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Glowing Glass

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Defined by the building law in each publicly accessible building (e.g. schools, administration etc.) emergency exit routes have to be marked usually by means of active or passive lightening systems. The use of passive lightening systems require comprehensive components with an independent, battery-powered energy-supply that produces light even in the case of an energy black-out (e.g. disaster situations). The use of powerlines plus the frequently service of battery-powered systems is complicated and expansive. Alternatively after-glowing, phosphorescent signs, attached on walls, wallpapers or doors are an existing alternative. Mostly known to everybody are the green emergency exit signs. Furthermore phosphorescent paints on floors or walls are also used to guide people on the quickest escape way. Used inside of buildings their appearance has mostly a disturbing and negative attitude, even more at premium interior designs. Therefore, the composition of passive lightened systems with premium-quality surfaces leads to a widely usable product phosphorescent glass. This glass consists of laminated glass with a phosphorescent paint application within the glass interlayer. The paper describes the research and development of phosphorescent glass with a strong emphasis on materials testing, application technics and the behavior as laminated safety glass.

Keywords: glass, laminate, phosphorescent, glowing

1. Introduction

If we look into our office or residential spaces there are many situations with illuminated signs in the dark. The most common ones are emergency exit signs. State of the art is the use of phosphorescent plastic signs or battery powered lighted signs that are attached to walls. Also phosphorescent paint is used for emergency exit lanes in train station or similar buildings. All together is the lack of high quality surfaces with phosphorescent functions.

Starting with this situation, we were wondering if the integration of phosphorescence into glass can be achieved. We asked if we could obtain laminated glass with patterns, which can glow in the dark with our phosphorescent materials inside the bulk of our glasses, therefore somewhere between a glass panel and an interlayer or between two interlayer sheets.

Possible applications of this phosphorescence glass should be divided into interior design uses without any building code requirement. The second group covers load bearing glasses, usually structural elements that bear loads (e.g. wind) and are used in facades. For these structural elements the glasses need to meet building code requirements.

Generally, the build-up of the phosphorescent glasses consists of a laminated safety glass with phosphorescent paint in the interlayer. See chapter 2.5.

2. Materials and methods

2.1. The norms and test background

Depending of the interior or structural use of the phosphorescent glass, its behavior will be investigated in three fields: (i) long term behavior at accelerated climate loads, (ii) shear test of laminated phosphorescent glass and (iii) mechanical behavior compered to standard laminated safety glass.

(i) The long term behavior of laminated safety glass has been generally well investigated (durability test). There is no relevant aging test procedure for LSG that helps us judging the resistance of the specimens against humidity and temperature. Therefore to investigate the reaction and the aging of the phosphorescent glass at extreme temperatures and humidity we have decided to inspire ourselves with the aging cycle of the norm EN 1279-2:2002 Glass in building; Insulating glass units; Part 2: Long term test method and requirements for moisture penetration for our aging test. This test puts the glasses into a hard but realistic climate aging process. As result we describe the visual appearance of the glasses as qualitative comparable test about the resistance of the glasses against humidity and temperature.

(ii) For the shear resistance, we will simply compare the shear resistance of our samples and compare them to standard laminated glass we can find in construction. The test results serve as qualitative comparable values of the shear strength of the laminates.

(iii) The ball drop testing according to standard LSG tests is the final test series to describe the relative behavior of different phosphorescent glass build-ups to standard LSG. These tests allow considering the use of the phosphorescent glass as structural element.

2.2. Constraints

In this project, our industrial partner should be enabled to control the whole production process, which means we did not consider solutions to use existing films which already have a phosphorescent characteristic for our laminates to prevent any chemical incompatibility due to lack of product control. Therefore, we were limited to the use of different phosphorescent paint to produce our samples.

2.3. Material behavior

Generally, for the samples, the materials float glass, different EVA-interlayers and different phosphorescent colours were used. For the shear and aging tests we used respectively 6 mm and 3 mm float glass. Together four different EVA-products, covering major brands as well as small or no-name brands.

For the research different phosphorescent paints, bought from the paint market were used. There is phosphorescent paint in different colors. In our research we focused on green phosphorescent paint. This is the standard colour for such applications with maximum glowing intensity compared to other colours. Standard brush paint ("Afterglow Color Water-based green" from UV-elements) and spray ("Phosporescent Spray Paint" from StardustColors) were used for the specimens.

In preliminary testing, the wetting of different glass and interlayer surfaces were investigated by means of surface angle measurements using the Krüss drop shape analyzer DSA 25. To do so, different combination have been tested: water on float glass, water on sanded float glass, spray paint on float glass, spray paint on sanded float glass, water on EVA film and spray paint on EVA film.

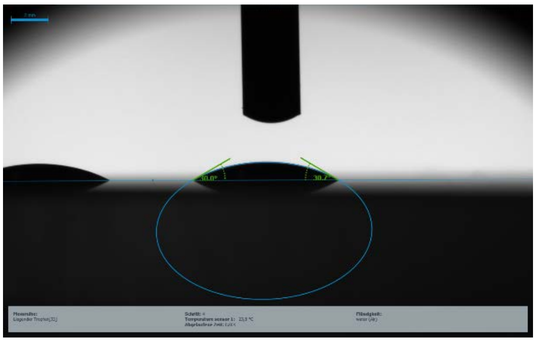


Fig. 1 Water on float glass

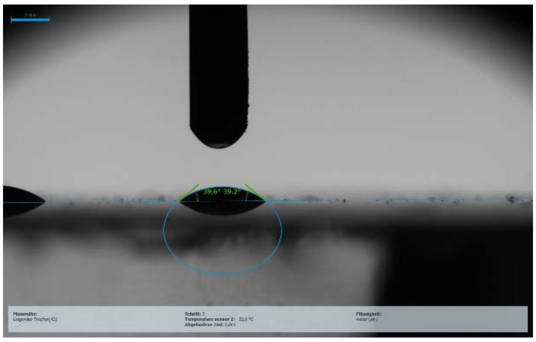


Fig. 2 Spray paint on float glass

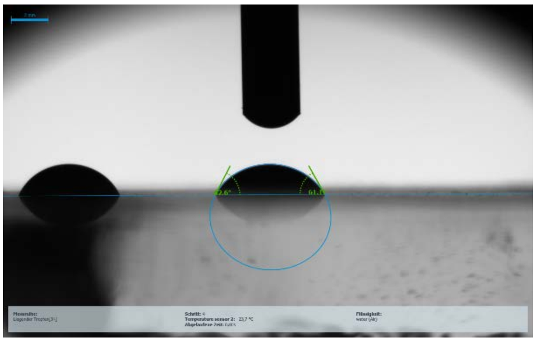


Fig. 3 Water on sanded float glass

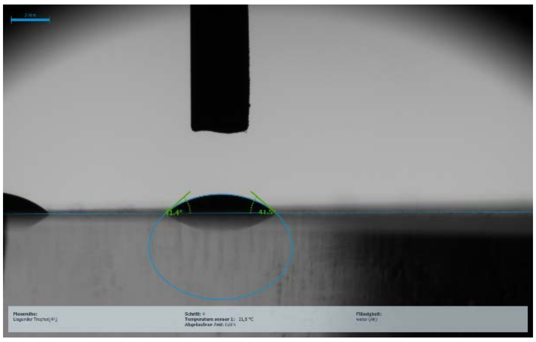


Fig. 4 Spray paint on sanded float glass

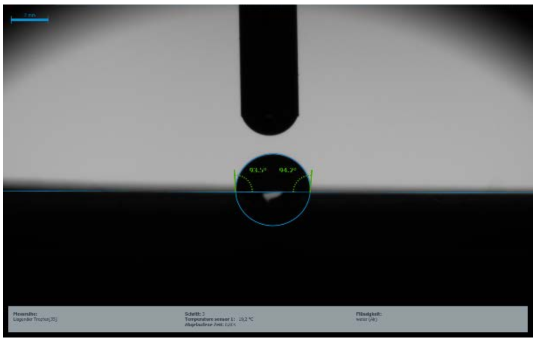


Fig. 5 Water on EVA film

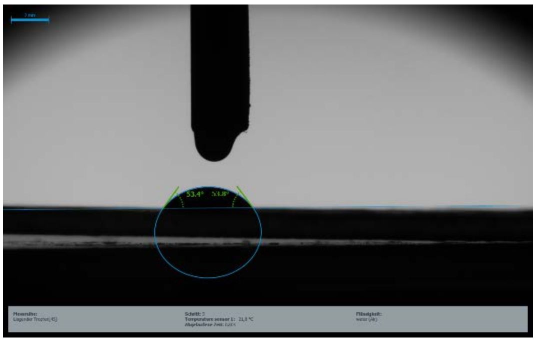


Fig. 6 Spray paint on EVA film

Table 1: Surface angle (°)

Water on glass	Water on sanded glass	Water on EVA film	Spray paint on glass	Spray paint on sanded glass	Spray paint on EVA film
27,3	62,9	93,8	45,7	46,5	68,8

The contact angles are read in a way, where 0° is a complete wetting. Between 0° and 90°, the solid is wettable and above 90° it is not wettable.

Surprisingly, the contact angle of the paint when in contact with sanded glass or smooth glass does not change that much. But as seen further, the results are much better on sanded glass, which comes from the drying of the paint which is much better on sanded glass. And regarding the contact on the film, it is clear that it should not be done as seen later.

About the risk in case of fire, it is as important as without the paint, this is because of the EVA films. In the technical description of the paint, it is not inflammable, but in case of thermo reaction, it will release carbon monoxide and carbon dioxide.

2.4. Concept of phosphorescence

Phosphorescence is where energy is absorbed by a material or substance and released as light. For this case, the energy to charge the material is UV-light. It is in some aspect similar to fluorescence except that the release of energy in the form of light takes a longer time. A phosphorescent paint will thus charge itself during an exposure to UV-light (contained in natural white light) and will "glow-in-the-dark" during the night. The progress of phosphorescent pigments has now reached a point where we can charge pigments enough during a short day to glow a whole night, although no producer can guarantee a full night with a powerful glow.

2.5. Design of experiment

The research was considered as a two stage process, with a broad preliminary testing and specified details testing series.

The preliminary testing covered the shear and durability test of the specimen. Objective of these tests was the main question about the principle build-up of the phosphorescence glass: does the paint need to be in contact with the glass or between two interlayer films? So logically, two build-up designs were chosen, shown in Fig 7 and 8.

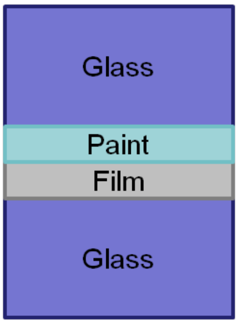


Fig. 7 Paint directly applied on glass

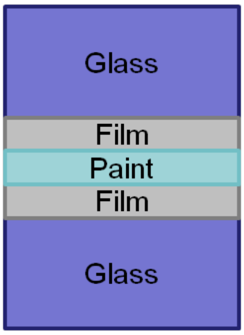


Fig. 8 Paint between two layers of film

Another factor was the choice between liquid paint and spray paint for the aesthetic aspect and the reaction with the films. Finally, four EVA-interlayers from major and minor brands which do and do not block UV light have been chosen. The chosen matrixes of experiment are shown in Table 2 and 3.

Table 2: Matrix for the desired samples of durability tests

	EVA 1	EVA 2	EVA 3	EVA 4	Total number of samples
Int. Spray	3	3	3	3	12
Int. Liquid	3	3	3	3	12
Gls. Spray	3	3	3	3	12
Gls. Liquid	3	3	3	3	12
Total number of samples	12	12	12	12	48

Table 3: Matrix for the desired samples of shear tests

	EVA 1	EVA 2	EVA 3	EVA 4	Total number of samples
Int. Spray	5	5	5	5	20
Int. Liquid	5	5	5	5	20
Gls. Spray	5	5	5	5	20
Gls. Liquid	5	5	5	5	20
Total number of samples	20	20	20	20	80

Int.: paint used as interlayer between two interlayer foils; Gls.: paint used directly on the glass; Spray: paint sprayed; Liquid: paint applied with a roll on the glass

The samples for the durability test have the dimensions 200x200 mm and the ones for the shear test 60x60 mm.

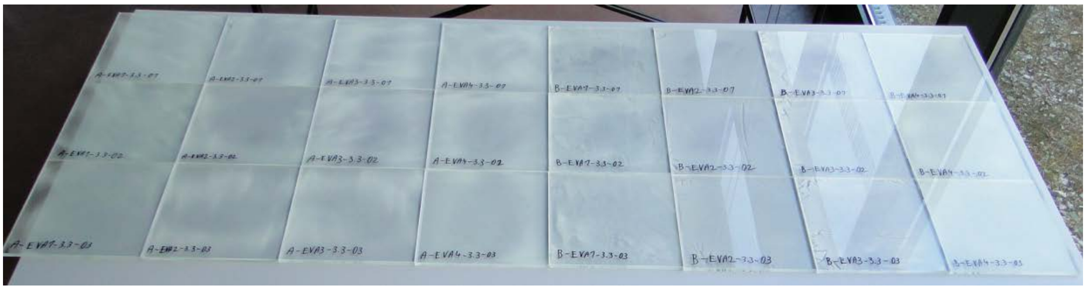


Fig. 9 Samples for the durability test with sprayed paint

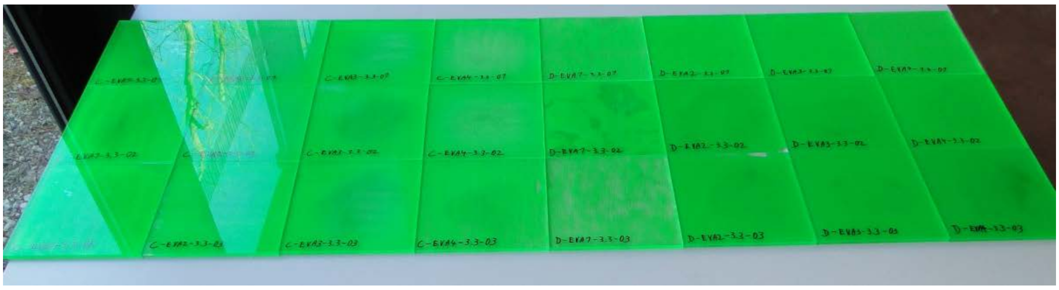


Fig. 10 Samples for the durability test with brush applied paint

Fig. 11 Samples for the shear test with sprayed paint

Fig. 12 Samples for the shear test with brush applied paint

2.6. Preliminary tests and protocol for paint directly on glass

The first panel of glass has to be cleaned; the paint is then applied in 6 layers with a drying time of 30 seconds between each layer for spray paint and one of 30 minutes for liquid paint. Then, the samples are left to dry for at least 4 days to reduce the volatile organic compounds. The second panel of glass is then cleaned as well. Afterwards the film is put in between the two glass panels and the glass is then laminated in a vacuum bag.

2.7. Preliminary test and protocol for paint between two films

The film on which the paint will be applied is cleaned; as for the previous protocol, 6 layers of paint are applied with the same drying time between each. After at least 4 days of drying, the glass panels are cleaned and the paint will be in between the two films which themselves will be in between the two glass panels.

2.8. Results of the tests

On the next pictures (Fig. 13 to 18) are the surfaces of different samples. Fig. 13 and 14, and Fig. 15 and 16 compare two samples before and after the aging process and Fig. 17 and 18 show two samples with bad optic qualities which do not need this aging process comparison. The aim of this aging process is to see if some delamination has occurred with time and a comparison between the two states is necessary.

Fig. 13 Sample EVA 1 and paint sprayed on the glass before the aging process

Fig. 14 Sample with the EVA 1 and paint sprayed on the glass after the aging process

Fig. 15 Sample with the film 3 and paint sprayed on the glass before the aging process

Fig. 16 Sample with the film 3 and paint sprayed on the glass after the aging process

Fig. 17 Sample with the film 2 and paint sprayed between two films

Fig. 18 Sample with film 4 and brushed paint between two films

Regarding the samples with paint sprayed between two films (Fig. 17), lots of paint cracks appeared even before the aging process. As for the brushed paint between two films (Fig. 18), lots of bubbles are present before even going in the climate chamber. For the samples with paint sprayed on the glass, delamination starts to appear after the aging process with the films EVA 2 and 3 (Fig. 15 and 16), whereas the films EVA 1 and 4 give a satisfying result with minimum delamination (Fig. 13 and 14). Furthermore, the aesthetic value of the brushed paint is not convincing, therefore only the sprayed paint will be used for further tests.

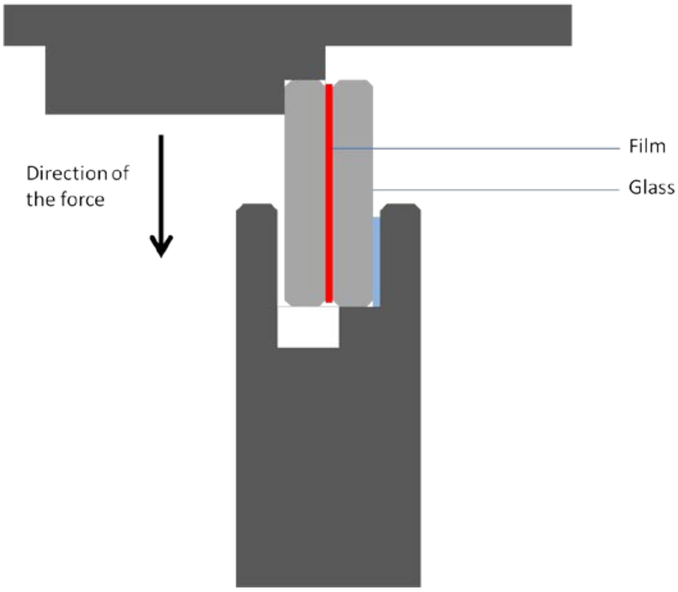


Fig. 19 Mechanism of the shear resistance test

Table 4: Average shear modulus of the samples with sprayed paint (MPa)

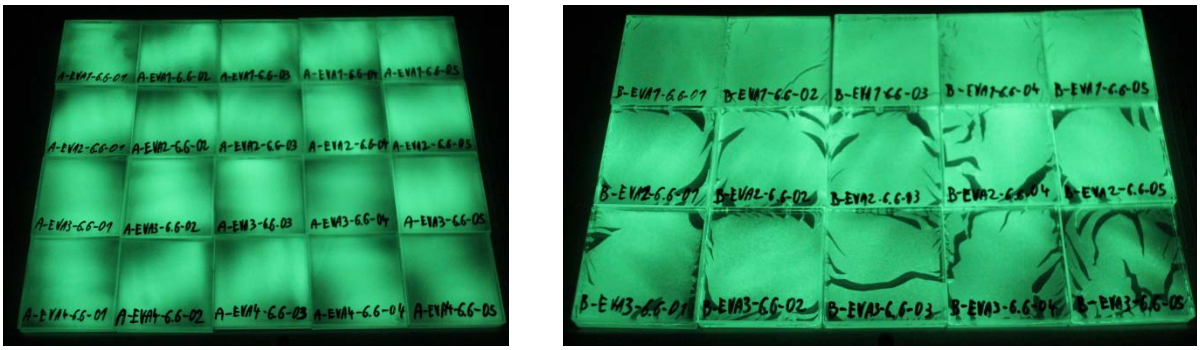
Directly on the glass				Between two films		
EVA 1	EVA 2	EVA 3	EVA 4	EVA 1	EVA 2	EVA 3
1.205	0.819	0.491	1.425	0.549	0.525	0.677

Table 5: Average shear modulus of the samples with liquid paint applied with a brush (MPa)

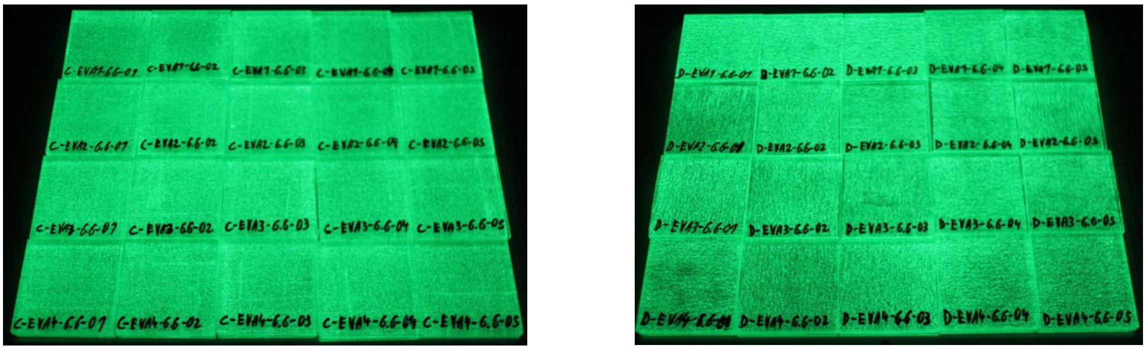
Directly on the glass				Between two films			
EVA 1	EVA 2	EVA 3	EVA 4	EVA 1	EVA 2	EVA 3	EVA 4
1.339	1.045	1.008	1.360	1.011	0.911	0.932	1.472

Before analysing the results, it is important to talk about the missing value for the EVA 4, between two films column in the table 4. This comes from the fact that it was never possible to get the paint to stick to the film after it dried. It would always peel off and it was impossible to make a sample. As seen on the tables 4 and 5, the best results are with the paint applied with a brush and the EVA 1 and 4. All the values are under a standard of 3MPa of shear resistance. The liquid paint applied with a brush has been abandoned for a lack of aesthetics. In the end, stays only the sprayed paint applied directly on the glass with the EVA 1 and 4. They show furthermore the best shear values in Table 4. One foreseen solution to improve the modulus is to partially paint the glass and to have more contact in between the interlayer film and both glasses.

2.9. Luminescence tests



a) b)



c) d)

Fig. 20 Samples in the dark a) Paint sprayed on the glass, b) Paint sprayed between two films, c) Paint brushed on the glass and d) Paint brushed between two films

To obtain the values in the table 6 and 7, the samples have been charged 12 hours with standard interior lights. This choice seemed to be the most natural as one of the aim of the product is for interior and what works with standard light would work better with natural light.

Table 6: Average luminescence of the samples with sprayed paint (lux)

Directly on the glass				Between two films		
EVA 1	EVA 2	EVA 3	EVA 4	EVA 1	EVA 2	EVA 3
0,747	0,849	0,887	0,973	0,224	0,328	0,253

Table 7: Average luminescence of the samples with liquid paint applied with a brush (lux)

Directly on the glass				Between two films			
EVA 1	EVA 2	EVA 3	EVA 4	EVA 1	EVA 2	EVA 3	EVA 4
0,072	0,072	0,074	0,071	0,036	0,019	0,035	0,035

Although the samples seem to shine with the same intensity on the pictures, they do not. That comes from the fact that it was needed to set the camera (night mode, with a longer exposure time) to be able to take a picture of the samples with the liquid paint. With any other kind of setting, the samples were impossible to see on the picture, whereas the samples with sprayed paint were taken in picture with a standard setting (day mode). Measuring the luminescence in Table 6 and 7 confirms that the samples with sprayed paint glow with much more intensity. This result is an extra point in favor of the paint directly sprayed on the glass. Another point to note is that the samples with sprayed paint would still glow in the dark after several hours in the night whereas the samples with liquid paint would stop glowing after less than an hour. Applying phosphorescent paint between two films lead to much lower luminescence as the charging of the colour is hindered by the reduced transmission light spectrum of the EVA-films.

2.10. Secondary test

As said earlier, only the EVA 1 and 4 are used for the further tests and the paint will be sprayed on sanded glasses. It is expected that the samples will react differently according on the number of layers and the fraction of the painted surface. The aging tests have been until now good for the selected paint and films so only the number of the layers and the absence of paint on the edges will be tested (the product is expected to have a frame and cover the edges). The design of experiment in the table 8 will be used.

Table 8: Matrix for the desired samples of durability tests

	EVA1	EVA4	Total
4 layers	5	5	10
8 layers	5	5	10
Total	10	10	20

Fig. 21 Environmental chamber used

Fig. 22 Samples in the environmental chamber

For the shear test samples, the same factor for the number of layers will be used but also the covered area factor. It is interesting to know the difference of shear modulus with a glass where just the desired area is sanded and painted, a glass completely sanded and without paint and a non sanded glass without paint. These two last groups are interesting to see how big of an impact the sanded area has on the shear resistance. The design of experiment in the table 9 will be used.

Table 9: Matrix for the desired samples of shear tests

	EVA1	EVA4	Total
4 layers 20%	5	5	10
4 layers 50%	5	5	10
4 layers 80%	5	5	10
8 layers 20%	5	5	10
8 layers 50%	5	5	10
8 layers 80%	5	5	10
No paint sanded	5	5	10
No paint non sanded	5	5	10
Total	40	40	80

a) b) c)

Fig. 23 Sample a) 80% painted, b) 50% painted, c) 20% painted

The results of the detailed testing of shear and durability behavior are pending. Depending on the test results the following ball drop testing will be performed on a reduced number of build-ups and is content of a following publication.

3. Results and discussion

3.1. Our results and solutions

The detailed testing series were recently started and results of shear and durability testing are still pending. Nevertheless, in the preliminary testing series, a broad range of possible build-ups and materials combinations was investigated. As result, it became obvious, that especially the application process (delay between the layers, drying time, number of paint layers and the “understanding” of type of paint and application surface) is essential for a successful phosphorescent glass.

With the tested paint and interlayer foils, we observed that the several EVA-products perform much better in the durability test than other ones which show many bubbles and changing colours. Furthermore, the application of paint on an interlayer foil or a smooth glass surface is not satisfying regarding visual quality. In such cases, we observed many cracks in the colour and peeling from the substrate was observed.

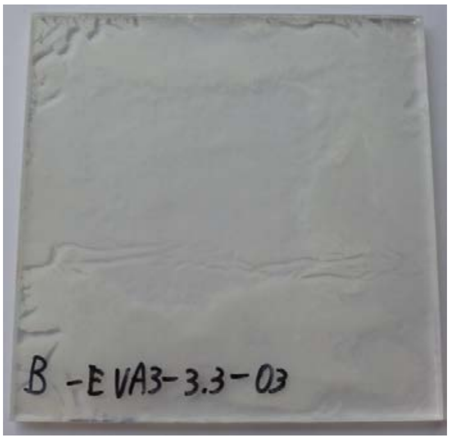


Fig. 24 Delamination of the sample with the paint between two films

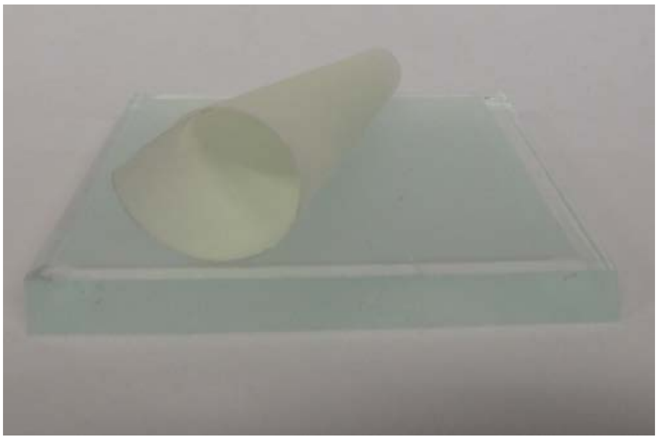


Fig. 25 Paint not sticking to the glass (here smooth glass)

Nevertheless, in the preliminary testing we were able to demonstrate that a fine tuned composition of paint, interlayer and surface plus an experienced application process (number of paint layer, delay between layers) lead to convincing specimens. A paint application on an interlayer foil should be avoided whereas the paint application on a sanded glass surface showed the most stable and durable paint application. The durability testing demonstrated the long term stability for interior uses. The use of whitish-greyish paint allows hiding the symbols during daylight and revealing itself glowing green at night.

Fig. 26 Samples in white light

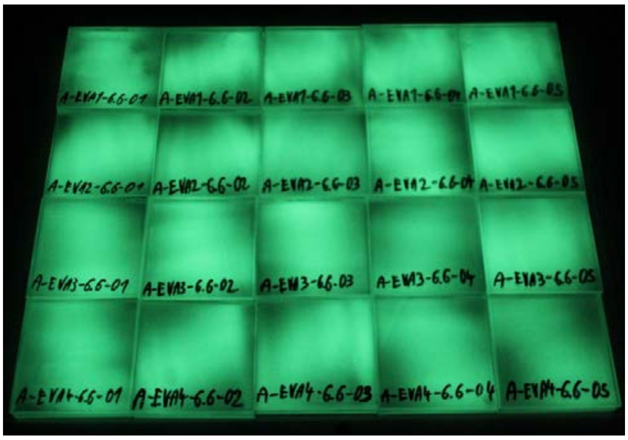


Fig. 27 Samples in darkness

3.2. Their limits and future work

Currently the detailed test is under way. With these results we concentrate on the comparison of shear and ball drop behavior between partly painted phosphorescence glass and standard laminated safety glass. These results will give an answer about the fulfillment of an LSG-adequate post-failure behavior and therefore show the possibility to use the phosphorescence glasses as structural elements in facades.

The results of the detailed research will be published soon in a further paper.

Acknowledgements

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References

EN 1279-2:2002 Glass in building; Insulating glass units; Part 2: Long term test method and requirements for moisture penetration.