Introduction to Laminated Glass Interlayers

Guidance to raise awareness on which laminated glass interlayer types to use

Introduction

Glass is widely used in buildings for its transparency and optical performance as well as resistance to the environment, such as wind, rain and temperature variations etc. However, as a basic material it is inherently brittle and has significant shortcomings for security applications. Using laminated glass is generally the preferred way of overcoming these limitations.

A laminated glass comprises two or more layers of glass which are permanently bonded together using an interlayer material. The layers in laminated glass are typically referred to as a ply or plies. For certain applications, plies of glass will be replaced with alternative materials such as polycarbonate to improve resistance. Laminated glass can be designed for a range of different security requirements, including for example:

- bullet resistance – where primary requirement is a high degree of impact resistance
- forced entry resistance – where the requirement is to protect against cutting and impact, although the impact requirements are much less than that required for bullet resistance
- blast resistance – where the requirement is primarily to absorb energy, which requires ‘ductility’

Laminated glass is a complex composite material, and its properties can be changed considerably by:

- the type of glass plies used (e.g. annealed, heat strengthen, toughened etc)
- the number, thickness and order/orientation of plies used
- the type of interlayer used between the plies of glass – mechanical properties, thickness etc
- the process used to manufacture the laminate glass (this can be critical)
- substitution of glass plies with other materials, such as polycarbonate. Substitution may also lead to other types of interlayer being used to ensure materials are compatible
- special coatings applied to individual plies or the laminate as a whole

Interlayers have developed over time to meet different requirements, and as such there are a variety of products commercially available. Whilst they may all be referred to as interlayers, their performance, especially against blast and other security threats, can vary significantly. Unless specified, some glass processors may select an interlayer which may not be suitable for a security product.

GLASS STRENGTH

Annealed Glass	Heat Strengthened Glass	Toughened Glass
1	2-3 x Annealed Glass	3-5 x Annealed Glass

The aim of the document

The aim of this document is to raise awareness and inform potential users, specifiers, designers and engineers of the different types of interlayers available and the recommended interlayer types to be used where there is a blast performance requirement. This guidance note should be read in conjunction with the suite of glazing guidance notes relating to effective blast performance of glass.

How is laminated glass manufactured and how does it perform if it breaks?

Interlayers are most commonly supplied as a roll of thin sheet material, normally 0.38mm or 0.76mm thick. The interlayer is laid between plies of glass of the required thickness, with multiple sheets of interlayer being used to achieve the required thickness when required i.e. 2 x 0.76 = 1.52mm thick interlayer. Extreme heat and pressure are then applied to the assembled composite, in a controlled manufacturing process which bonds the layers of interlayer and glass together. Storage of the stock interlayer and the subsequent lamination process are undertaken in a controlled environment as the final product performance is heavily dependent upon the care taken during manufacture.

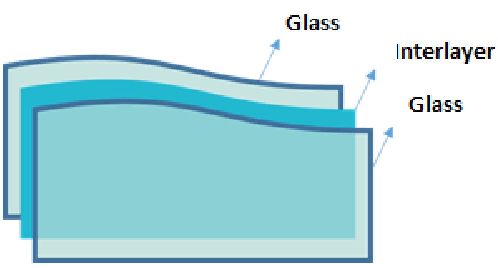

Figure 1: Components of laminated glass

Should the glass break, the glass fragments should be held in position by the adhesive bond between interlayer and glass. The ductility and toughness of the interlayer will also play a vital part in delivering acceptable post-fracture performance of the laminate. Interlayers can be classified based upon their strength and adhesion level. Variation in these parameters can have a significant effect on the performance of the glass if it breaks.

How does temperature impact the properties of the interlayer?

Recent research has shown that strength and adhesion levels achieved by a specific interlayer can also vary depending on the temperature of the product at breakage. Generally, higher temperatures will increase the elongation properties of the interlayer i.e. its stretchiness, whilst colder temperatures will make the material more ridged. In terms of adhesion level, higher temperatures will typically reduce the strength of the adhesive bond. Such effects are known to CPNI, and a research programme is underway to assess the influence of temperature on the blast performance of PVB laminated glass.

Types of interlayer

A range of interlayers exist which are used by glass processors to produce laminated glass. Selection of a particular interlayer is based upon a host of parameters including: availability, durability, cost of material and manufacturing equipment, optical clarity and blast performance. Where there is a blast requirement, the following two interlayers may be considered most appropriate:

Polyvinyl Butryl (PVB)

PVB is one of the most popular and commonly used interlayers within the architectural, automotive and transport sectors. Whilst laminated glass is manufactured by many different processors, the PVB polymer itself is manufactured by a relatively small number of companies. Within Europe the main manufacturers include Kuraray, Solutia and Everlam. PVB is popular due to its relative high durability, predictable mechanical behaviour and ease of manufacture. Many different grades of PVB exist, having been modified to achieve a range of structural properties, impact resistance and acoustic performance.

For cost effective manufacture of a laminated glass incorporating PVB interlayers, in most situations an 'autoclave' must be used which applies both heat and pressure as part of a controlled cycle. The laminated panel is first assembled by placing PVB interlayers between two or more pieces of glass within a clean room. This 'sandwich' of different materials is initially de-aired and stuck together using a vacuum or series of rollers before the laminate is placed within an autoclave and subject to approximately 10 bars of pressure and heated to approximately 130°C to produce the final laminated product.

Ionomer (SentryGlas®)

This interlayer is commonly marketed under the trade name SentryGlas® (or SGP) and was introduced into the architectural market in 1998. The ionomer material was originally developed to improve the performance of glazing when subject to debris strikes resulting from hurricanes. SentryGlas® is a much stiffer and tougher interlayer than PVB. The material also bonds well to some metals which can be an advantage when designing bespoke glass structures. SentryGlas® is intended for use in structural glass applications; for example, large unsupported sections of feature glass and glass stairs, floors and beams.

SentryGlas® interlayers are typically processed in the same way as the PVB interlayer i.e. using an autoclave. Due to the stiffness of SGP, this material may transfer more load to the supporting structure when compared to PVB interlayer and this behaviour needs to be reviewed during the design stage.

Other interlayers are commercially available and are used for commercial glazing. However, these may not be suitable when a blast performance is required:

Ethylene-vinyl acetate (EVA)

EVA interlayers were most commonly used for the lamination of photovoltaic (PV) cells due to the high adhesion levels achieved to silicon PV cells. The material is also highly malleable around embedded components such as electrical connections. High adhesion levels can further increase the edge stability of the interlayer which increases the resistance to delamination and therefore the durability of the product.

Similar to PVB, EVA is supplied on a roll in varying thicknesses and can be layered to achieve the required thickness/performance. The glass and interlayers are placed in a vacuum bag and heated to approximately 120°C to create the laminated product. Due to the use of a vacuum bag, a hot box chamber is sometimes used instead of an autoclave. For low volume manufacture, a hot box can be a relatively low cost entry option making EVA laminated glass the preferred material for smaller and lower cost fabricators. However, the processed cost is generally similar to PVB laminated glass.

EVA interlayers are known to rupture or tear and may not always be suitable for security applications or where they are required to support fractured glass for long periods of time. Due to the properties of this material, EVA interlayers may not be as suitable as PVB or SentryGlas® interlayers for structural applications. EVA laminates have been shown to perform much worse than PVB under blast loading.

Poured resin (cast in place)

Poured resin interlayers were commonly used for laminating architectural glass products in the 1990s and particularly for toughened and heat strengthened laminated products. This lamination process involves the creation of a cavity between two or more panes of glass using a clear tape around the perimeter of the glass. A liquid resin is subsequently poured into the cavity and is cured using UV light, heat or catalytic reaction.

Poured resin interlayers are now used to laminate cast, patterned glass and curved glass which is difficult to laminate using sheet interlayers like PVB. Poured resin interlayers are not as durable as other interlayer products and, as such, are only used for specialist applications in non-safety critical locations.

Polyurethane (TPU)

Polyurethane interlayers are typically used for specialist applications in which glass is laminated to acrylic or polycarbonate sheets for ballistic resistance applications. Polyurethane is used to bond such substrates because of its high adhesion and the ability to accommodate significant differential expansion which can occur between plastics and glass as a result of variations in temperature. The majority of ballistic rated laminates that utilise polycarbonate, acrylic or other plastics will incorporate layers of polyurethane between the glass and the polycarbonate. This interlayer is generally more susceptible to damage than other interlayers as it is not as durable, is thermally less stable than other interlayers and is also more susceptible to moisture and chemical contact. Cleaning fluids have been known to damage the polyurethane interlayer forming a white haze which can be an indication of delamination.

Interlayer summary table

	Interlayer type	Common thicknesses of the interlayer[1]	Comparative cost when processed	Common manufacturers & product name	Typical processing method	Typical application
May be used for a blast requirement	Polyvinyl butyl (PVB)	Multiples of 0.38mm, common thicknesses are 0.76mm and 1.52mm. (supplied in a roll)	£	**Kuraray** Trosifol® & Butacite® **Eastman** Saflex® **Everlam™** Lam 51H® **Sekisui** S-Lec™	Autoclave	• Commercial façade glazing • Glass balustrades • Blast-resistant glazing
	Ionomer (SentryGlas®)	0.76 mm, 0.89 mm, 1.52 mm, 2.28 mm (supplied in either a roll or flat sheets for thicker layers)	£££	**Kuraray** SentryGlas®	Autoclave	• Windows subject to impact • Large unsupported glass panels • Overhead canopies
Not recommended for a blast requirement	Ethylene-vinyl acetate (EVA)	0.38mm, 0.76mm, 1.52mm (supplied in a roll)	£	**Bridgestone** 'EVASAFE', plus variety of others, particularly from Asia.	'Hot box[2]' or autoclave	• Laminating photovoltaic cells • Locations with a high moisture content e.g. swimming pools
	Cast resin (CIP)	Circa 1 to 2mm (to match the thickness of the void between the glass) Supplied in liquid form.	££	**KÖMMERLING** 'Ködiguard'	Ultra violet or 2 Part catalytic cure	• Laminating 2 or more uneven glass surfaces e.g. cast or drawn glass
	Polyurethane (TPU)	1.25mm thick rolls	££££	Polymar	Autoclave	• Ballistic glazing

Notes

[1] Note that multiple layers of interlayer are typically used to create the desired interlayer thickness, e.g. 1.52mm PVB can be produced using 2 x 0.76 mm layers or 4 x 0.38 mm layers

[2] A 'hot box' is a chamber used to laminate glass which subjects the unprocessed laminate to heat only, unlike an autoclave which applies both heat and pressure. The laminates are individually sealed within purpose made plastic bags where a vacuum is applied which de-airs and 'squashes' the interlayer.

Laminated glass – standards and branding

There are a range of standards which can be used to establish the performance and durability of laminated glass. The following are some of the key standards to be aware of:

Production of laminated glass

BS EN ISO 12543: 2011 Glass in building. Laminated glass and laminated safety glass

BS EN 14449:2005 Glass in building. Laminated glass and laminated safety glass. Evaluation of conformity/product standard (The Harmonised European Norm for CE Marking)

These standard covers factory production control during processing as well as the processes required to evaluate the conformity for laminated safety glass for use in buildings. Companies who are processing glass should be able to demonstrate that the laminated glass which they are supplying complies with this standard. CE marking to BS EN 14449 is a legal requirement.

Performance specification

When laminated glass achieves a specific performance criteria, for example providing a predetermined resistance to a person trying to break through the glass, a range of standards are used to define the performance and ensure the appropriate combination of glass and interlayer are selected. The two standards listed below are commonly used to define a performance classification:

BS EN 12600:2002 Glass in building. Pendulum test. Impact test method and classification for flat glass.

This test standard is intended to classify flat glass products into three principal classes by performance under impact and by the mode of breakage. The classification relates to increased robustness and personal safety by the reduction of cutting and piercing injuries to persons and the containment characteristics of the glass. The classification is recorded as number, letter, number, e.g. 1C1, to describe and categorise impact performance.

BS EN 356:2000 Glass in building. Security glazing. Testing and classification of resistance against manual attack.

This test standard specifies requirements and test methods for security glazing designed to resist actions of force by delaying access of objects and/or persons to a protected space for a short period of time. The standard classifies security glazing products into categories by resistance to actions of force.

CPNI are concerned about forced entry attacks from terrorist threats and have developed a separate standard to address this threat. Products classified to BS EN 356:2000 do not necessarily meet the requirement of this CPNI standard. If you have any concerns, please contact your CPNI POC.

Compliance with the standards

It is possible to identify whether a glass product has been laminated (and/or heat treated) by checking the branding with which it has been marked. It is not always a legal requirement to brand a glass in a location which will be visible when glazed, however this is best practice and highly recommended. If the glass processor is a member of the BSI Kitemark scheme they are permitted to include a BSI Kitemark license within the branding. The branding, shown in Figure 2, may contain multiple product standards, as well as the ones mentioned in this test standard. If used, the BSI Kitemark should be visible and located in the corner of a pane of glass.

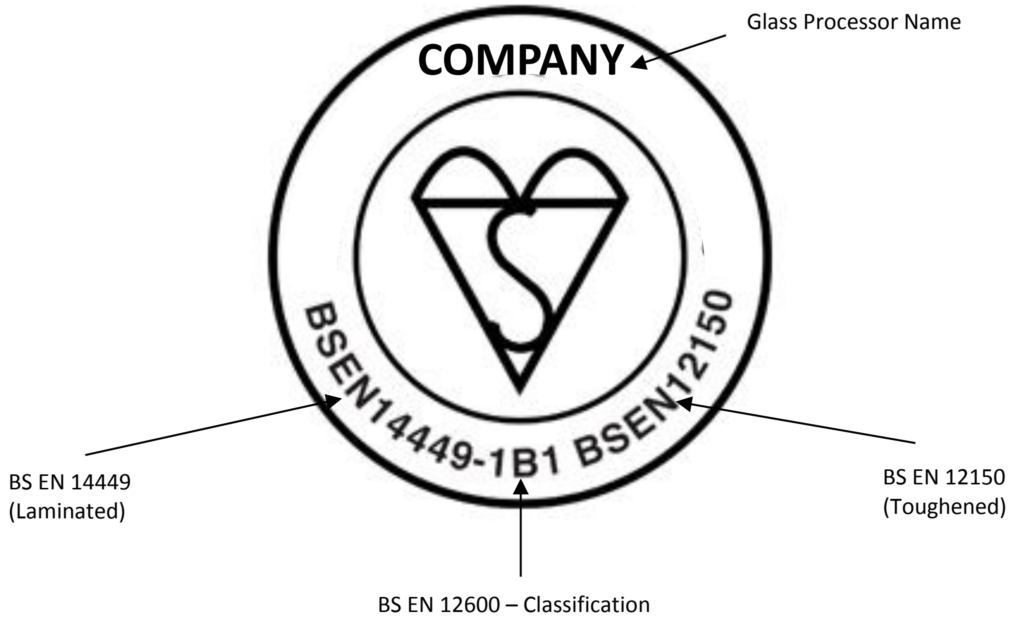

Figure 2: Product brand intended to identify source, glass type and impact performance

Use of interlayers to achieve blast performance

A wide range of interlayers have been developed for different applications. If there is a blast performance requirement, it is important that the appropriate interlayer is selected and information provided to ensure that the required performance is achieved. The following points should be noted:

- PVB interlayer should be specified and used. When used within an insulated glass unit (IGU) the laminated pane should be placed on the side of the IGU which is closest to the people or asset requiring protection.
- PVB interlayers which are at least 1.52mm (or thicker) are recommended. Different varieties of PVB interlayer are available and the performance of these are currently being reviewed by CPNI.
- EVA has been observed to perform poorly against a blast threat, and is not recommended for use in laminated glass where a blast performance is required.
- It is extremely important that the type and thickness of interlayer is clearly defined to the supply chain as there is a widespread lack of understanding concerning the different interlayer types and associated levels of performance which can be achieved. If the wrong interlayer type has been installed, it may be difficult to detect this and identify the associated risk of injury.
- It is important to check that the laminated glass supplier has the appropriate expertise and quality control in place e.g. successful testing in accordance with the relevant product standards which have been conducted by a notified body and continue to be monitored.
- Care must also be taken to ensure the durability of the interlayers after installation. Guidance can be found on the CPNI website.

Other factors which may affect the blast performance

It is known that the properties of the interlayer i.e. the material properties and adhesion bond between the interlayer and the glass, used in laminated glass are influenced by temperature, and may affect the blast performance. CPNI are currently reviewing this effect.