Understanding The Versatility Of Laminated Safety Glass As A Glazing Product Of The Future

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Abstract

The structural performance of laminated glass is dependant on its geometric properties such as aspect ratio, slenderness factor and composition. A theoretical model for the load sharing in asymmetric laminated compositions is discussed and simplified analytical procedure developed.

The application of heat strengthening and tempering to the components of laminated glass enhances the structural behaviour of the composite.

The use of solar control features and high performance coatings make laminated glass an ideal product for energy efficient buildings especially in warm climates. Furthermore, the opportunities in the selection of a variety of glass types offer a wide design palette.

Fig 1

Stress distribution on a laminated ¼ plate subjected to lateral pressure.

Introduction

The advent of powerful computing facilities has made stress analysis of laminated glass subject to lateral loading readily available to most engineers and scientists.

This has virtually eliminated the need for correction pressure factors to be applied to normal annealed glass design charts. The effects of the capacity of the pvb interlayer at elevated temperatures can also be correctly modelled.

It must be recognised that laminated glass does not vacate the frame system even after glass fracture has occurred. Tests have shown that both lites in the laminated composition do not necessarily fracture under load at the same instant. This really indicates that there is a latent strength associated with laminated glass.

Theoretical Issues of Laminated Glass Behaviour

Laminated glass like monolithic glass undergoes large deflections when subjected to lateral loads. Tests have shown that the response of laminated glass panels to lateral loading to be between the two extreme cases namely monolithic and layered. Vallabhan [1] has also theoretically demonstrated that for certain aspect ratios the performance of laminated glass to be better than equivalent thickness monolithic panels. Jacob [2] also validated this finding.

The mechanical properties like shear modulus of the pvb interlayer influence the performance of the laminated glass. The new high performance interlayer from DuPont called Sentry Glass® Plus is an example of the improved benefits from using modified interlayers.

Load Sharing in Asymmetric Laminated Glass.

The concept of load sharing between the components of the laminated glass is not new. It has been well recognised [4 & 5] that under the application of lateral loads the two components of the laminated panel share the applied load equally. This is only applicable when the two components of the laminated glass have equal thicknesses.

Practical tests have shown that the load distribution between the layers of laminated glass is a function of the thickness squared and not the thickness cubed as would be expected. Asahi have also demonstrated this behaviour [6] The centre deflection of the laminated glass panel was measured and checked against the theoretical values obtained from an FEA (finite element analysis).

Figure 1 below shows the stress build up in a quarter plate with asymmetric layers of glass (3 mm + 0.76 + 6 mm). There is a slight increase in the maximum principal stress when the thinner component is subjected to the maximum loading.

Using a laminated glass panel consisting of 3 mm annealed + 0.76 mm pvb + 6 mm annealed glass - 1800 mm X 1200 mm in size subject to a lateral pressure of 2.5 kPa. The results of an FEA on this product, given in Table 1 below indicate the following maximum stresses and deflections when both surfaces are exposed to the design wind pressures.

Table 1

Analysis on Laminated glass

Pressure – 2.5 kPa	Deflection mm	Maxm Stress - MPa
Positive	12.1556	19.258
Negative	12.1552	18.257

It can be observed that there is only a slight increase in the maximum stress in the 3 mm thick plate even though there is a significant difference in the glass component thickness.

Another analysis using an asymmetric construction of 3 mm annealed + 0.76 mm pvb + 8 mm annealed for a panel 1800 mm X 1200 mm the stresses and deflections developed are given in Table 2 below

Table 2

Analysis on laminated glass

Pressure – 2.5 kPa	Deflection mm	Maxm Stress - MPa
Positive	5.402	15.402
Negative	5.402	14.294

Again there is only a slight increase in the maximum stresses developed in the thinner layer of the laminated glass. This indicates that the load is shared between the components of the laminated glass.

This is an important feature of laminated glass. All architectural buildings are subjected to both suction and positive wind loads. They are generally of different magnitudes. The correct selection of the components of asymmetric laminated glass can be effectively used to accommodate these different pressures.

Test Results on Asymmetric Laminated Composites

A series of full-scale tests on asymmetric laminated glass was conducted in this investigation. The tests were carried out using two different sample sizes. Furthermore, the tests were conducted with both components of the asymmetric lamination being exposed to the lateral loads. This was carried out to be able to quantify the load sharing between the laminated components.

Table 3 provides the test results obtained. The asymmetric laminated glass construction consisted of 1 layer of 4 mm glass + 0.76 mm pvb + 6 mm thick annealed glass.

It can be readily seen that irrespective of which component of the asymmetric laminated glass is exposed to the applied lateral load, the glass with the maximum surface tensile stress and with some inbuilt flaw will fail first.

Generally it was found that the top layer of the laminated glass also failed if the applied load was maintained for a short period after the initial fracture of the bottom layer occurred. On the rare occasion both layers virtually failed at the same time, within seconds of one another. Even after both lites of the laminated glass had failed the fractured panel did not vacate the frame.

If a wet sealant system is used for the installation then it is likely that the laminated glass will not evacuate the framing system. This characteristic provides additional security and safety to the building occupants and the structure itself.

Table 3

Computed fracture Stresses
*Note * indicates the panels with the 6 mm glass component in tension. All other samples were tested with the 4 mm thick annealed component in tension.*

Sample no:	Panel Size mm	Pressure at Fracture (kPa)	Measured Centre Deflection mm	Calculated Stress at Fracture (MPa)
1	1440 X 1248	12	20	41.25
2	1440 X 1248	12.5	21	42.75
3	1440 X 1248	11.5	19.5	38.25
4	1440 X 1248	13.5	22	45.74
5	1440 X 1248	14.5	23	48.75
6	1440 X 1248	13.5	22.5	45.74
7	1440 X 1248	12.5	21	42.75
8	1440 X 1248	14	22.5	47.25
9	1440 X 1248	16	25	53.0
10	1440 X 1248	14.5	23	48.75
11	1440 X 1248	14.5	22.5	48.75
12	1440 X 1248	16.5	25	54.6
13*	1440 X 1248	11	11	38.25
14*	1440 X 1248	14.5	22.5	48.75
15*	1440 X 1248	15.0	23.0	50.0
16*	1440 X 1248	14.5	22.25	48.75
17	1748 X 1248	12	26	48.25
18	1748 X 1248	10.0	24.0	38.45
19	1748 X 1248	11	25	44.6
20	1748 X 1248	10.5	24	42.85

Computer modelling for lateral loads

The key factors that need to be considered in modelling laminated glass are:

- The boundary conditions
- The mesh size
- The material properties of the laminate composites
- The non linearity in the analysis
- The type of analysis – total Lagrangian, Eularian or modified Eularian

Each of these factors is directly related to the quality of the analysis. It is important to verify that the FEA model being used is capable of handling the non-linearity in composite panels. Some commercial FEA models are not suitable for use with laminated glass.

The use of a three dimensional model can be of benefit.

Latent Strength of Laminated Glass

During load tests conducted on laminated glass it was found that fracture generally occurred on one layer first. If the lateral load was maintained even after initial fracture then the second layer fractured. It must be noted that even after both layers of the laminated glass had fractured there was no evacuation of the laminated glass from the frame. This is a key factor that is often not recognised.

The load duration effects on glass behaviour are well documented. It could be considered that load durations effects are not a key issue as far as laminated glass behaviour is considered. It could be even considered that a lower allowable stress be used for laminated glass. The old concept that laminated glass of equivalent thickness is generally weaker than monolithic glass is incorrect. Jacob [3] reported that the earlier development of membrane stresses in laminated glass due to thickness effects permit the distribution of stresses in laminated glass earlier thus increasing its ability to resist lateral loading.

The fracture origin was observed to relate to the surface condition of the laminated glass. Consequently the allowable design stress for laminated glass is a function of the surface condition of the glass component used to manufacture the laminated glass. Using both statistical methods or fracture mechanics criteria it is considered that the same allowable stress be used for both annealed and laminated glass.

Benefits of heat strengthening and toughening to the components of laminated glass

- Additional strength
- Asymmetric composites facilitate sound control
- Low e and reflective composites could be used in typically single glazing
- Combinations of low e, reflective and body tinted glass in the one composite is possible.

Laminated glass can be assembled with a myriad of spectral compositions to provide the optimum spectral characteristics for a single glazing system. For instance a laminated composite consisting of a body tinted glass with a soft reflective coating + a tinted interlayer + a clear glass with a hard coated low e layer will offer a glass composition with a shading coefficient of 0.38 and a u value of 2.8 This is extremely useful when an I G unit is not required. Furthermore, the interlayer can be supplied in an exciting range of colours to match any other aesthetic feature.

Safety and Security with Laminated Glass

Many leading architects recognize that the use of laminated glass in the facades of high-rise buildings eliminates the serious danger of falling glass. Unlike all types of monolithic glass, laminated glass remains intact when broken. This characteristic ensures on going closure of the building envelope and the continued protection of the building interior and occupants. This is why in Thailand Regulation 48 (1997) Item 28 requires the use of laminated glass in the external walls and corridors of most high-rise buildings.

Security Glass

The tear and penetration resistance of a PVB interlayer helps make laminated glass resistant to intrusion. 6.38 mm thick laminated safety glass will provide some protection for residences and shop windows against vandalism and 'smash and grab' attempts. Most shopfronts in Australia use laminated glass. In the event of a breakage the laminated glass continues to provide a barrier to entry and there is no need to board up the shopfront prior to replacement of the glass.

By using additional layers of pvb in the laminated composition increased penetration resistance can be developed. For example a laminated glass with 1.52 mm thick pvb interlayer will provide additional penetration resistance. Jewellery stores shopfronts containing 11.52 mm "bandit-resistant" laminated glass (5mm float glass +1.52mm PVB + 5mm glass) has withstood determined break-in attempts by would-be burglars with sledgehammers. Bandit - resistant glass can be tested to European Standard EN 356 or to Underwriters Laboratories (USA) Standard UL 972.

Laminated security glass can be designed to resist forced entry with implements such as pick axes, hammers and crow bars. This type of glass is intended to delay access by the attacker. The pvb interlayer must be torn before a large enough opening can be created to permit entry. This provides increased time for detection and activation of security systems. Test procedures available for forced entry testing include EN 356, and ASTM F 1233 - 98 Standard (USA).

Bullet Resistant Glass

Multi layers of glass and pvb are used in the same laminated composition to make bullet resistant glass. The bullet fractures the layers of glass on the attack side of the laminate. The process of fracturing the layers of glass results in the absorption of the energy in the bullet causing its slow down and ultimately being captured within the multi lamination. The multiple layers of interlayer disperse the shock of the impact and hold together the broken glass fragments.

The type and velocity of the projectile will determine the total laminate thickness and the multi-laminate construction. Generally total 'BRG' thickness varies from around 27 mm to 60 mm when tested to national standard classifications. Test procedures available for classification of bullet resistant laminated glass include AS/NZS 2343:1997, European Standard EN 1063, Underwriters Laboratories UL 752, H.P. White Laboratory Test HPW-TP-0501.01, National Institute of Justice (USA) Standard 0108.01.

Energy Efficient Glazing Improvements Possible With Laminated Glass

Laminated glass offers the potential for a vast array of options in regard to the solar performance of building glazing. Laminated glass constructions incorporating the latest coated glasses and spectrally selective tinted glasses can minimize solar heat gain while allowing high levels of visible light transmittance. Low shading coefficients and reduced U-value can be achieved in a single glazing.

Laminate configurations include:

- Glass with a tinted interlayer
- Glass with reflective coatings
- Glass with a body tint
- Glass with metallic coatings
- Glass with a Low E coating – pyrolytic coating
- Or Laminates combining one or more of the above products.

Estimates of the spectral characteristics of any composition of laminated glass can be made using proven computer programmes.

Most metallic coated glasses can be laminated. When these coatings are positioned within the lamination they are protected from harmful dirt and surface damage through cleaning and handling. It is always recommended that a theoretical thermal assessment be carried out when using laminated glass with one or more heat absorbing components.

Bomb Resistance

A recent innovation in interlayer composition has resulted in a laminated glass capable of bomb resistance. The new SentryGlas® Plus used with ordinary annealed glass was successfully tested by DuPont to resist a bomb with a peak pressure of 450 kPa. [7] Dupond Laminated Glass News April 2003. This is exciting in that glass will no longer be the weak link in any building in terms of bomb resistance.

UV Resistance

Laminated glass with the standard pvb interlayer has been shown to screen in excess of 98 % of UV radiation. This property is invaluable in the prevention of fading.

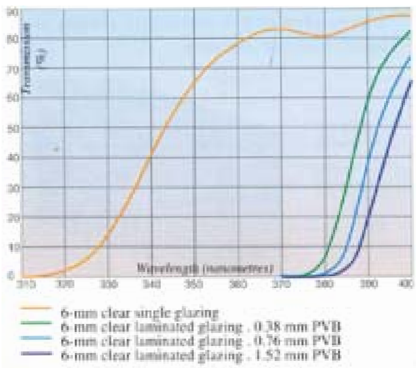

Fig 2

Percentage transmission versus wavelength for 6 mm monolithic clear glass and clear laminated glasses (UV cut-off is 380 mm)

Cyclone (Typhoon) Resistant Glass

Since Cyclone Tracy devastated Darwin in 1974 we have developed and used cyclone resistant glass with up to 4 mm of PVB (multiple PVB layers) in cyclone prone areas of Australia This product is designed to resist normal impact from a 4 kg piece of wood having 100 mm x 50 mm cross section striking the laminated glass with a minimum velocity of 15 m/s with no penetration.

After hurricane Andrew in 1992 several counties in Florida enacted building code changes and new test standards, which require the building envelope to be protected from penetration by windborne debris and wind pressure. Various glazing systems have been successfully tested and are being used in residential and commercial buildings. The new DuPont SentryGlas® Plus ionoplast interlayer is one such product. Windows and doors with laminated glass containing 2.28 mm of SentryGlas® Plus have successfully complied with the new standards.

Conclusions

The versatility of laminated glass is now being gradually recognised. Even when strength is required laminated glass can be provided with either heat strengthened or toughened glass components.

Laminated glass can be manufactured for virtually all applications for providing protection against impact, theft and burglary to solar control and UV protection applications. It can be used for structural glazing and with any combination of insulating glasses.

Laminated glass can be used for bullet resistance and bomb protection in buildings. It is a versatile product and offers latent strength and integrity. In the event of glass cracking and failure the panel generally remains in place thus protecting the built environment.

Toughened laminated glass can be used in structural applications with patch fittings and cable systems.

Laminated glass is available in different thicknesses, types and composition to provide a solution to a variety of applications in today's building. As it offers solutions to all our needs and creates opportunities for the future, it should be included amongst the most versatile of all glazing products currently available.

References

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