent unsafe post breakage behavior.

Tempered Safety Glass & Spontaneous Breakage

Nickel Sulphide (NiS) inclusions induced failure in toughened glass used in buildings continues to occur around the world. The heat soak post-treatment (HST) techniques and norms (EN 14179) allow eliminating or reducing the risk of spontaneous breakage at a 95% confidence level according to manufacturers. However, other sources of information (2) report that the concentration of NiS in glass may range from one inclusion in every 500 kg (worst reported batch case) to one in every 38 tones (best-reported batch case). Based on some other case studies, the success rate of the Heat Soak is about 75%. It is not surprising to see that litigations occur as the number of failures increases.

Heat strengthened glass has been specified to eliminate or reduce the risk of spontaneous breakage as a substitute for toughened glass. Although "zero" risk has not been demonstrated so far, it is indeed possible by providing tight tensile strength specifications. Of course, that switch is feasible when there is no other safety design consideration. In summary:

1 - It is not possible to produce NiS free glass
2 - Heat strengthened glass (as annealed glass) is not a safety glass
3 - Heat soak treatment does not fully eliminate the risk of spontaneous breakage

The safest way to prevent falling glass is to use toughened and/or heat strengthened laminated safety glass based on Saflex® / Vanceva® PVB interlayers from 首诺 Inc. Indeed, even in case of breakage, the glass (Annealed, Heat Strengthened or Toughened) will continue to stick to the interlayer until replacement of the laminated safety glass pane.

Post Breakage Behavior of Laminated Glass

It is well known that monolithic annealed glass, heat strengthened glass or even fully tempered glass do not display safe post breakage behavior, in particular for overhead glazing and structural applications. For this reason, the use of heat-strengthened glass in combination of fully tempered glass in architectural laminated glass has increased dramatically during the last decade. At first, the demand was for the point fixed glazing (or bolted) systems to help maintain the integrity of the other toughened glass panel after fracture in laminated glass. The superior mechanical and thermal strength made it also very attractive for structural (glass floor, staircase), security (burglar, bomb blast) and thermal/aesthetics (colors) applications. An additional advantage of heat strengthened glass to EN 1863 is that residual stress is reduced to a level at which the risk of spontaneous breakage due to NiS is acceptable without heat soaking. This leads to a greater perceived safety-in-use and business continuity for building owners.

The post breakage behavior of the glazing is one of the most critical parameters to consider when designing with glass. As a result, Laminated Safety Glass has to comply with several requirements, depending on their applications:

Overhead Glazing

Overhead glazing must have a minimum residual bearing capacity. Residual bearing capacity is defined as the resistance against a complete collapse of a broken system (3). Wide spanned broken laminated glass continuously supported by glazing beads have a risk of falling down. When the load approaches the fracturing load, the theory of the small deformations cannot be assumed any longer. In this situation, the theory of small deformation changes to the theory of large deformation. Membrane forces generated at the supports tend to pull the glass out of the supporting system.

Point Fixed and Bolted Glazing Systems

Nearly the same effect occurs in broken glass panels discretely supported by glass fittings. At the moment of the fracture there is a change in carrying behaviour, from small to large deformations and from pure bending moment to bending moment and traction. The traction membrane forces are concentrated near the supports, resulting in a ring of traction around the hole and causing an expansion of the hole. If the deformations at the edge of the hole are too large, the broken glass panel can slide out of the glass fittings. The main objective in this situation is to increase the residual bearing capacity to get a higher safety level.

Complex Curvature

The complex curvature trend was initially led by the aerospace and automotive design. The construction industry and the architectural glass processing industry are responding well with increasing capacity in the production of one or more directionally curved forms of tempered laminated glass (4). The applications of curved glass have become widespread, from the London Eyes capsules (1998), to the curved and twisted shapes of the Drugstore Publicist façade in Paris (2005). The technical difficulty of transforming flat float glass into curved, tempered and laminated glass is a challenge or requires state-of-the-art technology. In particular, it is very difficult to control and maintain the surface optical quality and glass residual stresses, which is why no Standards or even architectural specifications have been enacted so far.

Color and Risk of Thermal Breakage

Solar energy absorption in a glass pane causes it to heat up and may induce thermal stress. The temperature achieved by the central area of a pane, when subjected to solar radiation, depends on the proportion of the solar energy and radiation intensity absorbed by the glass.

The warmer central area expands relative to the cooler edges and causes tensile stress to develop in the edges of the glass. If the temperature difference between the warmer centre and the cooler edges is sufficiently high, the stress can cause cracks to develop perpendicular to and from the edges of the glass. It is possible to calculate the basic temperature difference for the glass subject to the environment at the place of use.

The calculated temperature difference can then be compared with the allowable temperature differences for the glass product, to assess whether the glass is thermally safe.

The allowable temperature differences for glass products depend on the edge finishing and the nature and thickness of the glass:

- Annealed Glass: between 26 and 45°C
- Heat strengthened glass: 100°C
- Toughened glass : 200°C
- Laminated glass: smallest value of the component panes

This explains why using tempered laminated glass (heat strengthened or full tempered) makes sense to avoid the risk of thermal breakage.

Colored and optically textured metallic Vanceva® interlayers offer a wide range of translucent or transparent colors that may compete in cladding applications with the opaque materials that traditionally occupy that portion. The need for heat strengthening or tempering the glass should be assessed on a case-by-case basis.

How to make a good/economical tempered laminated safety glass

The laminated glass processing is facing new challenges and individual solutions. Raw materials glass and interlayer suppliers are offering new and more differentiated products. Lamination equipments manufacturers are offering more sophisticated and innovative machines. As a result, we at 首诺 Inc. have been working closely with our customers to find the most appropriate process conditions to improve the overall laminated tempered glass production line efficiency. Each step of the lamination process has been scrutinized, from the float glass preparation, to the glass cutting, sawing, edge work, holes, notches and cut-out, to the glass toughening process and surface flatness control and finally to the assembly, de-airing and autoclaving process. The main lessons learned for successful lamination and further product performances durability are:

1- Always eliminate the thicker part of the float glass edge ribbon
2- Any deviations in the position of the holes, notches, cut-outs, squareness and tolerances on width and length of the glass panes may result in panel misalignment, glass/holes mismatching, and potential lamination issues (formation of bubbles and delamination). Respect the overall tolerances.
3- Horizontal tempering is the preferred process but vertical tempering has to be used to temper curved glass in spite of the resulting “tong” optical defect
4- The PVB (Poly Vinyl Butyral) interlayers allow for compensating about 10 % of the tempered glass voids defects. This translates to the use of 4 PVB layers to overcome the lack of flatness of the tempered glass of 0.08 mm (local bow) on the panel and 0.15mm at the top and end edges (“lift” effect).
5- Position each pair of glass on top of each other in order to have deformation “in phase”

6- Do not use clips at any stage of the process to close the edge in case of "open edge". Clips induce additional laminate stress along the edges, which will be liberated during or after installation in the building. As a result, edge delamination may/will develop.

Summary / Conclusions

Tempered laminated glass can be manufactured successfully both from an economical and quality standpoint. However, the quality of the finished product will depend largely on the quality of the tempered glass itself and in particular on its surface flatness and edge quality (deformation and thickness variation). Saflex®/Vanceva® interlayers from 首诺 Inc. can, to some extent, compensate these glass flatness deviations. Good tempered laminates can be produced even with two PVB layers (0.76mm), but requires optimal glass tempering processes. Tighter product specifications in terms of flatness have to be set and the interlayer supplier recommendations must be implemented. Using "standard" tempered glass will create more hassle to the laminator and will be more expensive. Indeed, thicker PVB interlayer (1.52mm) will have to be used and production yield loss are expected to increase with the degree of difficulty in manufacturing the required tempered laminated glass.

The current architectural market trends highlighted by the author have all been in favor of the use of heat-strengthened laminated glass. Although heat soaked fully tempered laminated glass is ideal for some applications, combination of HS and FT glass in laminated glass for bolted systems and structural systems is not only preferred, but also highly recommended. Both types of tempering offer a wide range of opportunities. Moreover, when combined with the new generation of safe counter sink or special fixation there is no need for using other interlayers besides PVB. 首诺 Inc (4), the undisputed worldwide PVB leader and supplier, is offering Saflex®/Vanceva® PVB interlayers which are the most reliable and economical interlayers for high quality standard laminated safety glass and tempered laminated safety glass.

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