High performance laminates with PVB and PET

Safety standards for glass are being met by a range of novel glazing systems. The following article describes the construction, testing and application of breakthrough glazing systems produced on standard laminating equipment. The special feature of this process is the use of bi-layers of PVB and PET with a hardcoat surface to significantly enhance the properties of conventional glazing under conditions of severe abuse or attack.

FIG. 1

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Modern architecture, with its increasing dependence upon glass, is stimulating the development of newer and safer glazing designed to meet tighter environmental and regulatory standards, while providing secure workplaces for employees and preserving the aesthetic intent of the building structure.

Safety threats

The predominant safety threat from glazing is glass fragments - flying or falling after deliberate or accidental breakage. These can be macro-shards from annealed glass, massed particles from tempered glass or micro-spall from the protect face of security glass under bullet, bomb or similar attack. Such shrapnel can be contained by providing the protect side of the glass with a polymeric face which must be:

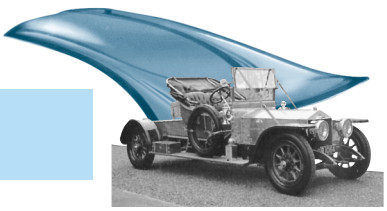
- integral with the glass;
- scratch and damage resistant;
- free from delamination and discoloration;
- designed for the lifetime of the structure;
- optically pure and free from distortion.

External surface coating

One solution is a composite film of PVB(polyvinyl butryaldehyde)/PET (polyethylene terephthalate), factory laminated to the glass surface. The PVB functions as an adhesive layer while PET, coated with an abrasion-resistant poly-siloxane hardcoat, presents a tough, optically flat external surface. The make-up of the bi-layer can be designed to meet the anticipated threat level but a typical construction would be PVB (0.76 mm) PET (O.19 mm) - adding just 0.95 mm to the glass thickness.

Manufacturing process

This composite is manufactured in a batch process with standard glass laminating equipment. The lay-up is de-aired and autoclaved under vacuum using a glass cover-plate to the polymer face - so the only standard requirement is a vacuum port to the autoclave and basic vacuum bag technology. Great care must be taken during manufacture to exclude surface contamination which can permanently imprint the polymer surface and cause loss of optical properties. The real challenges in developing this product lie in formulating the PVB interlayer to give adequate adhesion to both glass and PET and to produce a durable high-performance hardcoat for the external surface.



Essential properties

The bi-layer can be applied to monolithic glass but is more commonly applied to laminated glass, where it significantly enhances penetration resistance. The process is not limited to flat glass - bends are quite common (this is an off-shoot of windscreen coating technology). The finished laminates display a range of basic properties which are essential to meeting the needs of the primary glass market:

- *optics*: equivalent to glass. Flat and free from distortions, clear, non-yellowing and haze-free;
- *fire resistance*: self-extinguishing under ANSI Z 26.1-83 Test 24;
- *solvent resistance*: methanol, toluene, acetone, MEK, methylene, chloride and gasoline have no effect on the laminate surface;
- *abrasion resistance*: typical Taber abrasion test results position the laminates in the high performance area (Table 1).

TYPICAL TABER ABRASER* TEST RESULTS

Per cent haze increase

Abrasion-resistant Polycarbonate "A"	*Abrasion-resistant acrylic*	*Hardcoat PET*
2.3	1.4	1.7

**ANSI Z-26.1-1983 Test 34; ASTM D 1044-85*

TABLE 1

Advantages

PVB-screened laminates can be glazed using conventional sealing and framing systems, taking care to ensure that the selected design of the glass/frame/seal is matched to the anticipated threat. In service, laminates can be cleaned with normal glass cleaners such as mild soaps and detergents. Strongly alkaline cleaners should be avoided, as should sharp implements which could damage the polymer surface.

There are four key areas where the performance of conventional glazing can be compared and contrasted to that of the PVB/PET protected glasses described above:

- bullet-resistant glazing;
- bomb-resistant glazing;
- manual attack glazing;
- hurricane-resistant glazing.

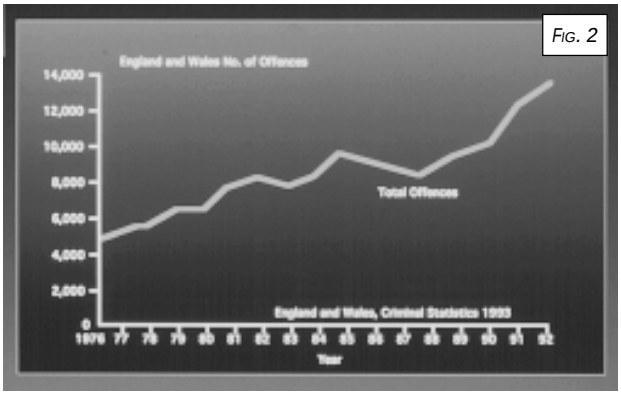


FIG. 2

Bullet-resistant glazing

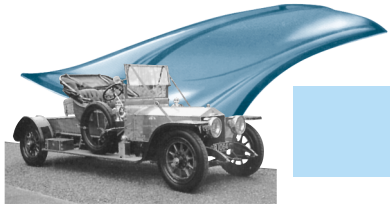
Most bullet-resistant glasses are multi-layered glass/PVB laminates, sometimes with an in-board polycarbonate layer. The key needs of minimum thickness and low weight must be balanced against the ability to stop bullets, with no danger to the person on the protect side of the glass. When attacked, the front layers are shattered, absorbing a large proportion of the energy. Subsequent layers absorb the lower-level transmitted shock wave. The rear of the glass is designed to minimise spall, usually employing a 1-mm glass sheet as spall-limiter. However, if the protect side of the glass is laminated with PVB/PET, then not only is spalling eliminated completely, but it is also possible to reduce the weight and the thickness of the installed laminate, while maintaining the same level of protection (Table 2).

Blast-resistant glazing

When a bomb explodes much of the injury and damage inside adjacent buildings is caused by glass fragments. Although much blast testing is done using actual high explosives, there is one recognised test standard for assess-

TABLE 2

Glass type		**Bullet resistant classification**			
		G0 *9 mm* *Handgun*	*G1* *.357* *Magnum*	*G2* *.44* *Magnum*	*S86* *12 bore* *Shotgun*
Typical conventional bullet glass	Thick	23 mm	36 mm	42 mm	42 mm
	Weight	52 kg/m^2	86 kg/m^2	98 kg/m^2	98kg m^2
Bullet glass with PVB/PET	Thick	20 mm	28 mm	35 mm	35 mm
	Weight	48 kg/m^2	64 kg/m^2	81 kg/m^2	81 kg/m^2



...PVB

ing blast-resist glazing - DN52290 Part 5 uses a static 'shock tube' to reproduce the pressure wave of an explosion. Test materials are classified D1, D2 or D3 according to performance (Table 3).

Use of PVB/PET protection allowed significant reductions in glass thickness and weight at each level of test. All of the PVB/PET glasses gave zero spall from the protect side, showing that they are especially suitable for sensitive areas such as computer halls and areas of human traffic. The central deflection of the glass after testing was of the order of 80-100 mm, indicating the ability of the glass to absorb energy while retaining integrity.

Manual attack glazing

In post offices, kiosks, and control rooms, zero spall performance - and complete peace of mind for the employee - is possible for even the most frenzied attack. When applied to monolithic 3 mm glass it will meet BS5544 and UL972 glass standards.

Hurricane-resistant glazing

Massive damage inflicted by recent hurricanes on the eastern seaboard of America (mainly Florida, where Hurricane Andrew in 1992 wreaked US$ 26 billion damage overnight) has prompted new legislation to ensure that buildings are glazed to withstand even the toughest storm. Virtually every study conducted after Hurricane Andrew identified the loss of windows and doors as one of the leading causes of building damage. Nearly 70 per cent of South Dade County homes sustained substantial window damage. The primary cause of initial window failure is breakage by flying debris. Once this occurs, winds enter the structure through broken glass. This generates increased internal pressure to roof and walls, subjecting them to forces beyond their design capabilities and blowing out the rest of the windows and often the walls and the roof as well.

As of 1 September 1994, Broward and Dade Counties implemented new building codes requiring all openings

TABLE 3

Test level	*Traditional glass* mm	kg/m²	*PVB/PET protected glass* mm	kg/m²	*Equivalent high explosive*
D1 (O.5 Bar)	14.5	29.0	8.4	17.0	50 kg @ 25 m
D2 (1.0 Bar)	21.0	43.0	11.8	24.0	50 kg @ 20 m
D3 (2.0 Bar)	30.0	54.0	21.5	46.0	150 kg @ 18 m

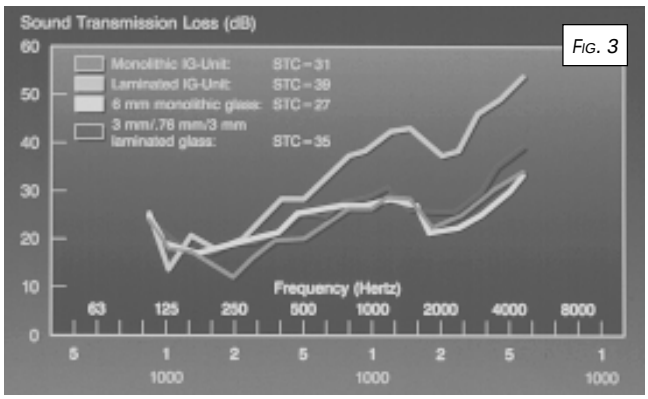


FIG. 3

to pass flying missile impact and windloading tests in order to be granted certificates of occupancy. The tests come in two parts:

Part 1

Window is impacted twice by a 9lb 2x4, timber projectile fired at 34 mph. Three samples are impacted in different positions.

Part 5

Impacted windows from Part 1 are subjected to cyclic pressure testing in a variable strength cycle, replicating the strong positive and negative pressures characteristic of hurricane winds. Each window undergoes 9,000 push/pull cycles, and to pass the windows must not only remain in their frame but remain virtually integral with no significant vents.

Monolithic glass with PVB/PET laminated bi-layer on the protect (household) side of the glazing was the first glazed option to meet the new codes and provide a sensible and attractive option to metal shutters - or to the traditional time-consuming remedy of boarding-up whenever a storm threatens.

Inboard PVB/PET/PVB interlayers

One characteristic of PET sheet is its excellent dimensional stability, which makes it a suitable carrier of numerous complex designs and patterns. Laminating decorated PET has not usually been successful largely due to inconsistencies in adhesion performance to glass. However, co-operative developments in PVB formulation, PET surface treatment and compatible inks and carriers has resulted in a whole new family of decorative laminates characterised by their precision printing and high

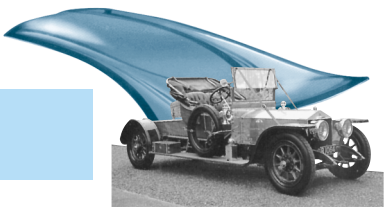


FIG. 4

mechanical property profiles. The decorated PET is sandwiched between two layers of specially formulated PVB, de-aired and autoclaved in the normal way to give a crisp, clean laminate. An infinite variety of patterns and colours are possible - limited only by the imagination of the artist. The major market for such laminates is probably partitions - but there have been some outstanding collages in familiar themes - which challenge all of us to put our imagination to work.

A glimpse of things to come

This is just a brief insight into some of the high-performance laminates being developed, bringing with them opportunities and new challenges for manufacturers, architects and builders.

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Fig. 1
Inverted pyramid, The Louvre (Paris, France)

Fig. 2
Statistical data on use of firearms in crimes

Fig. 3
Sound transmission / frequency data

Fig. 4
Security threat from rioting and looting