

Evaluating external coatings as a tool for safer freeform glass structures

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Abstract

Looking at the shapes of glass bottles, drinking glasses, chemical flasks, etc., it is clear that the technology exists to melt and fuse certain glass types into astonishing shapes. Transforming this technology to the scale of building components would create an innovative tool with a high architectural potential.

However, in construction industry such techniques are still in an experimental stage. In spite of several small successes that have been accomplished with e.g. the welding of glass for building applications [1],[2], a fundamental safety problem still needs to be solved: fused or welded glass is monolithic and brittle. Traditional laminating techniques cannot be used for several reasons, e.g. because polymer interlayers will burn or disintegrate when exposed to temperatures needed for glass fusing or welding.

Consequently, this contribution will focus on external coatings, mostly polymers, which can be applied at the outer surface of a monolithic glass structure. The purpose of the coatings is to form a safety film, which prevents shattering of the glass pieces and/or ensures a certain level of post-breakage strength and stiffness. A limited number of selected products will be tested experimentally on small test specimens, illustrating some of the potentials and limits of this technology in architectural freeform glass applications.

Keywords: glass structures, freeform design, coating, structural safety, failure mechanisms, glass column

1. Introduction

Inspired by the abundance of shapes existing in small-scale glass objects, such as glass bottles, drinking glasses, chemical containers, etc., several researchers have started to

investigate fusing or “welding” techniques of glass for structural building applications (e.g. Belis et al, [1], Bos et al, [2]). Other than alternative glass-connection techniques, fusing/welding have the unique advantage that joints between individual glass members can be realized in a very transparent and virtually invisible way.

However, in spite of the rapid pace at which fusing and welding techniques for glass are being developed, the lack of appropriate safety concepts for this kind of structures is very likely to endanger their practical applicability for real FFD glass constructions.

Traditional glass laminating techniques make use of a polymer interlayer, positioned in between (usually flat) glass elements and chemically bonded to them as a result of high pressure and temperatures applied during an autoclave cycle.

However, such traditional glass laminating techniques will often not be applicable as a safety concept for freeform design (FFD) glass structures, as the combination of complex convex and concave fitting glass shapes will physically not allow sufficient contact pressure at all positions. In addition, the type of polymer interlayers used (usually PVB) is unable to withstand the temperatures typically needed for glass fusing/welding techniques: it will simply melt, burn or disintegrate, making it impossible to create a continuous interlayer at the joints.

For these reasons, alternative techniques and technologies are under consideration in the study below in an attempt to find an acceptable solution to increase the safety of FFD glass constructions. The main idea is to accomplish an extra, transparent and protective layer at the outer surface of monolithic (possibly complexly shaped) glass elements.

2. Materials

Basically, two classes of possible solutions have initially been considered: protective films and protective coatings.

2.1. Protective films

Several safety films for glass are commercially available (e.g. Spallshield[®], DuPont [3]). They consist typically of strong, scratch resistant transparent films which can be adhered to glass, e.g. by the so-called *squeegee* technique. Even if high tensile strength and hardness values are useful advantages of these protective films, their use in FFD glass applications is usually limited by geometrical laws. More specifically, these originally planar films have only a limited capability to adopt a double curvature: this can be realized only with relatively large radii and small areas, such as in car windshields.

For this reason, protective films did not seem to be a good solution for FFD glass structures. Consequently, they have not been considered for further analysis here.

2.2. Protective coatings

Protective (polymer) coatings are frequently used to protect metal components from corrosion and scratches. A number of products and techniques have been applied on (usually small-scale) glass substrates as well, such as anti-shatter coatings on light bulbs or glass laboratory equipment (labware).

A first survey was carried out in order to compare traditional PVB with films, lab coatings and lamp coatings with respect to a number of selected parameters, such as processability, exposure temperature, chemical resistance, optical properties, adhesion, hardness, tensile strength, elongation at failure and modulus of elasticity. A qualitative overview is depicted in Figure 1.

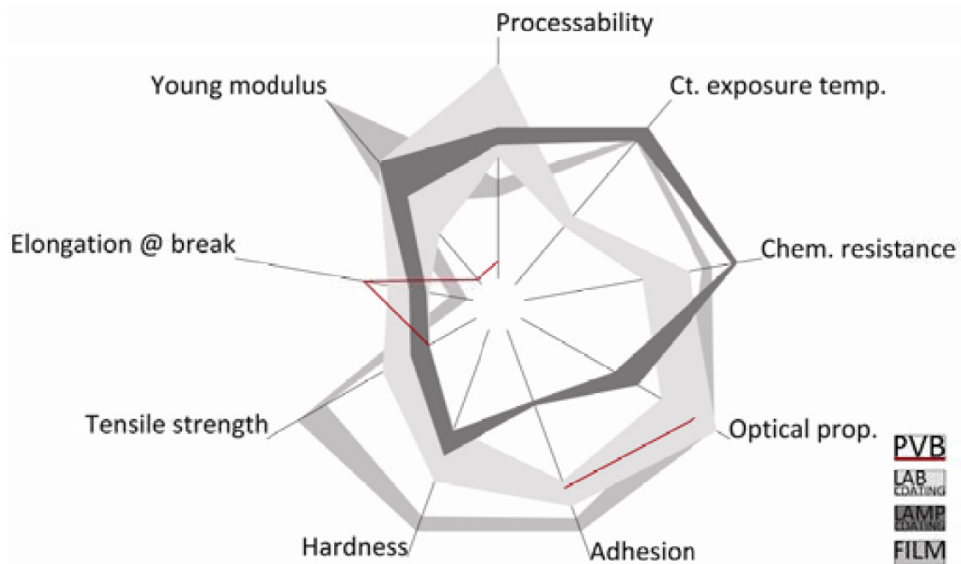


Figure 1: Qualitative overview of selected characteristics (and their dispersion) of different coatings types (lab coatings, lamp coatings), safety films and PVB [5]

From Figure 1, it can be concluded that in general coatings are not as omnipotent as protective films. However, they might be a valuable safety alternative, especially for FFD glass structures, on which protective films are no option. Moreover, it is clear that the right coating should be chosen carefully for a specific application, as its characteristics may vary significantly.

Even if numerous coatings are commercially available, no specific information was found on these products with respect to structural safety properties when applied to glass. In addition, it was found that technological information regarding the preparation and processing of samples was not readily available. Finally, adhesion of certain (organic) coatings could be improved by using chemical adhesion promoters (such as reactive silanes, [4]) or by mechanical pretreatment of the glass surface (such as sandblasting).

For these reasons, protective coatings have been investigated more in detail to investigate their potential as a safety concept in FFD glass constructions.

2.3. Coating properties

After an extensive literature review (De Cleen [5]), two representative products have been selected to discuss in this paper: Levasint[®] and Abcite[®]. The main material properties as provided by the manufacturer are presented in Figure 2. An experimental evaluation of both products on glass is discussed below.

General	Name	Levasint [®] S31	Abcite [®] 585
	Manufacturer	Bayer	Dupont
	Description	Ethylene vinyl alcohol copolymer	Ethylene acid copolymer
Properties	Melting point [°C]	105-108	100
	Young's modulus 23°C [MPa]	500	159
	Failure strength [MPa]	13	23
	Elongation at break [%]	70-300	494
	Hardness D	58	60
	Chemical resistance	Excellent	Excellent
	Transparency	Transparent	Transparent
	Mean coating thickness [µm]	300-600	300-600
	Adhesion promotor	No	No
Technique	Fluidized bed	Yes	Yes
	Electrostatic powder coating	Yes	Yes
	Flame spray coating	Yes	No

Figure 2: selected material properties of two representative lab coatings, as provided by their manufacturers

3. Experiments

3.1 Safety

The safety of different solutions was evaluated for the following mechanical criteria:

1. ability to provide an acceptable residual stiffness and resistance after glass breakage;
2. ability to keep together broken glass pieces after glass fracturing (“anti-shatter”);
3. ability to protect the glass from breaking;

3.2 Sample preparation

Both products have been applied on small pieces of flat borosilicate glass (230 mm x 50 mm x 2 mm) using the fluidized bed technique (Akzo Nobel [6]). During the coating

process, the preheated glass was immersed into the fluidized polymer bath and cured in an electrical radiation oven at Ghent University.

The purpose of the coating experiments on these samples was to identify and evaluate the major manufacturing parameters. The major parameters found were related to 1) the general visual appearance of the coated specimen (e.g. transparency, orange peel, air inclusions, etc...) and 2) the interlayer thickness (oven temperature, immersion time, immersion sequence, etc...).

Varying these manufacturing parameters, a relatively large amount of specimens was coated with different polymer coating thickness (varying from 0.1 to 0.5 mm). Subsequently, all specimens were subjected to a four-point bending test about the weak axis.

3.3 Bending tests

A displacement-controlled universal Instron testing machine was used for the four-point bending tests. Supports were positioned at a distance of 150 mm and the distance between both loading points was 50 mm. A constant loading speed of 2 mm/min was applied for all tests.

3.4 Results and discussion

Typical load-displacement curves are depicted in Figure 3.

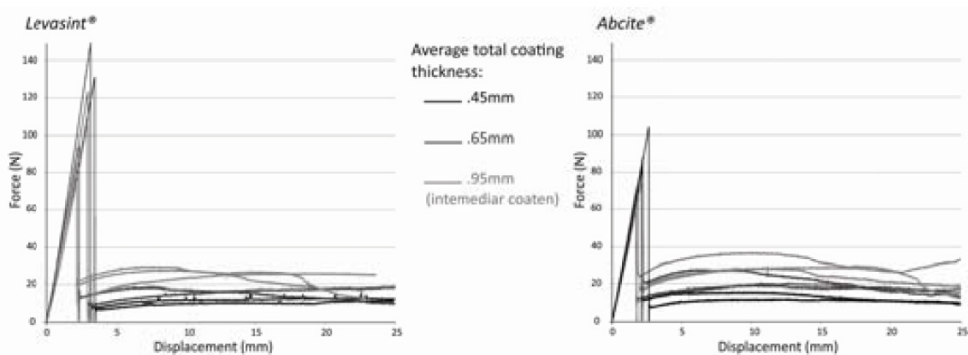


Figure 3: Typical load-displacement curves for flat borosilicate specimens coated with Levasint® (left) and Abcite® (right)

In general, both products globally demonstrated a similar load-displacement behavior. After a linear elastic increase of the load, typically a dramatic load reduction was caused by the breakage of the monolithic glass. Subsequently, a noticeable increase of the load indicated a certain residual strength and stiffness. However, the loading level remained far below the original failure level. Consequently, it can be concluded that the applied coatings could not

provide a sufficient residual safety level, in the sense that the specimen would not survive a destructive load-controlled test.

However, looking at the second safety criterion mentioned above, both coatings were perfectly able to keep all broken glass pieces together, acting as an “anti-shatter” protection. As the specimens were all simply supported, the specimens could slide on the supports as large deflections were applied. Consequently, the potential of the coating to act as a membrane could not be evaluated. However, even with relatively very large deflections imposed, all specimens remained stable.

Finally, an unexpected side-effect was noticed. As can be seen in Figure 3, failure values of specimens coated with Levasint[®] showed a significantly higher failure load. As random factors such as position of the cutting side or glass origin could be excluded, the resulting breakage loads seemed to be positively influenced by the coating. Possibly this is due to a “self-healing” effect of the polymer, which might have a positive influence on the stress intensity at the crack tips on the glass surface.

3.5 Case-study

Based on the previously described investigation, a case-study was performed on a very slender steel compression member stabilized by a monolithic cylindrical glass tube.

Axial compressive tests on these scale models revealed a remarkably high load-bearing capacity and structural safety after glass failure due to the crack-stopping effect of the coating. Consequently, overloading of the steel compression members lead to local buckling of the unsupported cantilevering steel ends instead of global buckling due to a loss of buckling support caused by glass failure.

For all three tests performed on similar hybrid compression members, the coating remained completely intact after destructive testing and a significant residual load-bearing capacity was noted.

4. Conclusions

A safety concept for freeform design glass constructions has been proposed, using selected transparent protective polymer coatings. From the experimental investigation, the following can be concluded:

1. The coatings discussed above could be produced with very acceptable visual appearance using the fluidized bed technique. A key parameter to obtain a good visual appearance was the specimen temperature.
2. Coated flat borosilicate specimens demonstrated a noticeable residual load-bearing capacity when subjected to destructive displacement-controlled four-point bending tests. However, the residual loading level remained far below the original glass breaking load.
3. Both coatings tested demonstrated excellent anti-shatter qualities: all broken glass pieces stayed adhered to the coating and the coating maintained physical coherence of all specimen parts, even at relatively very large deformations.

4. Subsequently, the initial glass breakage load seemed to be influenced by one of the coatings applied. The increased glass strength might be caused by so-called “self-healing” properties of that particular polymer, but more detailed investigations are needed to confirm this hypothesis.
5. Finally, a limited number of tests on small-scaled hybrid steel/glass compression struts proved that the safety concept was working very well for that kind of applications.

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