CPNI
Centre for the Protection of National Infrastructure

GUIDANCE NOTE

INFLUENCE OF DELAMINATION OF LAMINATED GLASS ON ITS BLAST PERFORMANCE

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Introduction

Laminated glass is glass which is manufactured using multiple panes of glass and a flexible interlayer which is bonded in between the panes of glass. When exposed to a blast load the glass breaks very quickly and interlayer holds the fragile panes of glass together; hence the reason it is frequently recommended where blast-resistant glazing is required. In such situations the bonds between the supporting structure and the edge of the glass and between the glass and the interlayer are crucial to ensure that the laminated glass is retained in position. Material defects such as edge delamination will reduce this bond and reduce the blast-resistance of the laminated glass.

This Guidance Note has been produced to raise awareness of the effect of edge delamination of laminated glass, on the glass' ability to resist a blast load.

Delamination of laminated glass is not a new phenomenon; car manufacturers have known about it for some years and use a black strip around the edge of laminated glass windscreens to hide any visible evidence (Figure 1). In environments where a level of blast enhancement is required, the reduction in glass-interlayer-glass bond within the frame rebate (Figure 2) can have a significant impact on the performance of the frame to retain the glass. This guidance note will discuss the issues which cause delamination and propose measures to reduce the likelihood of it occurring.

Figure 1: Edge delamination in car windscreen

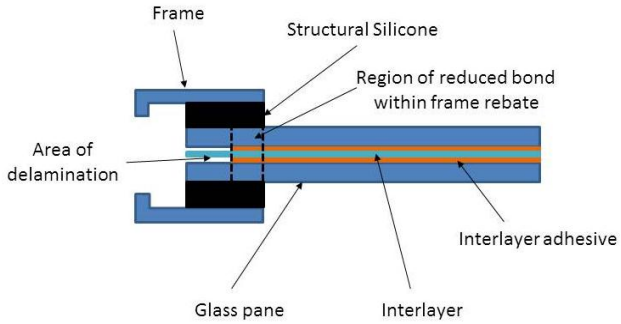


Figure 2: Diagram of edge delamination in window frame

Where and how does it occur?

Delamination of laminated glass usually occurs at the edge of a pane of laminated glass (Figure 3) or around a fixing where there is an exposed edge adjacent to the fixing (Figure 4). It can also be referred to as 'interlayer or edge staining'. Delamination is a reduction or, potentially, a total loss in the adhesive bond between the glass panes and the interlayer and is most prevalent in panes of laminated glass where a Poly-vinyl Butyral (PVB) interlayer is used. The increase in delamination is most prevalent during warm moist weather. There are a number of reasons why edge delamination can occur; these are summarised in Table 1.

Figure 3: Edge delamination in framed glass

Figure 4: Delamination around a point fixing

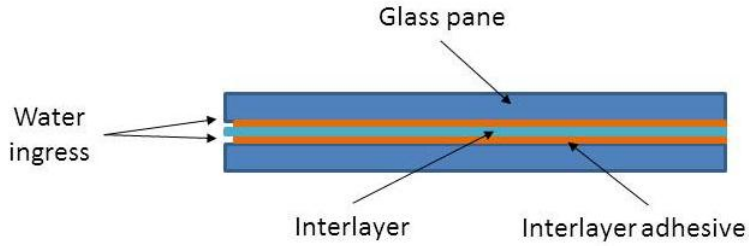
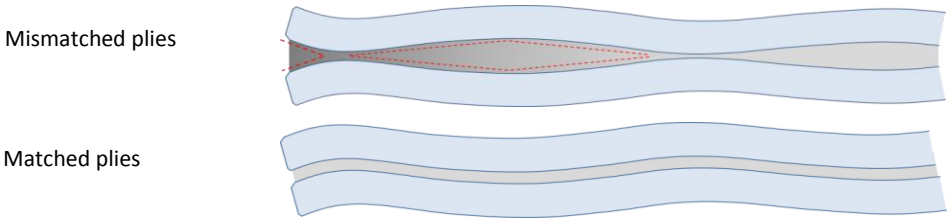
Problem	Cause
Excessive moisture	PVB is hygroscopic and absorbs moisture. If the panes are exposed to excessive moisture adjacent to the edge of the interlayer, the bond to the glass is reduced and delamination can occur. This is often due to poor detailing allowing moisture to collect, or poor installation where measures intended to reduce moisture build-up negated. The edge of the interlayer must be allowed to 'breathe'. 
Compatibility	It is important to ensure that the correct type of structural silicone is used to ensure it is compatible with the interlayer being used; incorrect selection can lead to delamination.
Mismatching of glass/poor processing	Thermally processed (toughened or heat strengthened) glass exhibits distortion within the glass caused by the rollers during the manufacturing process. This distortion is commonly known as roller wave or edge dip. If the distortion within the glass plies is not 'matched' peak to peak and trough to trough then there can be stresses applied to the interlayer, particularly at the edges. Delamination could occur if the interlayer is unable to withstand the stresses applied by the glass plies. 
Quality of installation	If not removed fully, cleaners and primers used to prepare the laminated glass prior to bonding with structural silicone can cause the adhesive layer to deteriorate, thereby promoting delamination.

Table 1: Common delamination problems

Which interlayers are susceptible?

Table 2: Types of interlayer and their susceptibility to delamination

Interlayer types	Susceptible	Remarks
Poly-vinyl Butyral (PVB) (thermosets)	Yes	PVB is the most common interlayer
Resin (Cast In Place)	Yes	Deterioration due to ultraviolet radiation should also be considered
Polyurethanes	Less	Issues of thermal expansion should also be considered
Ionoplast (thermoset)	Less	Such as Sentry Glass
Ethylene-vinyl acetate (EVA)	Less	Although less susceptible to delamination, EVA does not perform as well as PVB under blast loading

Why should I be concerned?

CPNI has conducted blast testing to assess the performance of 9.5mm laminated glass to which edge delamination had been induced and then bonded into a four-sided window frame with a 25mm wide bead of structural silicone. Three different depths of linear delamination (4, 8 and 25mm) were induced on all four sides as well as a control sample with no delamination. The panes were then subjected to a blast load of 100kg (TNT equivalent) at 25m. The results of these tests were:

- There was a significant reduction in the glass edge retention when the continuous linear edge delamination exceeded 4mm.
- 8mm linear edge delamination resulted in more than 50% pull out of the laminate from the structural silicone.
- All the panes with 25mm linear edge delaminated failed and were driven into the rear of the test cubicle.

The conclusion from these tests is that the glass will pull out of the frame and travel into the building (test cubicle) when there is 12-15mm or more linear edge delamination on all four sides.

Reduced silicone bites

Structural silicone is widely used to bond laminated glass into framed window systems or onto structural glazing systems. To enable less silicone to be used, manufacturers are introducing new structural silicone products with increased mechanical strength and elongation properties. In certain circumstances they can be used to reduce silicone bond widths between the glass and the supporting structure. The reduced bonded area places a greater importance upon the levels of adhesion between the glass and the interlayer (see Figure 2). If adhesion levels between the glass plies to which the silicone is bonded and the interlayer are reduced, as a result of delamination, then the risk of laminate failure under increased loads, such as those produced by an explosion, is much greater.

New laminate products

Architectural trends combined with new laminate materials are resulting in a range of products being laminated into the panes. Care should be taken to ensure that the interlayers chosen do not have reduced levels of adhesion.

Changing commercial approaches to delamination

The increasing awareness of delamination within laminated glass has meant that many glazing specifications are permitting increased levels of delamination, and some specifications now permit delamination as long as it does not protrude into the vision zone of the glazing. In blast systems this can be up to 25mm. In systems where the edges are exposed, such as structural bonded glass (glass which is bonded to the structure with structural silicone on one side only), delamination is being limited to 15mm from the edge of the glass. Where there is a 25mm bead of structural silicone, this would potentially mean that if full delamination occurred only a 10mm region of glass would be bonded to the frame (see Figure 2).

Recommendations to prevent delamination

Table 3 lists measures which may be adopted to reduce the likelihood of delamination occurring.

Measure	Description
Specifications	Where a level of delamination can be tolerated specifications should clearly stipulate the levels which are acceptable. The following form of words may be considered: 'Edge delamination of laminated glass with polyvinyl butyral (pvb) interlayers is known to occur in situations where there has been poor quality control during manufacture, specification and installation. It has also been demonstrated through actual blast-tests that edge delamination has a detrimental effect on the blast-resistance of bonded laminated glass. Delamination of the laminated glass appreciably reduces the blast resistance of the glass if it extends more than 8mm from the edge, and if it extends along more than 25% of the total perimeter. Where the primary reason for panes of laminated glass is to provide blast-resistance, and this tolerance is not achievable, guidance should be sought from a competent designer with experience in designing such windows. Such engineers can be found on the Register of Security Engineers and Specialists (www.rses.org.uk) or should be able to demonstrate that they meet the C-level competences of a Member of the RSES in the specialism B - Protection against the effects of blast.'
Quality control during processing	The laminated glass processor should demonstrate that: • Treated panes of glass (toughened or heat strengthened) are properly aligned prior to the laminating process. • The interlayer is being stored correctly. The interlayer must be stored at set humidity and temperature levels in accordance with the manufacturer's instructions. Failure to do so could reduce the interlayer adhesion levels. • The appropriate water conditions are maintained (conductivity, pH & water temp) when cleaning the glass prior to lamination. Bespoke produced glass laminated in an autoclave is recommended instead of pre-laminated 'stock sheets'. The cutting of stock sheets can lead to imperfections of the interlayer at the cut edge which can increase the risk of delamination when compared to glass correctly laminated in an autoclave.
Compatibility	Care should be taken to ensure that the structural silicones or gaskets that are being used are compatible with the interlayer. Most reputable manufacturers provide data on the compatibility of their products.
Moisture and contaminants	• Ensure that, when installing the pane, edges are ventilated to allow any moisture a free path away from the interlayer. Where possible avoid direct contact between the structural silicone and the interlayer. • Avoid accumulation of moisture or contaminants on laminate edges, especially at the top lateral edge. Ensure that membranes intended to remove risk of moisture contact do not inadvertently lead to a build-up of moisture adjacent to the laminated pane edge.
Quality of installation – methods of support	Ensure that the interlayer is not compressed by the frame/fitting(s). Compression of the interlayer can lead to voids which can in turn allow a build-up of contaminants, which remain in constant contact with the interlayer.

Table 3: Recommendations to prevent delamination

Acknowledgements

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