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Fire resistance of the vertical glass structures with thermal protection foil

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Abstract

Purpose – During the building designing, it is very important to deal with the fire resistance of the structures. The designed materials for escape routes should be selected to ensure the usability of the structures until the time of escape. Planning affects the glass structures similarly, so these can also be partition walls and load bearing structures, although the latter is less applied on escape routes. The heat protection of the glasses can be improved with heat-protective foils, while fire protection is provided by gel intumescent material.

Design/methodology/approach – To research the topic of fire resistance, laboratory experiments were carried out on small-scaled glass elements with thermal protection foil at Budapest University of Technology and Economics at the Department of Construction Materials and Technologies.

Findings – Fire protection of small model specimens was tested with blowtorch fire and furnace heat load. During the experiments, six foils were tested. Single pane glass, double layered and triple glazed specimens were tested with blowtorch fire.

Originality/value – Fire protection of small model specimens was tested with blowtorch fire and furnace heat load. During the experiments, six foils were tested. Single pane glass, double layered and triple glazed specimens were tested with blowtorch fire. In case of heat-protected glazing, the foils on the "protected" side of the single pane glass do not have a fire protection effect based on blowtorch fire test. For double glassed specimens, the P35 foil has a perceptible effect, even for the requirements of the flame breakthrough (E, integrity), when the foil is placed on the inner side (position 3) of the second

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glass layer. The stratification of each triple glazed specimens was effective against blowtorch fire load (3 M, S4&P35), so (EI, integrity and isolation) it can meet the requirements of flame breakthrough and thermal insulation.

Keywords Protection, Fire resistance, Glass, Foil, Vertical structures

Paper type Research paper

1. Introduction

In the recent architecture, it is generally important to let as much light as possible into our buildings; however, the glass also has a space-delimiting and fire retardant function. In this case, fire retardant materials can be applied. In most cases, fire-resistant vertical glazing is curtain walls, windows and doors. The retardant and the function of horizontal glass structures (for example, glass floors and glass roofs) deviate from the vertical glass structures. In the case of horizontal glazing, sprinkler systems cannot be positioned close enough, so the glass should be planned for 120 min of resistance (Schulte, 2015).

1.1 Fire and heat protection of glass

The regulations and requirements for the use of fire-resistant glazing have led to the definition of the European standardized fire-resistance performance classification, which comprises three classes:

(1) *Class EI*: fire-resistant glass in this category offers the highest level of protection from fire, smoke and radiant heat for a defined period (from 30 up to 180 min).

(2) *Class EW*: glass in this category offers an integrity performance (protection from fire and smoke) while reducing the transfer of dangerous radiant heat.

(3) *Class E*: fire-resistant glass which remains transparent in the event of fire offers protection from fire and smoke but does not reduce the transfer of dangerous radiant heat in the event of a fire (integrity only performance).

For integrity (E), it is important to prevent the spread of the flame, the hot and toxic gases and the smoke. In the past, wire glasses were used for this purpose. As an effect of flames, the glass ruptures which does not fall apart because the metal holds it together. The fire resistance of wire glass is 45 min. The drawback was that the glass was not completely transparent because of the wire inserts. Instead of wire glass, heat-treated glasses are used today. Thus, the glass remains completely transparent, but it has only 20 min of fire resistance. Glass ceramic has higher fire resistance, and owing to the lower thermal expansion coefficient, its fire resistance is 3 h (Schulte, 2015).

Along with integrity, the passage of heat (EW) must also be reduced for each glass structure element. Glass structures with this requirement are applied to protect escape corridors, as it has to ensure the way to the firefighters to the fire source. If coatings are applied, the measured heat radiation should be kept below 15 kW/m^2 at a distance of 1 m (Schulte, 2015; EN 674, 2011). Heat-insulating fire-resistant glasses (EI) also have thermal insulation. These structures may also need 120 min, as the effect of the fire on the surface protected by the structure would reach 180°C (OTSZ, 2011).

It is important to know about the behaviour of glass at high temperatures that its primary damage is the breaking of glass panes because to heat. To study the thermal fracture of window glass in compartment fires (e.g. rooms, enclosures), two main physical processes which are related to each other should be considered. The first is the heat transferred by radiation and convection from the fire source and the hot combustion products to the glass; radiation remaining is the dominant mode of heat transfer in a fire environment. The second process is the mechanical stress distribution and glass fracture. Most theoretical studies on glass fracture in fire applications were concerned with improving heat transfer models. A theoretical value of difference temperature is 80°C is reported for initial fracture and cracks (Keski-Rahkonen, 1988). For thermal breakage in fire conditions, few studies have however investigated thermal stresses, i.e. the second physical process mentioned previously (Dembele *et al.*, 2012; Haodong *et al.*, 2017; Pagni, 2002).

The fire protector glasses can be classified according to the Chinese standard (GB/T 15763.1, 2019). There may be several ruins during the heat load of the glasses: one is the fracture caused by high temperature differences, the other is the softening and flow of the glass. The softening point of the glass is between 600°C and 800°C; therefore, the glass heats up and softens as a result of the heat load. Then, some items of the points may become thinner and run out. At temperatures above 600°C, glass structures are difficult to resist on their own. Because of the rigid properties of glass, there is a big difference between compressive strength and tensile strength. The surface of the glass defects on the edges cause a tension concentration and also may cause a completely glass break. Therefore, if the surface is properly transported and installed, the resistance to fire is also increased (Yang *et al.*, 2011). However, it is important to note that, in addition to edge machining, the connection between glass and frame can have a significant impact on fire resistance that is it requires a special design.

Huizinga *et al.* (2017) conducted a fire resistance test on a large-scaled vertical glass structure. The type of fire load was the ISO fire curve. In the bottom raw, four standing large elements (1,897 × 924 mm) were installed side by side, while small glass elements (924 × 924 mm) were installed as top lights. Two experiments were made. In the first case, double-layered glasses were applied, while in the second, measurement triple glazing was tested. The thickness of the glass in the layer was 4 mm, while in the 12 mm air gap argon gas was filled with 90% saturation. Based on the experiments, the triple glazing only increased the time of the first small amount of glass breakage by 9 min compared to the two-layer glazing. 21 min after the start of the study, the amount of the falling-out fractures increased in both cases. The amount of break glass fracture is related to the surface temperature and to the temperature difference. It is interesting to note that less stresses are created in the small-sized test specimens, thanks to the heat. Thus, it was later broken and was able to withstand higher temperatures, so the size of the glass panes also influenced their resistance to fire.

Because of the brittle behaviour, the glass does not have a high fire resistance limit. This limit can be improved by various methods, such as heat strengthening, laminating, using a special fire protection gel or possibly glueing foils to the glass surface.

1.2 Heat protection foils

Glass structures can be covered with different foils. These can affect the mechanical attributes of the glass, its light transmittance and its fire behaviour. During the use of buildings somtimes come to fire; therefore,the foiled glass structures are also exposed to fire. As foils are made of plastic and are sensitive to high temperatures, it is important to examine the behaviour of glass structures under fire. The purpose of recent research is to select and use a protective foil that is suitable for fire protection in the future. The glass structures protected with foils also mean a major problem, as they can modify the behaviour of glass and glass structures under fire. An important and interesting question is how safety and sunscreen foil, most of which are made of polymer, behave under fire?

In our experiments, we analyzed how glass and glass with safety and sunscreen foil develop in case of fire. The aim of our experiments was to get to know the behaviour of glass structures with different foils. The tests were carried out under the influence of blowtorch fire and furnace heat load, simulating the fires of the buildings. In our experiments, the behaviour of the foils was investigated, which are used in practice and are present in the market.

2. Experiment

2.1 Experimental plan

In the present research, fire resistance tests were carried out on small-sized test specimens. The cost of this test is significantly lower than the costs of the test with large element structures. So the aim of the future is to examine the impact assessment of the size difference.

The single-, double- and triple-layered heat protection thermo glasses (EI) were prepared with the application of heat protection foils and were tested with blowtorch fire and furnace examinations on it. The following types of foils were used during the experiments:

- SkyFol Security S security foil series (S4S, S12);
- SkyFol ThermoProtect Power glass foil series (P35);
- SkyFol ThermoProtect Exterior Longlife glass foil (EXT);
- SkyFol ThermoProtect Silverall glass foil series (SI15); and
- S20SIAR400 (safety foil 3M).

The properties of the foils are given in Table 1.

In the experiments, $200 \times 200 \times 4$ mm float glass sheets were tested without heat strengthening. According to the design of the insulating glass, a silicone seal was placed on the edge of the glass. Between the insulating glasses, there was a 12 mm wide air gap. The foils were placed on protected surfaces. In the marking system, the position of the foil is indicated by numbers. The numbering from the side of the fire is started with a symbol 1 and moved to the protected side (from fire protected side) taking into account both sides of the glass plates. Figure 1 summarizes the position of the foil and the experimental plan of the tested specimens. Single-pane glass, double-layered and triple-glazed specimens were

Table 1.
Properties of foils

Types of foils	Function	Thickness	Structure	Tensile strength
SkyFol S4S	Splinter protection	100 μm	Single layer polyester	2.0 kg/mm
SkyFol S12	Explosion protection	300 μm	Multilayer polyester	6.2 kg/mm
SkyFol ThermoProtect	Heat protection	38 μm	Cu sputtered polyester	–
SkyFol ThermoProtect Exterior	Heat reflection	38 μm	Aluminium metallized polyester	–
SkyFol ThermoProtect Silverall	Heat protection	50 μm	Aluminium metallized polyester	–
S20SIAR400	Splinter protection (car)	42 μm	Multilayer polyester	–

Types of foil	Blow torch fire test			Furnace test	
	Single glass	Double glass	Triple glass	Double glass	Triple glass
S4S	2	3	5	-	-
S12	2	3	5	-	-
P35 P35M	2	3 4	2	-	-
EXT	2	3	-	-	-
SI15	2	3	5	-	-
3M-1 3M-2	2	3	5	2&3	5 2&3&5
S4S&P35	-	2&3	3&5	-	-

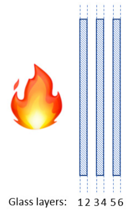


Figure 1.
Experimental plan of the examination of the heat foils and the position of the foil in the glass layer

tested with blowtorch fire. In case of the furnace test, the double-layered and the triple-glazed foils were examined. During the tests, 28 experimental arrangements were used.

2.2 Test procedures

2.2.1 Blowtorch fire test. The specimens were first examined with blowtorch fire. The test ended when all glass layers in the given specimen were broken or when the temperature difference of 180°C was reached (insulation limit state [OTSZ, 2011]). The glass sheets were examined in a fixed position without capture. This is explained by the fact that each glass structure is flexibly fixed; otherwise, it would break owing to the stresses on it. The temperature was measured with a digital thermometer on both the glass-exposed and fire-protected side of the glass plate, using *K*-type thermocouples directly on the glass surface (Plate 1). Normal propane-butane gas was applied in the blowtorch fire test. During the blowtorch fire test, the rise of the temperature was very fast. It means that it reached 1,000°C in a few seconds (Figure 2). The real fire effect is modelled in this way when many combustible materials are placed in the window glass

Plate 1.
Blowtorch fire test

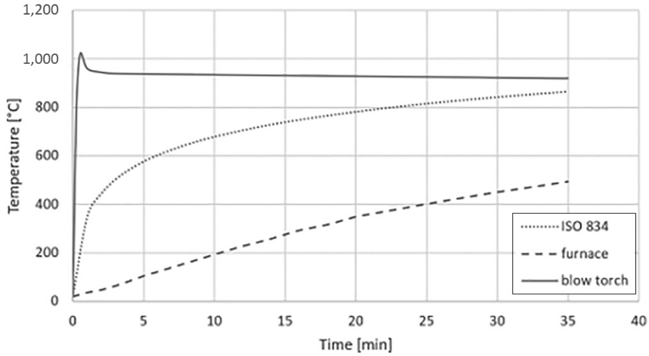


Figure 2.
Temperature increase as a function of time

environment. However, during the blowtorch fire test, the fire is point-specific, which is different from the real fire model. Based on these, furnace tests were needed.

2.2.2 Furnace test. The resistance against fire was illustrated with a furnace test, where the heating is slower compared to the blowtorch fire test, but it effects on the entire surface of the glass structure. An electric furnace was used for thermal loading, with a heat-up curve shown in Figure 2. Based on the measured data, the curve of the furnace is different from the standard fire curve (ISO 834–1, 1999); therefore, the experiment cannot be called a standard test.

The experimental arrangement is shown in Figure 3. During the test, the specimens were fitted as close as possible to the opening of the furnace. In the furnace, the heating temperature was measured with a built-in thermocouple, and at the same time, the temperature of the test furnace and the "protected" side with *K*-type thermocouples.

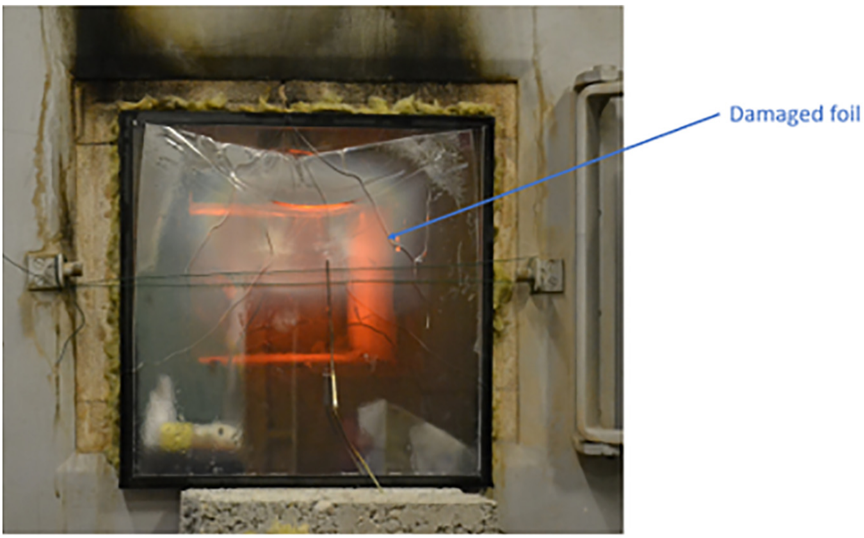


Figure 3.
Furnace test

2.3 Experimental results

2.3.1 Blowtorch fire test. Different phenomena were observed at single-pane specimen with different foils during the blowtorch fire test:

- blowtorch fire test of the foil (S4, S12);
- the denser crack pattern on the glass surface (EXT);
- the density of the crack pattern became smaller and discoloured (P35, SI15); and
- soot effect (3M).

Similar phenomena were observed in case of double-layered and triple-glazed glasses with the air gap. Discolouration occurred in case of the application of the combined foils. However, in case of triple-glazed specimens, there was no attribute of drop burning and high cracking density (Plates 2 and 3).

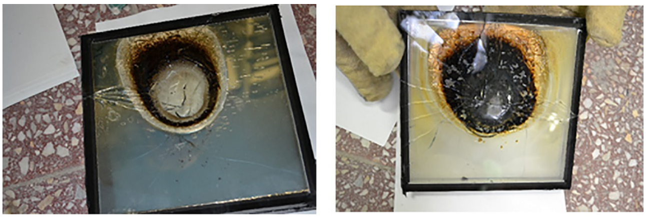
In case of heat protection glazing, the foils on the "protected" side of the single-pane glass did not have a fire protection effect (E, OTSZ, 2011*)*. For double-layered specimens, the P35 foil has a perceptible effect when the foil is placed on the inner side (3rd position) of the second glass pane (Figure 4). Some layering of the triple-glazed specimens is very effective against the blowtorch fire load (3 M, S4&P35).

In case of double-layered glass, after the glass break, the foil held the layer together so that no flame breakthrough was created (E, OTSZ, 2011*)*. The double-layered specimens did not meet the insulation requirements because the rise of the temperature on the "protected" side of the glass was higher than 180°C (Figure 4). At the triple-glazed glass structures, the foil was able to hold the glass together, so no flame breakthrough could occur.

(a) **(b)**

Notes: (a) EXT; (b) S4&P35

Plate 2. Result of the blowtorch fire test on double-layered specimens in case of foils



(a) **(b)**

Notes: (a) 3M; (b) S4&P35

Plate 3. Result of the blowtorch fire test on triple-glazed specimens in case of foils

On the “protected” glass side of the glass, the rise of the temperature was lower than 180°C. This experiment can also prepare for a standard (EI, OTSZ, 2011) test (Figure 5).

Figures 6 and 7 show the time of the breaking of the glasses in case of double-glazed specimens and triple-glazed specimens.

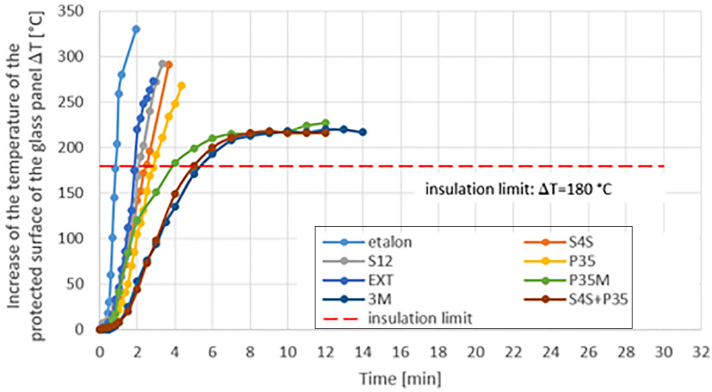


Figure 4. Protected side of the temperature of surface of double-glazed specimens on the basis of a blowtorch fire test

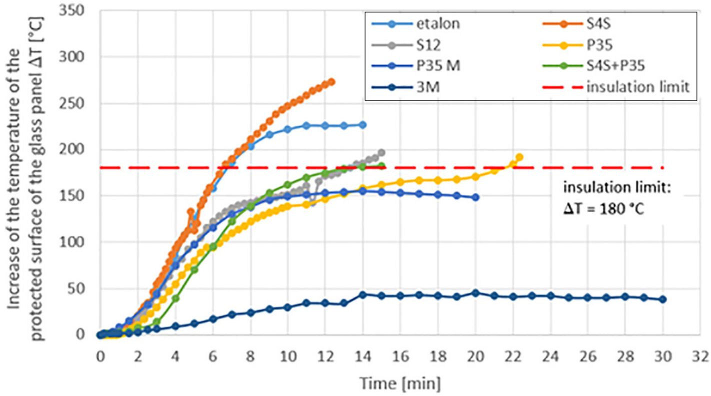


Figure 5. Protected side of the temperature of surface of triple-glazed specimens on the basis of a blowtorch fire test

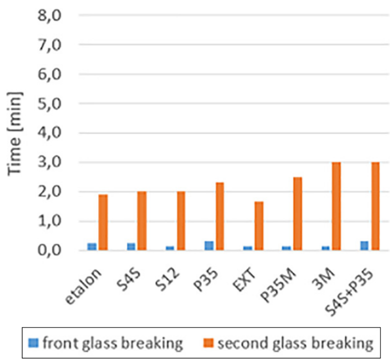


Figure 6. Time of the breaking of the glasses in case of double-glazed specimens

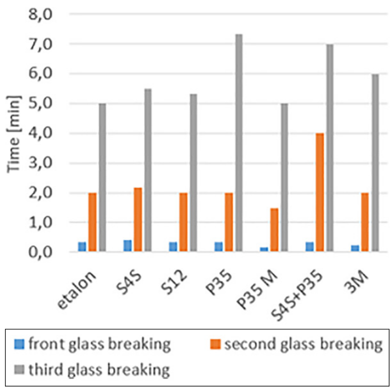
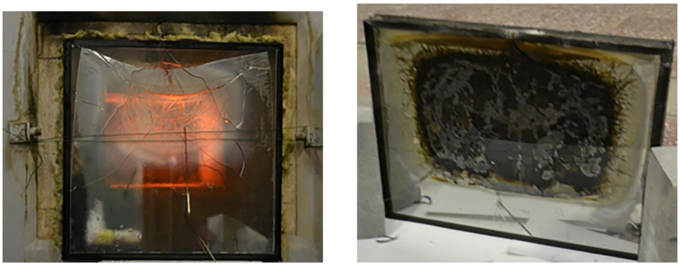


Figure 7. Time of the breaking of the glasses in case of triple-glazed specimens



(a) (b)

Notes: (a) Detachment of foil; (b) the burnt down result of the foil

Plate 4. Furnace test

2.3.2 Furnace test. In case of furnace tests, it was a conspicuous result for the double- and triple-glazed specimens that the use of the foil had a favourable effect on the cracking sensitivity of the glasses. The adhesive melted under the effect of continuous heat, so the foil separated from the glass layer. As a result of the heat load, the 3 M foil flew away, and later, it burned dripping in the test of the cracks of the specimen. The use of foil did not affect the

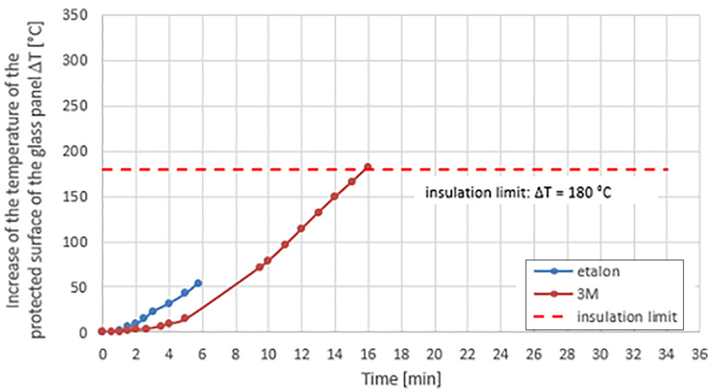


Figure 8. Protected side of the temperature of surface of double-glazed specimens on the basis of a furnace test

rate of the temperature increase. It can be stated that the foils have a negligible role during the insulation, which can be explained by the burning of the foils after the crack of the glass sheets (Plate 4). On the protected side, a higher temperature was achieved within a short time owing to the foil design. This is thanks to the heat reflective properties of the foils. The crack of the first layer is also because of these reasons. The breakage of the second layer slows down the ruined process because the foil of the first layer holds the glass layers together for a limited time.

During the tests, the specimen with 3 M foil showed better behaviour, which cannot be seen in the furnace experiments. The explanation for it may be that in case of blowtorch fire test, the blowtorch fire only heated the glass structure on a small surface. The performance of the

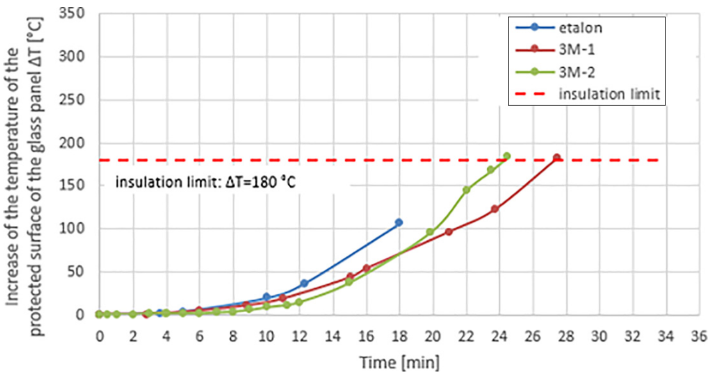


Figure 9. Protected side of the temperature of surface of triple-glazed specimens on the basis of a furnace test

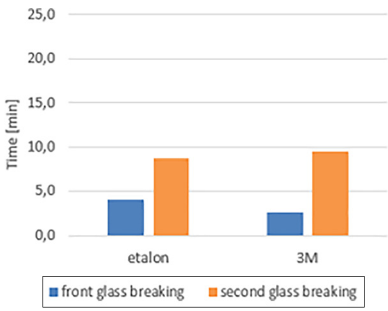


Figure 10. Time of the breaking of the glasses in case of double-glazed specimens

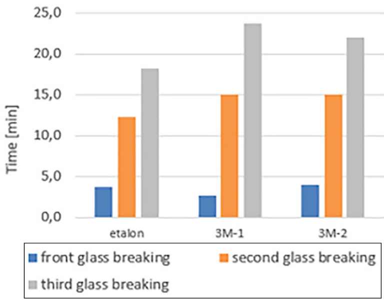


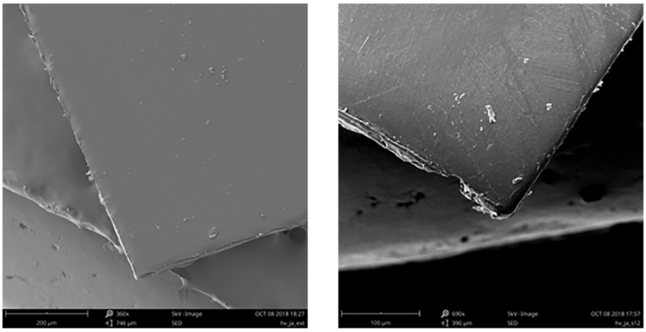
Figure 11. Time of the breaking of the glasses in case of triple-glazed specimens

blowtorch fire was not enough to warm up the entire glass structure. During the furnace experiment, the glass structure overheated the entire surface. Thus, the foil was able to melt on the surface by providing no additional protection.

Figures 8 and 9 show the increase of the temperature of the protected surface. Figures 10 and 11 show the time of the breaking of the glasses in case of double-glazed specimens and triple-glazed specimens.

3. Scanning Electron Microscope

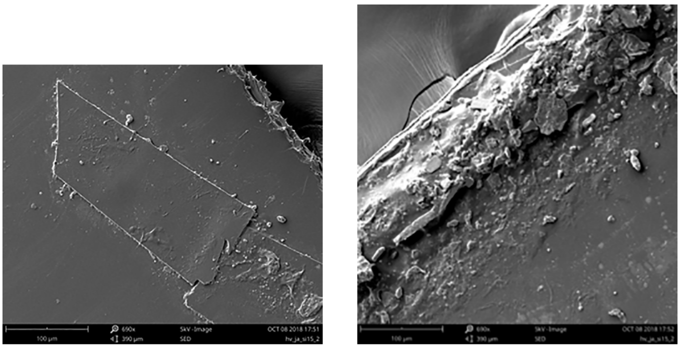
The surface of the foils was examined with an electron microscope. In case of foils, which were posteriorly glued to glass surfaces, the adhesion may not work at some points, so the foils do not stick perfectly to the surface. The refraction of the glass system can also change at these points. There will be no homogeneous reflection, which is rather an aesthetic problem. The previous phenomenon is a major problem for customers. They can complain about the quality of work. Blistering, fragmentations, scratch marks and other defects and also many small impurities can be observed on the foils. The gluing of the foils is preceded by the thorough cleaning of the glass sheets. However, the foil itself may contain an impurity that inhibits the steady gluing. The freshly cut edges of the foils appear to be more



(a) (b)

Notes: (a) EXT (360 × magnification); (b) S12 marked (690 × magnification)

Figure 12. Electron microscopy picture of foils



(a) (b)

Figure 13. Electron micrograph picture of SI15 foil at 690 × magnification

even in Figure 12, compared to the previously cut edges. It is caused by the ageing and abrasion of the foils. The destruction on the edges and the surfaces was the most significant in the SI15 foil (Figure 13). In this case, there was also a layered surface separation.

4. Conclusions

Fire protection performances of the glass specimens were studied with different heat foils under laboratory conditions in the present paper. The experiments of fire protection performance on small-sized glass elements with heat protection foils were carried at the Budapest University of Technology and Economics at the Department of Building Materials and Technologies. The fire protection of small model glasses was tested with blowtorch fire and furnace test. The cost of these tests is significantly lower than the cost of the large element structures. That is why we have set a target for the size effect study in the future.

In case of heat-protected glazing, the foils on the "protected" side of the single pane glass do not have a fire protection effect based on blowtorch fire test. This may be because the foils melt owing to the heat applied to the glass, wherever they are placed.

For double glassed specimens, the P35 foil has a perceptible effect, even for the requirements of the flame breakthrough (E, integrity), when the foil is placed on the inner side (position 3) of the second glass layer. In the case of double-layered glass structures, the warming of the glass structure is significantly slowed down by the gas filling between the two glass panes so that the film on the second glass sheet cannot melt and is effective.

The stratification of each triple-glazed specimens was effective against blowtorch fire load (3 M, S4&P35), so (EI, integrity and isolation) it can meet the requirements of flame breakthrough and thermal insulation.

The effectiveness of the foils can only be achieved with two- or three-layered glass structures.

In the blowtorch fire test, the test specimen with 3 M foil showed better behaviour, which was not observed in the furnace experiment. The reason for this may be that in case of the blowtorch fire test, the blowtorch fire only heated the glass structure on a small surface. The performance of the blowtorch fire was not enough to warm the entire glass structure. In the furnace test, the glass structure warmed the entire surface, so the foil was able to melt on the surface, providing no further protection.

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