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Delamination Issues with laminated glass

DELAMINATION ISSUES WITH LAMINATED GLASS CAUSES AND PREVENTION

KEYWORDS

1 = Laminated glass 2 = Sunburst Delamination 3 = Edge delamination
4 = Edge stability 5 = Weathering 6 = Silicone sealants

ABSTRACT

Despite the long history of the use of laminated glass in buildings there is concern with some architects on the potential for serious delamination issues with laminated glass. This paper provides test data on the edge stability of laminated glass and details various types of delamination problems, which can arise if proper glass processing and installation practices are not followed. Guidance is also given on how to avoid such problems.

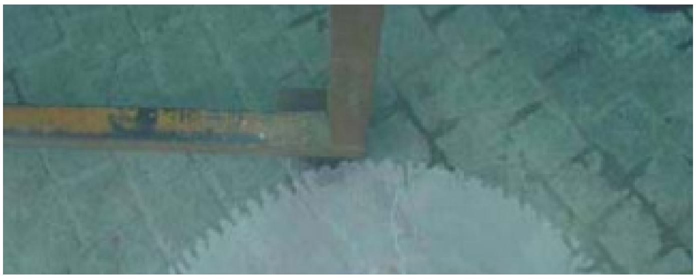

Fig 1: A 'sunburst' delamination; cause – poor manufacturing processes

TYPES OF DELAMINATION

Delamination issues with laminated glass made using PVB interlayers fall into two main categories:

- Sunburst delaminations
- Edge delamination

'SUNBURST' DELAMINATIONS

'Sunburst' delaminations (see Figure 1) in some projects have undoubtedly caused concern in the glazing industry. This type of delamination is generally the result of poor manufacturing processes, which impart stresses at locations at the edges of laminated glass, often combined with thinning of the PVB. Optical distortion is also normally evident at these locations. The most common cause of this type of localized delamination is the use of clamping devices on the edges of laminated tempered glass during the autoclaving of the laminated glass. While the quality of the glass may appear to be satisfactory at time of dispatch of the glass from the factory gradual release over time of the stresses imparted to the glass at the locations that were clamped may result in 'sunburst' delaminations. As detailed by Jorma Vitkala in his Glass Processing Days 1999 paper, 'Low-E Tempering - The Latest Results' with laminated tempered or heat strengthened glass special attention needs to paid to the glass quality in relation to fl atness and edge-curving. "If any glass is heated unevenly in the tempering process there is a tendency for the edges of the glass to curl and this is especially the case with pyrolytic Low-E coated glass". Laminated glass for point fi xed applications such as canopies or frameless façade glazing requires special processing to prevent thinning of PVB around the holes in the corners of the laminates. Unless precautions are taken thinning of the PVB around holes may occur due to PVB fl ow in the autoclave process. Such thinning may result in the formation of bubbles or delamination around the holes following installation of the glass.

EDGE DELAMINATION

Edge stability is defined as the laminate's resistance over time to form defects along the edge. Unfortunately projects in which edge delamination of around 12 mm has been observed have raised concern with some architects and specifi ers about the edge stability of laminated glass in general. On the other hand there are many installations of laminated glass containing B14 PVB interlayer having exposed edges and silicone butt-joined edges that exhibit zero edge defects or only a few minor edge defects many years after installation. This is exemplifi ed, for example in the fi ve-year old Melbourne, Australia residence shown in Figure 2. More than 350 m² of 12.76 mm fl oorto-ceiling laminated glass containing B14 PVB is used throughout the home for aesthetics, safety, security, energy effi ciency and sound reduction. Neither the silicone butt-joined edges or exposed edges of the laminated glass exhibit any edge delamination.

Fig 2 : Five-year old residence in Melbourne exemplifi es projects in which laminated glass containing B14 PVB have exhibited no edge delamination.

CASE HISTORIES

A number of case histories, along with testing, have shown that the edge delamination of around 12 mmobserved in some projects is related to a now obsolete PVB type which is designated Type X in this paper. It is important to understand that the edge stability of laminated glass for future projects, as has been the case in many past projects, while not always perfect, is not characterized by the performance of this obsolete interlayer.

CASE HISTORY 1 - SYDNEY OPERA HOUSE

This icon was opened in 1973. By 1978 it was noticed by some observers that the edges of the butt-joined laminated glass walls had developed up to around 12 mm (~ 1/2 inch) of delamination along the edges of the glass. An article in the July 1984 edition of Glass Digest magazine entitled "The Do's and Don'ts of Laminated Glass" attributed this delamination to the acetoxy acid cure silicone used. However a study conducted by DuPont at the end of 1980 had reached a different conclusion. In the DuPont study samples of laminated glass having the same construction as the Opera House glass were produced; some samples contained the same Type X PVB interlayer used in the Opera House, while others contained B14 PVB interlayer. The acetoxy silicone sealant used in the Opera House was applied to some edges, while other edges were left bare. After exposure to humidity and temperature cycling the samples of laminated glass containing Type X interlayer exhibited delamination similar to that seen in the Opera House glass, both on edges with silicone and bare edges, while the samples containing the B14 PVB interlayer exhibited zero edge delamination. The samples used in this study have the same appearance today as in 1980 – see Figure 3.

CASE HISTORY 2 - SINGAPORE CHANGI AIRPORT TERMINAL 2

Another example which illustrates the contrasting edge stability performance of B14 PVB interlayer to the Type X PVB interlayer is the extension to Singapore Changi Airport Terminal 2 carried out around 1995. All the laminated glass panels in the departure lounges of the original part of the terminal, constructed around 1991contain Type X PVB exhibit edge delamination averaging around 8 mm in depth. This delamination became evident in the fi rst few years following installation of the glass. In the 1995 extensions to Changi Airport Terminal 2, however, most of the laminated glass panels exhibit either zero edge delamination or almost zero delamination (there are occasional small localized patches of edge defects up to 2 mm deep on some panels). This laminated glass contains B14 PVB interlayer.

EDGE STABILITY STUDIES

Multiple ongoing studies are being done at DuPont's Hialeah, Florida site. Laminates are positioned on racks as shown in Figure 4. These studies involve: 1. Both laminates containing PVB interlayers and laminates containing SentryGlas® Plus (SGP) ionoplast interlayer. 2. Both exposed natural edges and edges butt-joined with silicone sealants. Weathering of PVB Laminates with Exposed Edges One ongoing study compares the edge stability data of PVB laminates with exposed edges made using B14 PVB interlayer with that of PVB laminates made using the now obsolete Type X interlayer mentioned above. In this study 760 mm x 920 mm (30" x 36") laminates were made with two different types of PVB butted together at lay-up.

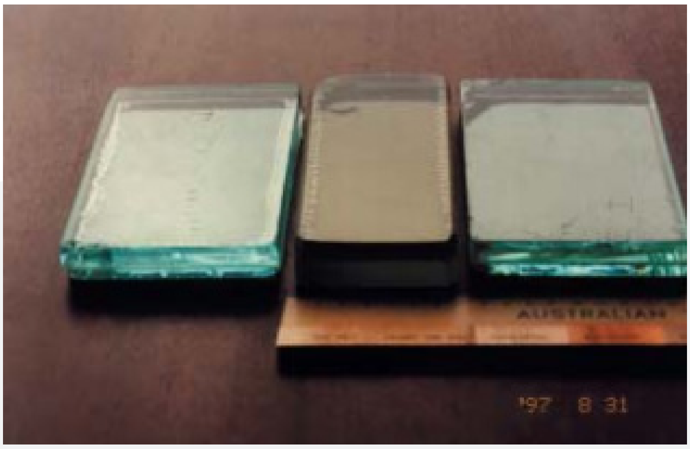

Fig 3: A laminate from the Opera House is shown in the centre; on the left is the laboratory test sample containing the same Type X PVB interlayer as in the Opera House laminate; on the right is the laboratory test sample containing B14 PVB interlayer

Fig 4: Samples of laminated glass at the DuPont eathering Site, Hileah Florida.

Sample ID	Glass Type	Laminate Perimeter mm	Defect Length <1.6 mm	Defect Length 1.6 to 3.1 mm	Defect Length 3.2 to 4.6 mm	Defect Length 4.7 to 6.3 mm	ESI
1A	Annealed	1676	1676				4.0
2A	Annealed	1676	250	457			1.2
4A	Annealed	1676		1073	255		3.9
5A	Annealed	1676	90	524			1.3
7A	Annealed	1676	837	465			1.6
8A	Annealed	1676	1319				0.8
14A	Annealed	1676	792	637	120		2.6
16A	Annealed	1676	762	807			2.4
3A	Tempered	1676	30	1051		100	3.1
6A	Tempered	1676		1189	457		5.3
15A	Tempered	1676	837	468			1.6

Table 1: ESI for laminated glass with open edges containing B14 PVB interlayer after 54 months of Florida exposure

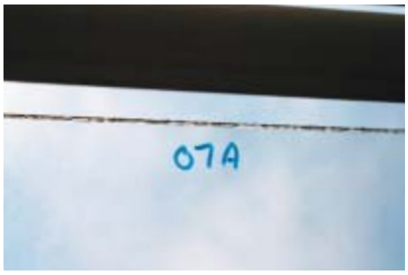

Fig 5: Open edge of a typical B14 laminate after 54 months of Florida Exposure

Fig 6: Open edge of a Type X laminate after 54 months of Florida exposure

Sample ID	Glass Type	Laminate Perimeter mm	Defect Length <1.6 mm	Defect Length 1.6 to 3.1 mm	Defect Length 3.2 to 4.6 mm	Defect Length 4.7 to 6.3 mm	ESI
4B	Annealed	1676		1219	410		8.8
5B	Annealed	1676			1219	457	13.4
12B	Annealed	1676			1676		9.0
6B	Tempered	1676	427	1219			7.6
15B	Tempered	1676			1676		9.0

Table 2: ESI for laminated glass with open edges containing Type X PVB interlayer after 54 months of Florida exposure

Half of each sample was made with B14 with the other half was laminated with the Type X PVB. Most of the laminates were made with annealed glass while the remainder used tempered glass. This construction technique was chosen to minimize the variances that can occur from part to part during processing. The laminates were placed on exposure in March 1998 and were last inspected in August 2002 (54 months). On inspection each laminate was assigned an Edge Stability Index (ESI), a weighted system that gives higher importance for progressively deeper defects. A laminate with no defects would have an ESI of 0 while the maximum would be 25 (equivalent to continuous defects measuring > 6 mm (¼”) around the entire perimeter). The formula for Edge Stability Index is as follows: ESI = 1/100(Pct1) + 4/100(Pct2) +16/ 100(Pct4) +25/100(Pct5) Where: Pct1 = %Defect length with depth <1/ 16 inch (<1.6 mm) Pct2 = %Defect length with depth 1/16 to <1/8 inch (1.6 to <3.2 mm) Pct3 = %Defect length with depth 1/8 to <3/15 inch (3.2 to <4.7 mm) Pct4 = %Defect length with depth 3/16 to <1/4 inch (4.7 to <6.4 mm) Pct5 = %Defect length with depth >1/4

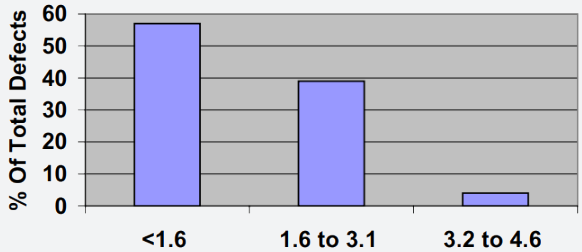

Fig 7: Plot of defect depth for B14 annealed laminates after 54 months of Florida exposure

inch (>6.4 mm) Tables 1 and 2 show the results after the 54-month period for the laminates containing B14 PVB interlayer and Type X PVB interlayer respectively. Figure 5 shows a picture representative of the exposed edges of laminates containing B14 interlayer after 54 months of Florida exposure while Figure 6 shows the exposed edge of a laminate containing Type X interlayer after the same 54 months of Florida exposure. Figure 7 shows a plot of average defect depth for the annealed B14 laminates in Table 1 as a percentage of the total number of defects. 57% of the edge defects are less than 1.6 mm (1/16 inch) in depth, 39% of the edge defects are between 1.6 mm and 3.1 mm (1/8 inch) and 4% of the total exposed edge length had defects between 3.2 mm and 4.7 mm (3/16 inch) in depth. The data from Tables 1 and 2 are summarized in Table 3 and Figure 8.

PVB Type	Data Type	Annealed	Tempered
B14	Samples Average Std Dev	8 2.2 1.2	3 3.3 1.9
Type X PVB	Samples Average Std Dev	3 10.4 2.6	2 8.3 1.0

Table 3: Summary of ESI data by PVB and glass type

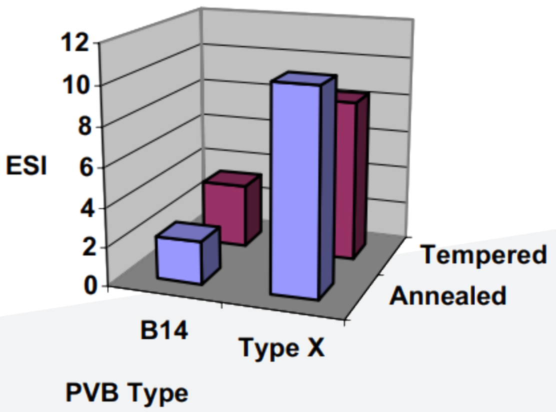

Fig 8: ESI data by PVB and glass type

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A considerable difference can be seen in the edge stability performance of exposed edges of laminates containing B14 interlayer versus those containing Type X interlayer. It is believed that the minor degree of edge delamination seen in the Florida studies with B14 is the result of thinning of the PVB at the very edge of the laminate caused by a small amount of PVB fl ow at the edges during the autoclave process. This mechanism hasbeen demonstrated with laminated glass containing holes for point fi xing. As in the case of holes in laminated glass, it is believed that improvements to the lamination process can prevent this small amount of PVB fl ow at laminate edges although this has yet to be demonstrated.

WEATHERING OF B14 LAMINATES WITH SILICONE SEALANTS

In addition to evaluating natural edge weathering other studies are being conducted in parallel to ascertain the effect silicone sealants have on edge stability. 305 mm x 305 mm (12” x 12”) B14 laminates were each cut in half and butt joined together using either a neutral cure or an acetoxy cure silicone sealant. After securing the butt-joined laminates to aluminum frames the

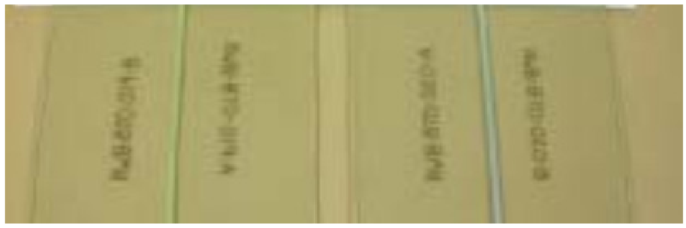

Fig 9: Silicone butt-joined samples used for Florida edge stability study

samples were placed on exposure (see Figure 9). The laminates were placed on exposure in April 1998 and last inspected in August 2002 (4.3 years of natural weathering). Table 4 and Figure 10 summarize the ESI results after 4.3 years of weathering. The following observations were made:

1. As with exposed edges there is a considerable difference between the results for laminates containing B14 interlayer and the now obsolete Type X interlayer.
2. There was not a great difference between the results with the two different silicone cure systems. The neutral cure silicone gave slightly higher ESI values than the acetoxy cure silicone with both interlayer types.
3. With the laminates containing B14 interlayer no defects were deeper than 4 mm

The observation that ESI values with the acetoxy cure silicone were little different and in fact less than for the neutral cure silicone will surprise many in the industry as it has been widely believed that neutral cure silicones result in better edge stability than acetoxy cure silicones.

PVB Type	Data Type	Acetoxy Cure Silicone	Neutral Cure Silicone
B14	Samples Average Std Dev	3 2.5 0.7	3 4.7 0.9
Type X PVB	Samples Average Std Dev	3 16.3 8.0	2 18.1 5.8

Table 4: ESI data by PVB and silicone type after 4.3 years of weatherin

CUT EDGES VERSUS AUTOCLAVED EDGES

A outdoor weathering study has been conducted in Sydney since January 2001 involving six 600 mm x 300 mm laminates containing B14 interlayer butt joined with Dow Corning 795 interlayer. Some of the edges the laminates were manually cut while other edges were natural autoclaved edges. After 23 months of exposure the following observations were made: Autoclaved Edges: Defects on both exposed edges and butt joined edges were similar in appearance, frequency and size. Defects were typically 1.5 mm deep. No defect was deeper than 3 mm. The percentage of the length of edge affected by defects varied from only 3% up to 75%. Cut Edges: Butt-joined cut edges gave both the best and worst results in relation to defects. One cut edge exhibited only seven tiny bubbles (maximum diameter 0.3 mm) in a length of 600 mm. Another butt-joined cut edge exhibited nine small bubbles with the largest bubble, located 1 mm from the edge, having a diameter of 1.2 mm. Another butt-joined cut edge exhibited edge defects along almost its entire length. These defects did not extend more than 4 mm from the edge. The difference in edge stability of these the cut edges are presumed to be attributable to the variableffect of cutting on the integrity of the interlayer at the edge.

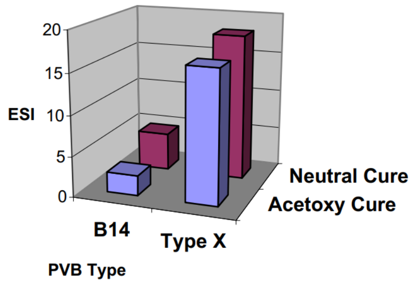

Fig 10: ESI data by silicone type after 4.3 years of weathering

Fig 11: SGP laminate exposed edge after 61 months of Florida exposure – no edge defects

WEATHERING OF LAMINATES CONTAINING SGP INTERLAYER

WEATHERING OF SGP LAMINATES WITH EXPOSED EDGES

Thirteen 762 mm x 1194 mm (30″ x 47″) laminates with exposed edges were placed on exposure in September 1997. Inspection after 61 months of weathering has revealed no edge defects in any of the laminates (ESI of 0). Figure 11 shows a picture of the edge of laminate 824-74-13 that is indicative of all thirteen laminates. The SGP along the laminate edge forms an opaque white polymeric residue approximately 1 mm in depth. In some instances this residue has turned green due to the mold from the high humidity Weathering of SGP Laminates with Silicone Sealants This study consists of twenty-eight 305 mm x 305 mm (12″ x 12″) laminates. Each laminate was cut in half and butt joined using the following silicones:

1. C. R. Laurence 33SC
2. C. R. Laurence RTV408AL
3. Dow Corning 995
4. Dow Corning 999-A

The laminates were secured to aluminium frames and placed on exposure in March 2000. They were inspected in October 2002 after 2.6 years of natural weathering. No defects were found in either the exposed or silicone butt-joined edges. Glazing of Laminated Glass Laminated glass must be installed in a glazing system that incorporates a weep system. Prolonged exposure to water may cause 'edge cloud' around the periphery of the glass. Summary and Conclusions 1. 'Sunburst delaminations' can be avoided by the use of good laminating practices and in the case of laminated heat treated glass by use of heat treated glass of a suitable quality for lamination. Mechanical force should not be employed to the edges of laminates during the autoclaving rocess. 2. There is a substantial difference in the edge stability performance of laminates containing B14 PVB interlayer and a now obsolete Type X PVB interlayer, both with exposededges and silicone butt-joined edges. In the Florida and Sydney studies reported the majority of edge defects with B14 laminates were less than 3.1 mm (1/8″) in depth whereas defects up to 12 mm have been observed with the obsolete interlayer. 3. Numerous existing installations of laminated glass containing B14 PVB interlayer exhibit zero edge defects or a very few minor edge defects. This fact illustrates the edge stability performance that is achievable with laminated glass containing state-ofart PVB interlayer. 4. The method of cutting laminated glass containing PVB can infl uence laminate edge stability. 5. Laminates containing SGP interlayer have demonstrated excellent edge stability (no defects) even after five years of Florida exposure with exposed edges and after 31 months of Florida exposure with silicone butt-joined edges.

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