

Lightweight Laminated Glasses for Building Applications Without Compromises on Performances

Richard Villey^a, Hadrien Heuclin^b, Keyvan Piroird^c

- a Saint-Gobain Research Compiègne, France, richard.villey@saint-gobain.com
- b Saint-Gobain Glass France, France, hadrien.heuclin@saint-gobain.com
- c Saint-Gobain Glass France, France, keyvan.piroird@saint-gobain.com

Abstract

When a building glazing requires enhanced safety, security, or resistance to extreme weather conditions, laminated glass is typically the solution of choice. This type of glass is generally composed of two sheets of float glass bonded together with a polyvinyl butyral (PVB) interlayer. While float glass thickness is usually a multiple of one millimeter, PVB layers are commonly available in fractional inch measurements (*e.g.*, 0.38 mm, 0.76 mm). However, there is no inherent reason why optimal laminated glass configurations must adhere to these standard thicknesses. By thoroughly testing experimentally the impact resistance of laminated glass, we have optimized both glass and PVB thicknesses to develop a new range of lightweight laminated glasses. This innovation achieves up to a 50% reduction in weight and is compatible with usual manufacturer capabilities and industry standards. The breakthrough lies in identifying the ideal glass-to-PVB thickness ratio. This significant weight reduction is accomplished without compromising performance in terms of impact resistance (EN356 and EN12600 levels of performance are the same as in an usual -thicker- laminated glass), wind load resistance (stress and deflection are kept identical to the usual window compositions without laminated glasses) or processability (these new laminated glasses can be cut and assembled in Insulated Glazing Units without hardware modifications of the transformation lines).

Keywords

Lightweight, laminated glass, building

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1. Introduction

Laminated glass has been used for more than a century (Benedictus, 1909) in building and automotive applications to protect persons against injuries by glass shards, to prevent objects or persons from passing through a glazing, and to delay forced entry through a door or window.

A laminated glass is made of at least two glass plies glued together by a polymeric interlayer, in most of the cases PolyVinylButyral (PVB). A laminated glass can be as thin as 4 mm, for thin windshields, or as thick as 10 cm or more, with much more than 3 layers, in the case of bulletproof glass. While it appears evident that thicker laminated glass can support more energetic impacts without perforation, there are only very generic rules to design laminated glasses compositions depending on the applications: for example, the minimum thickness in the case of PVB is 0.38 mm (15 mils) since before the 1950s, because a thinner film would be hard to extrude and then to manipulate for assembling a laminated glass; when anti-intrusion properties are required, multiples of 0.38 mm are used depending on the severity of the threat (more than 10×0.38 mm can be used for high-range applications).

In residential buildings and houses in Western and Southern Europe, standard windows since the 1970s are made of an insulated glazing unit (IGU) with typically two 4-mm glass plies. The glass thickness may vary and is chosen to withstand typical wind loads. But when a safety or security function is needed, then one of the two 4-mm plies is usually replaced by a laminated glass of typically 8 to 9 mm, made of two 4-mm glasses and an interlayer of typical thickness 0.38 mm or 0.76 mm, resulting in an increased thickness of glass.

However, there is no inherent reason why optimal laminated glass configurations must adhere to these standard thicknesses. It is for example relevant to use glass that is thinner than 4 mm if the quasi-static loads applied to the glazing are not too severe, to increase the handling ability of the glazing and to reduce its carbon footprint (in a 44.2, *i.e.* two 4 mm glasses linked by 0.76 mm PVB, the glasses account for 85% of the total CO₂ footprint of the product (Saint-Gobain Glass France, 2026)).

Such an approach has already been applied in the automotive industry where windshields have been using glasses of 2 mm and less since decades, and the existing products have no difficulty complying with the applicable standards. In the building sector however, it is still uncommon to find laminated glasses using glass plies of 2 mm or less. One reason for that is the compliance to safety and security standards: for example, in Europe, safety of persons is assessed by EN12600 (pendulum test) and security against manual attack by EN356. For windows ensuring a guardrail function, level EN12600 1B1 (maximum level of performance) is required; and for roof windows, level EN356 P2A is required to avoid for example perforation due to hail. While a 44.2 complies with both these levels, this is not the case of a 22.2 (Guardian Glass 2026; Saint-Gobain Glass 2026). Similarly, a 44.6 will comply with EN12600 1B1 and EN356 P5A but a 33.6 or 22.6 will not (AGC 2022; Guardian Glass 2026; Saint-Gobain Glass 2026).

We present in this paper how we applied a well-known experimental method (the mean break height method) to quantify the relative importance of glass thickness and PVB thickness on the final performance of laminated glass to the EN356 ball drop test. Based on these quantitative comparisons, we show that new laminated glasses can be designed, that are thinner than the usual products on the market, but with similar impact resistance performance.

2. Effect of material parameters on impact performances of laminated glass

A test according to EN12600 or EN356 on laminated glass is essentially a binomial test: either the impactor goes through the laminated glass, and it fails, or it is not pierced, and it succeeds. To transform such a pass-or-fail test into a quantitative test, a method has been used on laminated glasses since the 1960s (Lavin 1966): the mean break height. The simple method is explained on Fig. 1: a first laminated glass is tested at a given height according to a given impact test; if the glass passes the test, a new one is tested at a higher height; if not, a new glass is tested at a lower height. The difference between the heights tested should be constant.

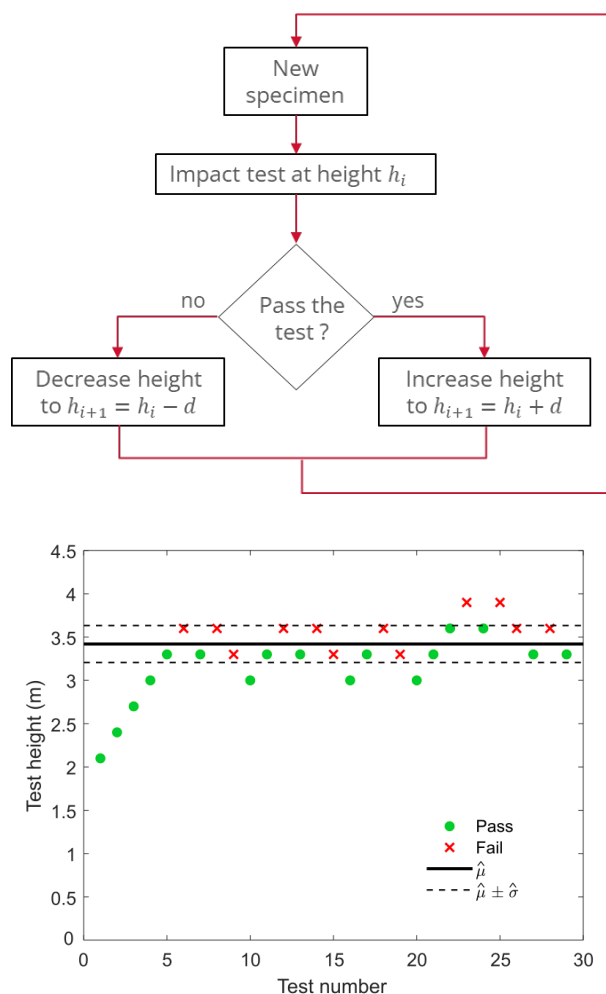


Fig. 1: Top: Procedure of the “Mean Break Height” (MBH).

Bottom: Typical raw data generated by the mean break height procedure, starting at 2.1 m with a step $d=0.3$ m.

The sequence of heights explored in the process (Fig 1. Bottom) converges and then oscillates around a given height. This height, the mean break height $\hat{\mu}$, can be mathematically computed from the sequence using the method developed by Dixon and Mood (1948). The standard deviation $\hat{\sigma}$ can also be computed to estimate the dispersion of the oscillations around the mean value $\hat{\mu}$.

The Mean Break Height method is widely used in the automotive sector, but instead we applied this methodology to the impact test defined in the EN356 standard (for building applications) to rank levels from P1A to P4A, in which 3 balls of 4.1 kg fall on a laminated glass sample of 900 mm x 1100 mm. Fig. 2 shows the mean break height value $\hat{\mu}$, as a function of the PVB thickness for laminated glasses made

with 2 mm, 3 mm and 4 mm glass. To our knowledge, such a plot has never been presented in the technical or scientific literature nor used to design laminated glasses. The main point is to see how small is the effect of glass thickness on the resulting mean break height compared to the effect of PVB thickness. On one hand, at constant PVB thickness, increasing the total glass thickness in the laminated glass by 4 mm is estimated to increase the mean break height by 0.6 m. On the other hand, at constant glass thickness, increasing the PVB thickness by only a few tens of micrometers is enough to increase the mean break height by a similar amount. This finding, being far from obvious, allowed us to patent new laminated glass designs with tailor-made thicknesses (Villey 2019), as presented in the next section.

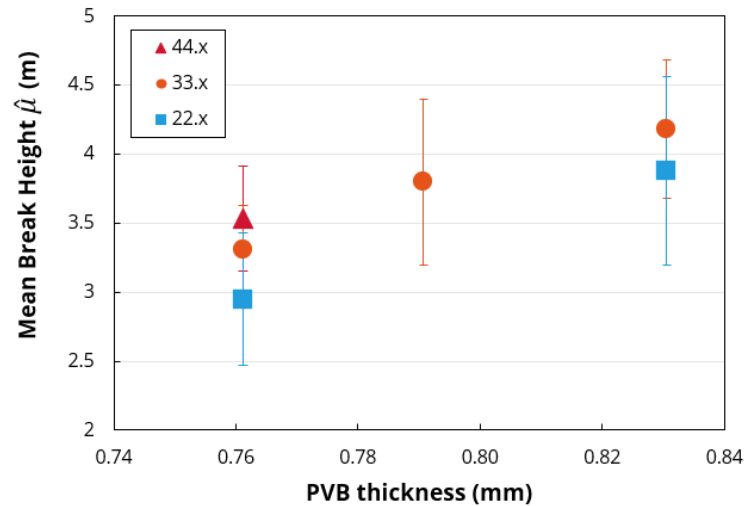


Fig. 2: Estimates $\hat{\mu}$ obtained from the MBH protocol with 3 balls according to EN356, for various laminated glasses compositions. 22.X (resp. 33.X; 44.X) are laminated glasses using two 2 mm (resp. 3 mm; 4 mm) glasses and various PVB thicknesses. Vertical error bars are the standard deviations $\hat{\sigma}$.

3. Optimized product design

The data from Fig. 2 enables to design laminated glasses with reduced glass thickness while maintaining the same impact resistance as the standard products in the market, compensating a strong decrease in glass thickness by a minute increase in PVB thickness. We have started to apply this principle to standard products using 0.76 mm PVB: 44.2 is well recognized as complying with EN356 P2A level. We have thus designed the so-called products “STADIP® PROTECT 33.2 PLUS®” and “22.2 PLUS®” using tailor-made PVBs, a few tens of micrometers thicker than the standard one, to bring the 33.2 and 22.2 products to the P2A level. These new designs have been tested using the standard EN356 method to ensure that our predictions were right and the EN356 P2A external third-party certifications were obtained for these two products.

This 22.2 complying with P2A, because of its thickness that is very close to the standard 4 mm glass used in IGU, is of particular interest to replace a 4-mm glass into a double glazing unit without significantly increasing its thickness, so that the IGU can fit in the same standard window frame. Compared to a 44.2, this thinner laminated glass is 48% lighter and has a total GWP approx. 35 % lower (expressed in kg CO_{2eq} per m² for A1-A3 stages).

An important point to consider as well in the design is the resistance to quasi-static loads applied by wind on the double glazing unit. We have compared the behaviour of a 4_16_4 double glazing unit

(two 4-mm glasses assembled with a 16 mm spacer) and a 4_16_22.2, where one of the 4 mm glass has been replaced by a 22.2 laminated glass. The verification has been done both experimentally (in a wind chamber) and numerically, using finite element softwares Abaqus and Mepla and also using the analytical formulas of standard EN16612 (all 3 calculations are very close). Notice that EN16612 is one of the bases of the soon-to-be-applied Eurocode 10 (EN 19100) that will be the normative reference framework for structural glass design. An example is given in Fig.3 on double glazing units of size 1x1.6 m², up to 4 kPa (290 km/h wind speed).

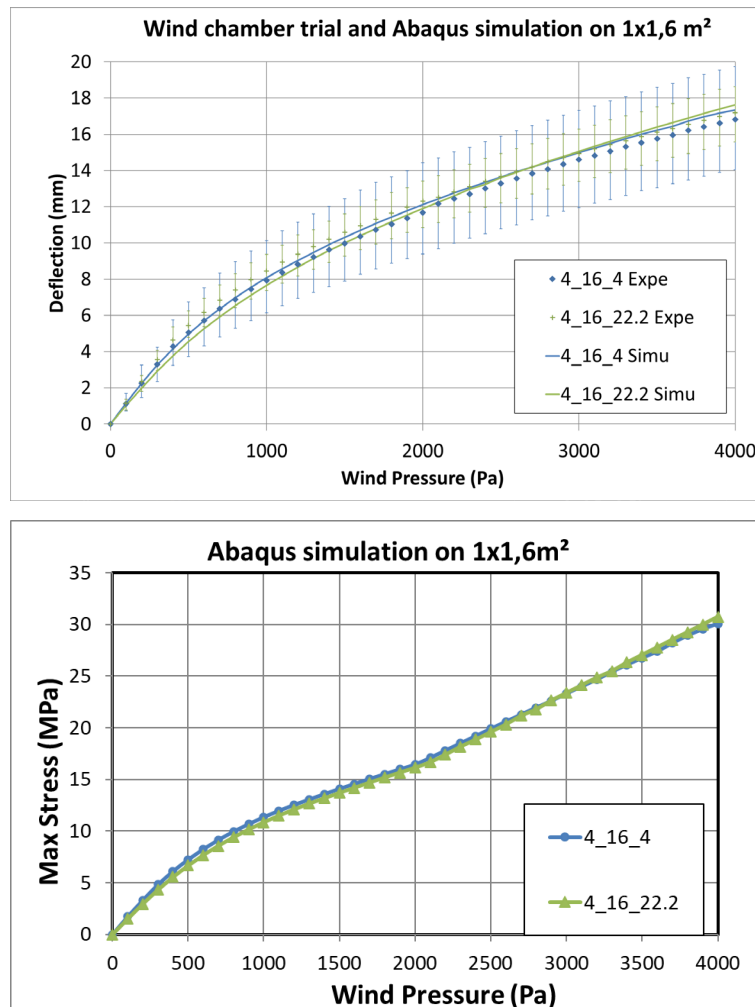


Fig. 3: Comparison of experimental and simulated deflections and stress for 1x1.6 m² double glazing units with and without laminated glass. The presented stresses are the maximum ones in all the glass plies. The presented deflections were obtained with the load applied on the laminate (if present), but when the load was applied on the other side, no significant difference was observed on the deflection vs. pressure curve. The error bars on the experimental deflection correspond to the min and max of the four measurements per composition: 2 different double glazing units in overpressure and two in depression.

4. Conclusion

Using the Mean Break Height method adapted to the EN356 ball drop test, we have studied the influences of glass and PVB thicknesses on the impact performance of laminated glasses. The main result of the MBH test, the “ $\hat{\mu}$ ” value (that can itself be called the Mean Break Height), is a simple but efficient way of appreciating the impact performance of a given design of laminated glasses. Plotting $\hat{\mu}$ against the interlayer thickness for several glass thicknesses creates a useful abacus that enables to precisely choose a composition of laminated glass given the severity of a threat.

This abacus clearly shows that PVB has a much larger effect than glass on impact performance, which enabled to design new laminates with significantly thinner glasses, reducing the glass thickness by millimeters while increasing the PVB thickness by tens of microns to ensure the P2A level is reached.

The 22.2 complying with EN356 P2A that was developed is of particular interest for use as a replacement of a standard 4-mm glass in a double glazing unit, bringing an intermediate safety level without significantly increasing the weight (+7%) or the thickness (+4%) of the double glazing unit. Resistance to quasi-static loads has also been assessed and it was found that it is possible to replace a 4-mm glass by a 22.2 laminated glass in a double glazing unit without affecting its deflection or maximal stress under wind load, following the rules of EN16612 and the future Eurocode 10.

This method was applied here to the case of design optimization for the EN356 P2A level and we are currently working on the application to other impact tests, to develop new lightweight laminated glasses.

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