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Impact Performance of Thin Glass-Polycarbonate Composite Panels

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Safety glass is usually the proper designer choice when glazing may be subjected to the impact of a person. In order to avoid people injuries, glass products must comply with appropriate safety practices. Existing technical standards classify safety glass products by mode of breakage and post-breakage behavior. Critical demanding applications in terms of self-weight saving, like high efficiency elevator cars in buildings or aircrafts and other means of transportation interiors in aerospatial and automotive industries, are currently driving the innovation in the development of safety glass. In this framework, glass-polycarbonate composite panels offer a lightweight alternative which is at once able to preserve the aesthetic and safety aspects of traditional laminated safety glass. The aim of this paper is to present an experimental investigation on the performance under impact of thin glass layer with a cellular polycarbonate backing joined together by an auto-adhesive interlayer film. Different coatings (mirror and paint) at the glass-adhesive interface are also taken into account.

Keywords: Glass-polycarbonate, Panels, Impact

1. Introduction

In several applications, glass products must comply with safety requirements to avoid damage to people. To this scope, safety glass is widely used in practice when accidental impact of a person may occur.

Existing technical standards classify safety glass products by mode of breakage and post-breakage behavior (EN 12600:2002). National regulations may specify minimum levels of impact performance with respect to the particular intended, the expected loading conditions and the possible consequences in case of breakage (UNI 7697:2014).

Typical applications consist in high efficiency elevator cars in buildings, aircrafts or, generally, other means of transportation in aerospatial or automotive industries. The need of defining self-weight saving solutions is thus currently driving the innovation in the development of safety glass.

In this framework, a lightweight alternative is represented by glass-polycarbonate composite panels, which are also able to preserve the aesthetic and safety aspects of traditional laminated safety glass. Researches currently available in literature generally deal only with mechanical properties (Tiedemann 2015), structural design (Weimar 2012) or high-speed impact behavior and ballistic response (Walley et al. 2004; Hu et al. 2013) of this composite material. However, low velocity impacts and also the presence of a coating at the bonding interface are not investigated yet.

The aim of this paper is to present an experimental investigation on the performance under impact of such thin glass layer (3 ÷ 4 mm) with a cellular polycarbonate backing joined together by an auto-adhesive interlayer film. The novelty of this products (patented by Vetreria F.lli Paci, Seregno, Italy) regards not only its new composite structure, which leads to very lighter panels in comparison with standard alternative products (for the same purposes typically a 4 + 4 mm PVB laminated glass is used), but it also involves the manufacturing process where the use of an auto-adhesive interlayer film significantly simplifies the assembly phase avoiding the traditional lamination procedure.

The current European test method to assess the impact performance of safety glass products is the so called "pendulum test" with the twin-tyre impactor body developed by CEN/TC 129/WG13 in the nineties to replace the old leather bag impactor that was in use at the time in most of European countries (Serruys et al. 1999). This test method and the related test setup result in a pendulum test that is reproducible, repeatable and additionally provides an acceptable product performance classification with respect to the response of glass panes to human impact.

In the present work, although the impact behavior was experimentally investigated by means of EN 12600 pendulum tests, the assessment procedure was slightly modified as described later on in order to better evaluate the behavior of the different product alternatives that have been taken into account.

2. Specimen identification and test procedure

2.1. Specimen

Three different types of glass-polycarbonate composite panels were investigated. Each of them is composed of a thin glass layer (t_1) with a cellular polycarbonate backing (t_2) joined together by an auto-adhesive interlayer film. All the panels had a nominal size of (876 ± 2) mm width x (1938 ± 2) mm height. The interlayer was a thin acrylic supported double coated tape ref. "230" supplied by Erga tapes.

The panels differentiated in type and thickness of the layers and in the coating according to the following specifications:

- Type S7: 7 mm (3 mm glass + 4 mm PC) with mirror coating at the glass-adhesive interface;
- Type S8: 8 mm (4 mm glass + 4 mm PC) with mirror coating at the glass-adhesive interface;
- Type V8: 8 mm (4 mm glass + 4 mm PC) painted at the glass-adhesive interface.

Additionally, Type R8: 8 mm (4 mm + 4 mm PVB laminated glass) with mirror coating was also taken into account. This reference sample allows a comparison with a standard product widely used in practice for the same purposes.

Moreover, S7 panels are 25% lighter then S8 and V8 panels, while they are respectively about 50% and 75% lighter then R8 panel type.

2.2. Test apparatus

The test apparatus for impact performance tests is depicted in Fig. 1 and it was developed to comply with the specifications of EN 12600 "Glass in building – Pendulum test – Impact test method and classification for flat glass" (EN 12600:2002).

Key

1. Main frame
2. Clamping frame
3. Impactor
4. Suspension system
5. Impact release mechanism
6. Support member

Fig. 1 Test apparatus.

2.3. Experimental test procedure

Samples were stabilized in laboratory testing room for at least 12 hours at ambient temperature (20 ± 5 °C) this condition was kept and monitored during the tests execution.

Testing started at the lowest drop height, class 3 (190 mm) and it was increased up to class 2 (450 mm). This maximum drop height was declared by the manufacturer as appropriate for the considered material. Each test piece was placed in the clamping frame so that its edges are encased in the rubber to a minimum depth of 10 mm and, when clamped, the rubber was compressed by not more than 20% of its thickness. Both impactor tyres were inflated to a pressure of (0,35 ± 0,02) MPa and the pressure was checked before each drop height.

Fig. 1 also depicts the impactor raised at the drop height, and it shows that the suspension cable is taut and that the axis of the impactor is adjusted such to be in line with the cable. Finally, the drop height is checked before the test starts.

The impactor is then released so that it falls following a pendulum movement and with null initial velocity. An additional rope connected to the impactor body and hold by a lab technician provides that the impactor does not strike the test piece more than once. The tests were carried out on the glass side only. The same sample was tested at higher impact levels if remained unbroken at a lower drop height.

3. Test results

Table 1 reports the test results based on the sample's inspection carried out after the impact. For the purpose of this paper the pass/fail criterion associated with the sample behavior highlights samples which at a given drop height are able to preserve serviceability, meaning that "pass" is assigned if the glass layer facing the impact side remains unbroken. Additionally, test requirement, mode of breakage and particles weight refer to EN 12600 notations and they are summarized below for reader's convenience.

The EN 12600 standard distinguish the following test requirements:

a) numerous cracks appear, but no shear or opening is allowed within the test piece through which a 76 mm diameter sphere can pass when a maximum force of 25 N is applied (in accordance with EN 12600 Annex A). Additionally, if particles are detached from the test piece up to 3 min after impact, they shall, in total, weigh no more than a mass equivalent to 10.000 mm^2 of the original test piece. The largest single particle shall weigh less than the mass equivalent to 4.400 mm^2 of the original test piece;
b) disintegration occurs and the 10 largest crack-free particles collected within 3 min after impact and weighed, all together, within 5 min of impact shall weigh no more than the mass equivalent to 6.500 mm^2 of the original test piece. The particles shall be selected only from the portion of the original test piece exposed in the test frame. Only the exposed area of any particle retained in the test frame shall be taken into account in determining the mass equivalent.

Table 1: Test results.

Sample ID.	Drop height / Sample behavior			Test requirement	Mode of breakage	Particles weight
	190 mm	450 mm	1200 mm			
S7-1	Pass	Pass	Fail	a)	Type B	negligible
S7-2	Pass	Pass	Fail	a)	Type B	negligible
S7-3	Pass	Pass	Fail	a)	Type B	negligible
S7-4	Pass	Pass	Fail	a)	Type B	negligible
S8-1	Pass	Fail	N.T.	a)	Type B	negligible
S8-2	Pass	Pass	Fail	a)	Type B	negligible
S8-3	Pass	Fail	N.T.	a)	Type B	negligible
S8-4	Pass	Fail	N.T.	a)	Type B	negligible
V8-1	Pass	Pass	Pass	-	-	no particles
V8-2	Pass	Fail	N.T.	a)	Type B	negligible
V8-3	Pass	Pass	Pass	-	-	no particles
V8-4	Pass	Pass	Pass	-	-	no particles
R8-1	Pass (*)	Fail	N.T.	b)	Type B	297 g / 21,5 g

(*) Failure occurred in glass layer opposite to the impact side.

Additionally, the possible modes of breakage are:

- Type A – numerous cracks appear forming separate fragments with sharp edges, some of which are large;
- Type B – numerous cracks appear, but the fragments hold together and do not separate;
- Type C – disintegration occurs, leading to a large number of small particles that are relatively harmless.

It is noticed how – when failure was reported – test requirement a) associated with Type B mode of breakage was observed, except for R8 where the particles weight after the impact at the drop height of 450 mm exceed the maximum associated with test requirement a). Typical failures are reported in Fig. 2.

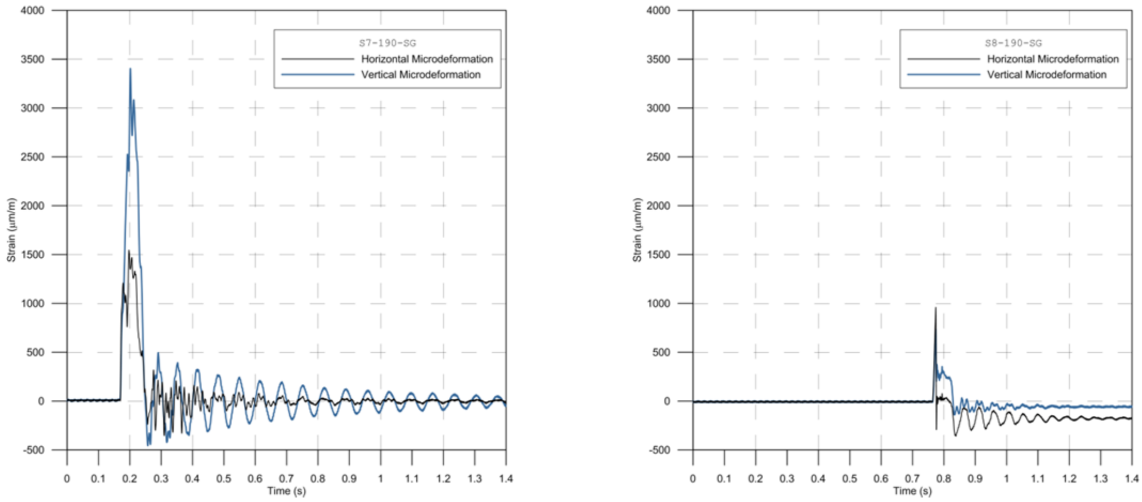
The impact response of one S7 and the R8 samples was also investigated by measuring the horizontal and the vertical micro-deformation at the impact point. The strains measurements were carried out by means of a constantan rosette strain gauge fixed to the center of the glass pane opposite to the impact side. The applied strain gauges comply with the following specifications according to EN 12600 Annex B:

- resistance at 24 °C 350,0 Ω ± 0,5%
- length of the grid 3,18 mm
- width of the grid 4,57 mm.

Fig. 3 reports the recorded strains vs. time diagrams for the above mentioned panel types subjected to impact at a drop height of 190 mm. At the drop height of 450 mm yielding of the strain gauge was observed in both cases. The collected data shows a stiffer response of the R8 sample which can be associated with a lower energy dissipation capacity.

a) b) c)

Fig. 2 S8, V8 and R8 panels following impact at a drop height of 450 mm (a), b) and c), respectively).



a) b)

Fig. 3 a), b) Strains vs. time diagrams for S7 and R8 panels, respectively, subjected to impact at a drop height of 190 mm.

4. Discussion

Fig. 4 reports, for panel types S7, S8 and V8 the percentage of specimens which, at a given drop height, passed unbroken the impact test. R8 panel type is not plotted because one sample only was tested.

It can be noticed that at the lower drop height (190 mm) all the panel types easily pass the test without any failure. At the intermediate drop height (450 mm) all the S7 and the majority of V8 panels didn't broke while S8 panels show numerous cracks (although with a negligible loss of fragments). Increasing the drop height up the maximum tested value (1200 mm), only V8 panels were able to withstand the impact without breaking.

On the basis of EN 12600 pendulum test requirements, all the analyzed products show a good safety performance and are allowed to be classified at least as 2 (B) 2. However, such classification does not allow distinguishing among the different behaviors that were observed.

Hence, the previously introduced stricter pass/fail criterion that takes into account also the serviceability aspect of the investigated element needs to be accounted. By doing so it can be noticed how the V8 panel type provides the overall better performances. Additionally, only the S7 panel type is always able to pass unbroken the test at both 190mm and 450mm drop height, while the S8 panel type (which presents a thicker glass layer with respect to S7) generally "fails" at 450mm. Consequently, the S7 type represents the lighter solution providing also the higher reliability for EN12600 class 2 (B) 2. This is probably due to the optimized ratio between the thicknesses of glass and polycarbonate layers that provides an excellent capacity of energy dissipation resulting in a significantly valuable alternative to standard PVB laminated safety glass.

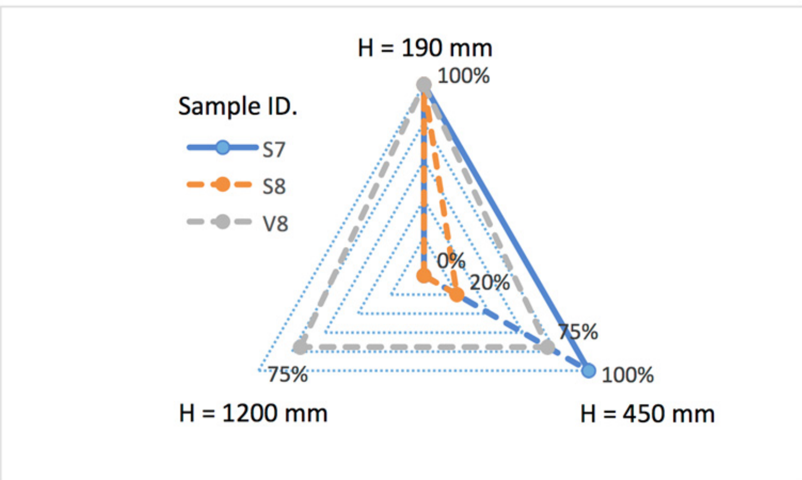


Fig. 4 Percentage of specimens passing unbroken the impact test at different drop height (H).

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References

EN 12600: Glass in building – Pendulum test – Impact test method and classification for flat glass. CEN – European Committee for Standardization, Bruxelles, (2002)

Hu, W., Wang, Y., Yu, J., Yen, C.-F., Bobaru, F.: Impact damage on a thin glass plate with a thin polycarbonate backing. International Journal of Impact Engineering, 62, 152-165 (2013)

Serruys, F., Marcke, G., Waldron, J.B.: CEN-Impact test prEN 12600. In: GPD 1999 Proceedings Book, Glass Processing Days, Tampere, Finland, 13-16 June 1999, (1999)

Tiedemann, S.: Determination of shear connection of glass-polycarbonate composite panels. In: GPD 2015 Conference Proceedings, Glass Performance Days, Tampere, Finland, 24-26 June 2015, (2015)

UNI 7697: Safety criteria for glazing application. UNI – Ente Italiano di Normazione, Milan, (2014)

Walley, S.M., Field, J.E., Blair, P.W., Milford, A.J.: The effect of temperature on the impact behaviour of glass/polycarbonate laminates. International Journal of Impact Engineering. 30, 31-53 (2004)

Weimar, T.: Design of glass-polycarbonate composite panels. In: Bos, F., Louter, C., Nijsse, R., Veer, F. (eds.) Challenging Glass 3: Conference on Architectural and Structural Applications of Glass, pp. 759-767. IOS Press, Delft, Netherlands, 28-29 June 2012, (2012)