Challenging Glass 7
Conference on Architectural and Structural Applications of Glass
Belis, Bos & Louter (Eds.), Ghent University, September 2020.

ISBN 978-94-6366-296-3, https://doi.org/10.7480/cgc.7.4471

Tests of the Embedded Laminated Glass Connection Under Short-term Tensile and Eccentric Shear Loads

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The embedded laminated glass connection belongs to the group of the most widely used ways of the glass components connecting. As it becomes common to use glass as a material for load-bearing elements, the connection must be able to bear stresses arising during the lifetime period. To find out the load capacity of the connection under different loads, experiments have to be performed. Within the ongoing research at the Faculty of Civil Engineering of Czech Technical University in Prague, two series of experiments of the embedded laminated glass connection have been performed. There were two sets of identical samples. Both sets included several combinations of glass panes and types of foils. The first series of tests was focused on the characteristics of this type of connection under the short-term tensile loads. The second one was dealing with the characteristics under the short-term eccentric shear loads. Due to using the identical samples for both series of tests, it was possible to compare the obtained results. The experiments show that the tensile load capacity of the connection is much higher than its eccentric shear load capacity. It also reveals reaching the tensile resistance limit of the weakened glass pane as a dominant mode of failure. However, further research consisting of numerical modelling and additional experiments is in progress.

Keywords: Embedded connection, Laminated glass, Laminated connection, Tensile load, Eccentric shear load, Experimental testing

1. Introduction

Nowadays, glass in structures no longer serves only as a material for window panes. Trends in modern architecture are heading towards a complete transparency of structures. Due to this tendency, it becomes common to use load-bearing components made of glass. Modern architecture works with glass facades and roofs, as well as with columns and beams. Those components have to bear all stresses arising during the lifetime period and meet high aesthetical standards at the same time, which causes the increase in requirements for connections of glass components.

Many mechanical and adhesive point-fixing systems have been developed in recent decades in order to achieve as much transparency as possible. However, because of specific characteristics of glass, connections of glass elements are considered to be the most critical part of the glass structure design. There are many possible point-fixing ways of connecting. Generally, they can be divided into three large groups – mechanical, adhesive and laminated connections.

Although being commonly used, mechanical connections (based on the classic or countersunk-head stainless steel bolts) suffer from a drilling process and a very small contact area leading to high local stresses in the bolt-hole area (Bedon 2017).

Adhesive connections are based on a layer of adhesive material placed between the steel and the glass element or between two parts made of glass. This connection provides more uniform transfer of loads and the absence of a drilling process. However, the strength of adhesives can be affected by many factors, such as temperature, humidity, UV radiation and also the type and duration of loads (Haldimann 2008).

Laminated connections combine the mechanical and adhesive connections. They consist of a steel element (a bolt or a plate) connected to a glass part by an adhesive interlayer (represented by thin foils). The steel element can be placed (embedded) between two glass panes or connected to the glass surface itself. The interlayer foils are typically made of Ethylene Vinyl Acetate (EVA), Poly Vinyl Butyral (PVB) or transparent Ionomers (SentryGlas). The manufacturing process is the same as for the standard laminated glass panes. The biggest advantage is that the connection realized by this process can be used immediately (there is no need for a curing time like in case of adhesive connections), which makes it suitable for in-situ application (Bedon 2017).

Systems of glass connections are still developing and laminated connections belong to the most progressive ones. There are many ongoing researches dealing with the characteristics of this fixing system and the design procedure is mostly based on experiments. This paper is dealing with two sets of experiments focused on determining the load capacity of laminated glass connection under short-term tensile and eccentric shear loads.

2. Tests of the embedded laminated glass connection

Within the ongoing research at the Faculty of Civil Engineering of Czech Technical University in Prague, two series of experiments focusing on the characteristics of the embedded laminated glass connection were performed. The first series was dealing with the characteristics under the short-term tensile load and the second series was dealing with the characteristics under the short-term eccentric shear force. Two sets of identical samples were used for the experiment. Both sets included several combinations of glass panes and types of foils. Due to using the identical samples for both series of tests, it was possible to compare the obtained results.

2.1. Description of the samples

Nine equally sized sets of glass panels with embedded laminated fixing system were provided for both series of experiments. The length of each panel was 500 mm, the width was 300 mm and the thickness of each glass pane was 10 mm (Fig. 1).

All the samples consisted of a steel fixing element, two glass panes, while one on them was weakened by previously drilled hole for placing the embedded fixing system, two HDPE liners preventing the direct contact between the steel element and the glass pane, and two layers of foil bonding the glass panes and the steel element together.

Each set of samples had a different combination of glass panes (float glass and tempered glass, or float glass and semi-tempered glass) and a type of foil. EVA and SentryGlas foils were used for the samples. The EVA foils were of two types – clear (Fig. 2a) and opaque (Fig. 2b).

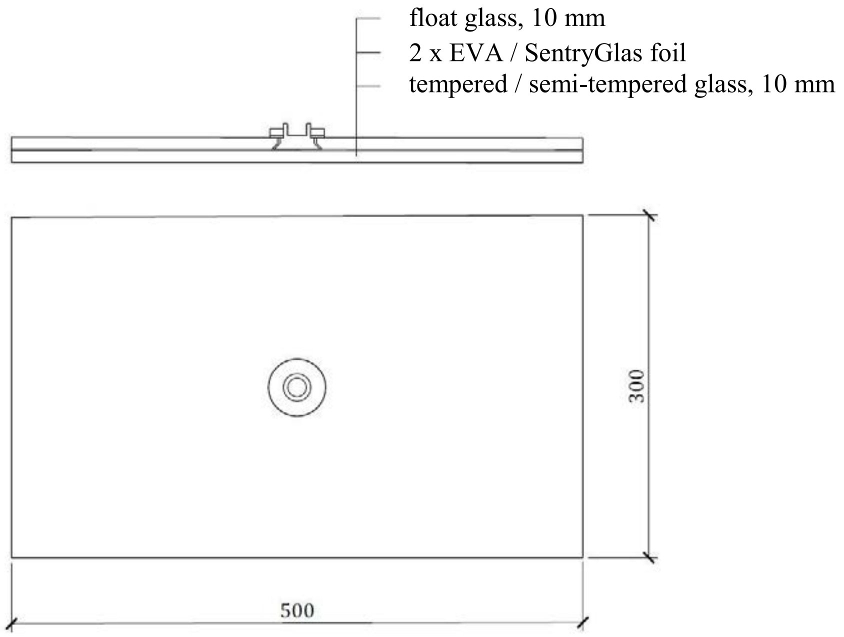


Fig. 1 Scheme of the samples.

a) b)

Fig. 2 a) Sample with a clear EVA foil, b) sample with an opaque EVA foil.

In order to reveal the production defects, all the samples were carefully checked before the experiment. Most frequently the samples suffered from small bubbles surrounding the edge of the steel element, or the HDPE liner, or both. Some samples had bigger bubbles in the area of the steel element but some samples were without defects. These defects do not have an influence on the performance of the connection but they might be unacceptable for the aesthetical reasons.

a) b) c)

Fig. 3a), b) Samples with defects, c) sample without defects.

2.2. Description of the arrangement of the tests

The first series of tests was focused on finding the load-bearing resistance in tension. To apply the tensile load, a special frame with detachable bottom part had to be manufactured. The samples were placed on the steel bed with two cylindrical supports and plastic pads (Fig. 4, Fig. 5).

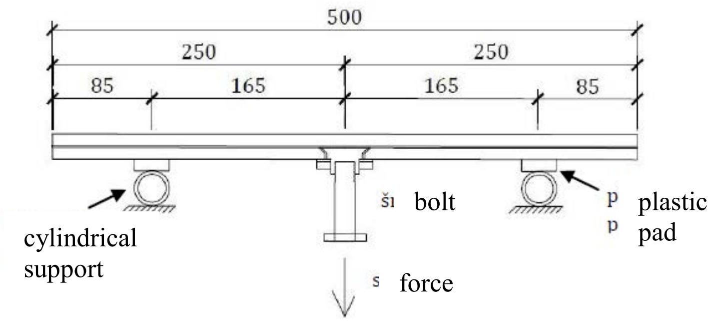


Fig. 4 Scheme of the tensile tests arrangement (Zdražilová 2019).

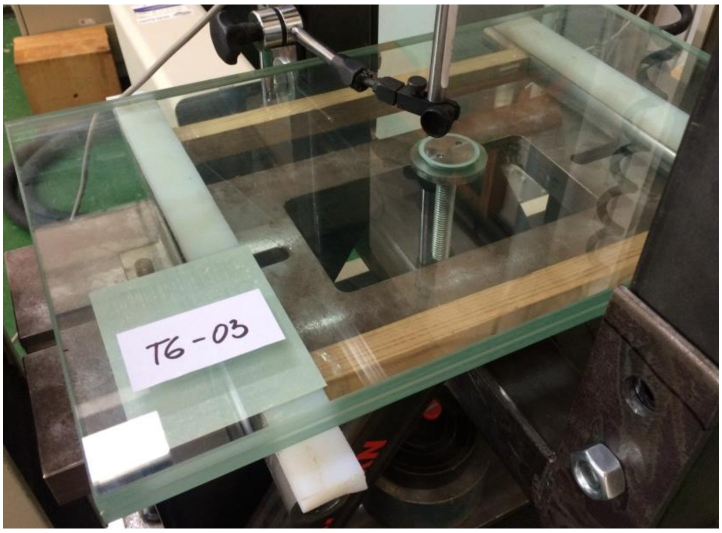


Fig. 5 A sample ready for a tensile test.

The second series of the tests was focused on finding the resistance of the connection under the eccentric shear load. In this case, the glass pane was vertically clamped to a steel frame with a detachable upper part. Plastic pads were fixed to the frame to avoid the direct contact between the glass and the steel. To create the eccentric shear force load, a special steel tool was put on the bolt which was screwed in the steel element (Fig. 6, Fig. 7).

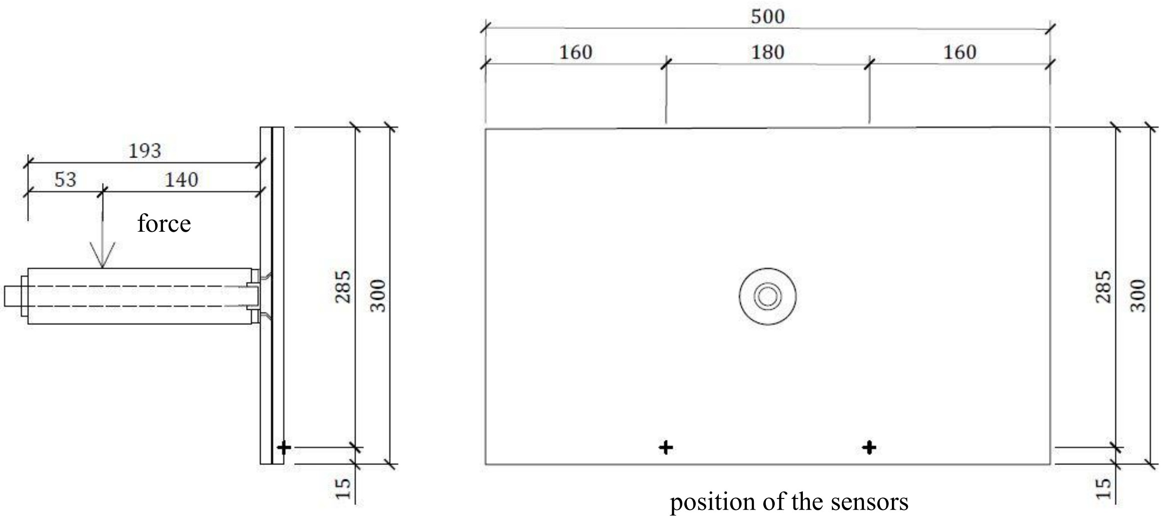


Fig. 6 Scheme of the eccentric shear force tests.

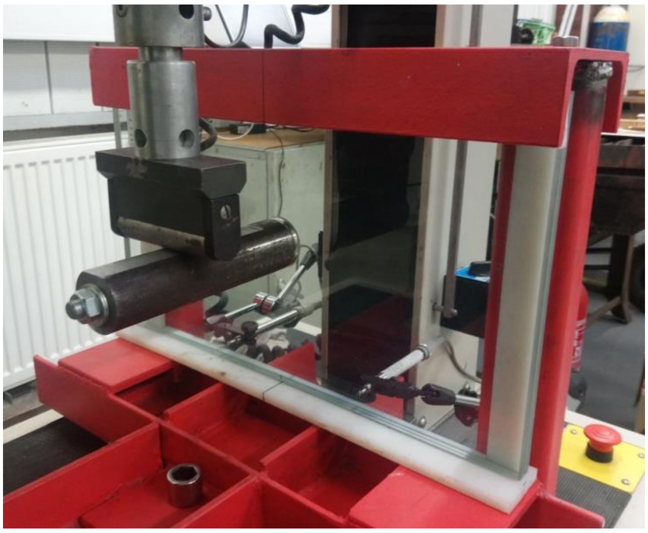


Fig. 7 A sample ready for an eccentric shear force test.

2.3. The testing procedure

The main goal of the experiment was to determine the resistance under two different types of loads – tensile load and eccentric shear load. However, all the changes of appearance were carefully noted during the whole time. The mode of failure of each sample was observed as well.

There were three expected possibilities of failure:

- failure of the weakened glass pane caused by local stress peaks in the area around the connection,
- delamination due to reaching the tear resistance limit,
- failure of the foil caused by reaching the normal stress resistance limit.

The testing process for both series included several loading and unloading cycles with 1 kN or 2 kN increments for the tensile tests (Fig.8, Zdražilová 2019) and 0,25 kN for the eccentric shear force tests (Fig. 9). After each cycle, the load was kept on a constant value for 1 minute. In case of the eccentric shear force tests, the load was after reaching 4 kN constantly increasing until the collapse. The experiments were held at the temperature of 30°C.

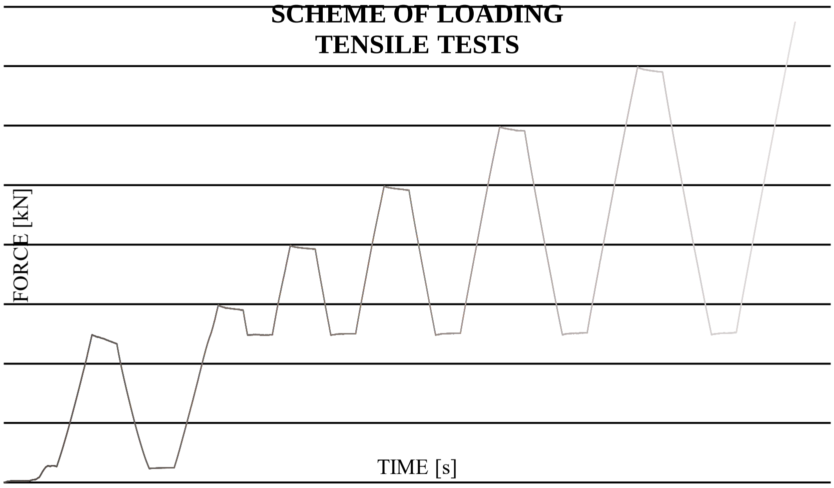


Fig. 8 A scheme of the tensile tests loading (Zdražilová 2019).

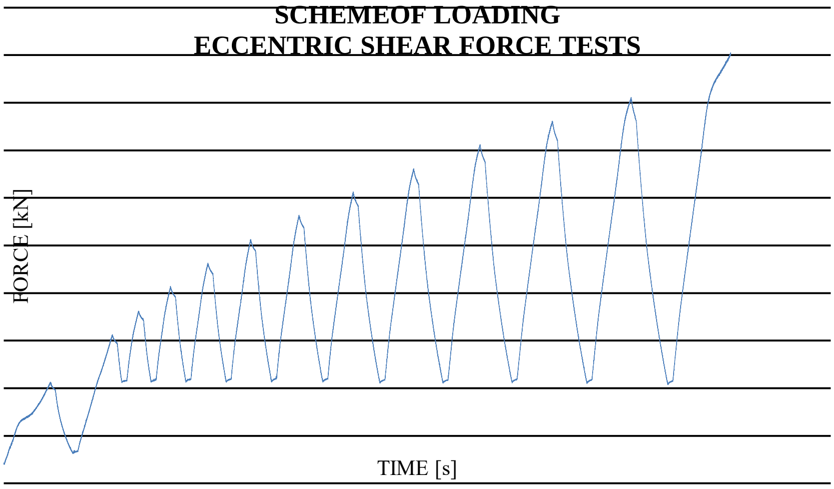


Fig. 9 A scheme of the eccentric shear force tests loading

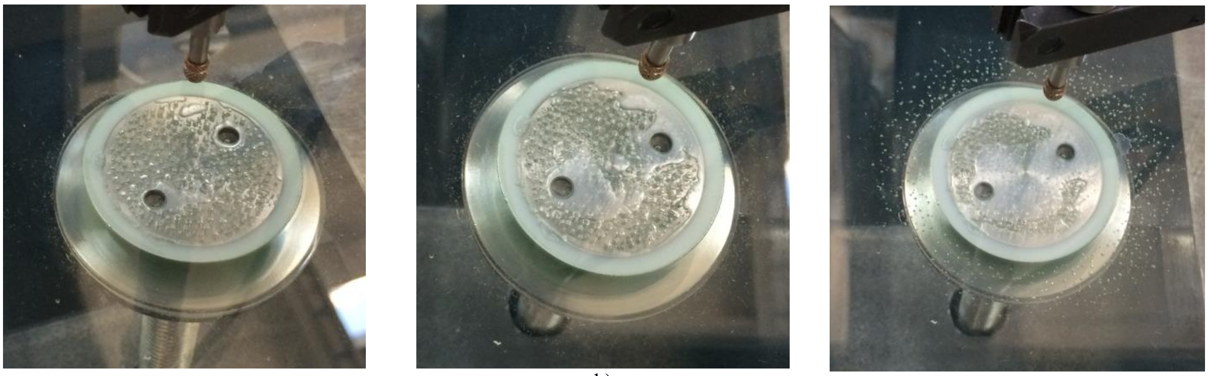
2.4. The course of the tests

All the visible changes of appearance arising during the loading were carefully observed and noted. The course of the experiment was essentially the same for all the samples. Small bubbles appeared in the area of the connection. The number of bubbles was increasing with the increasing load and after reaching a certain point; they started to merge into bigger bubbles.

The bubbles covered the whole area of the connection during the tensile tests. In some cases, smaller or bigger amount of bubbles appeared out of the connection, specifically around the steel element (Fig. 10). Despite merging of the bubbles inside the connection, no visible delamination of the glass panes appeared. During the experiment, the deflection of the sample was measured at two specific points. Figure 5 shows that the first sensor was placed on the top of the glass pane and it measured its vertical bending deflection. The second sensor measured the vertical deflection of the top of the bolt. This value represents the total deflection, including the bending of the glass pane, deformation of the HDPE liner and also possible delamination (Zdražilová 2019).

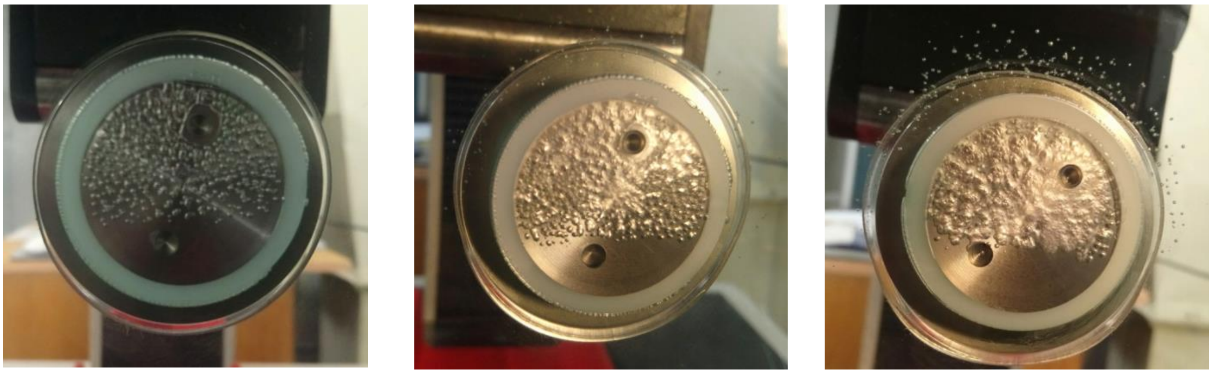
In case of eccentric shear force tests, the bubbles appeared only in the part of the connection exposed to tension. After reaching certain point, the bubbles clearly divided the tensile and pressured part of the connection. The bubbles outside of the connection also appeared only in the tensile part (Fig. 11). Moreover, a visible gap between the glass pane and the steel element was arising and the HDPE liner was deformed with the increasing load (Fig. 12).

During these experiments, a vertical deflection of the loading arm and the bending of the glass pane at two specific points were measured.



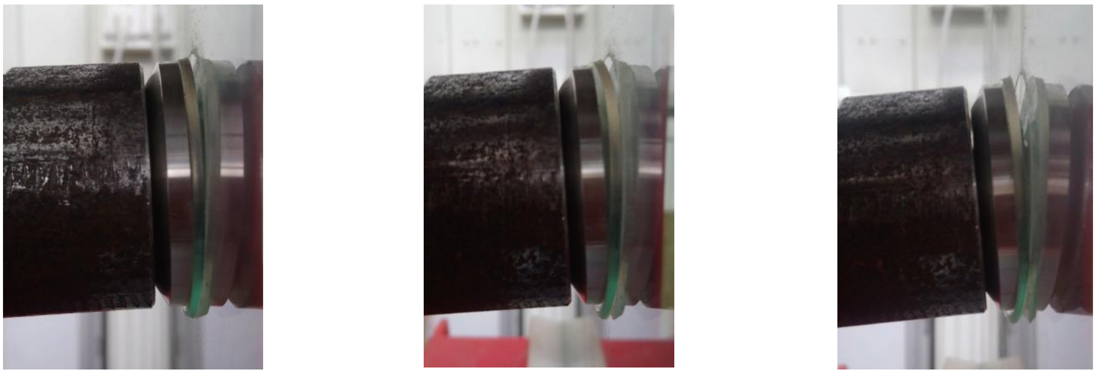
a) b) c)

Fig. 10 a), b), c) The course of the tensile test.



a) b) c)

Fig. 11 a), b), c) The course of the eccentric shear force test.



a) b) c)

Fig. 12 a), b), c) The deformation of the HDPE liner.

2.5. Results

The experiments showed that the majority of samples failed suddenly due to reaching the tensile resistance limit of the weakened glass pane. Among the eccentric shear force tests, essentially all the not weakened float glass panes resisted. There were few cases among the tensile experiments when both glass panes collapsed at the same time.

The steel element was pulled out of the glass pane in most cases of both series of test. There was not any foil left on the surface of the steel element and the foil did not seem to be damaged. However, there were some cases when the steel element stayed inside of the fractured glass and could not be pulled out. It happened randomly and shouldn't have any relation to the type of the foil.

Generally, the tempered glass fractured in granular chunks and the fracture of the semi-tempered glass was shaped as a spider with the connection as a centre. The fracture could be considered as biaxial symmetrical for tensile and uniaxial symmetrical for eccentric shear force tests (Fig. 13).

The graphs (Fig. 8, Fig. 9) show, that the tensile resistance of the connection is about three times higher than the eccentric shear force resistance. This difference can be explained by comparing the tensile parts of the connection surface. In case of the tensile tests, the whole connection is in tension. In the other case, the eccentric shear force causes a bending moment. Only a certain part is in tension and the rest of the connection is pressured. It means that a smaller surface of the connection transfers the tensile load and it leads to a smaller resistance.

a) b)

Fig. 13 a) Fractured tensile tests sample, b) fractured eccentric shear force tests sample.

3. Conclusion

The embedded laminated glass connection was tested to determine the short-term tensile and eccentric shear force resistance. Moreover, all the changes of appearance arising during the loading process were observed and noted. The experiment was focusing on finding the dominant mode of failure as well. Thanks to using two identical sets of samples, it was possible to compare the obtained results.

The experiment revealed reaching the tensile resistance limit of the weakened glass pane as a dominant mode of failure. It also showed that the tensile load resistance is considerably higher than the eccentric shear force resistance. This imbalance is caused by a smaller surface transferring the tensile load.

However, more tests should be performed to determine the exact collapse load and mode of failure. Further research consisting of full scale tests for applications (roof panels, handrails) and numerical modelling is in progress.

4. Acknowledgements

This paper was prepared with the support of the grant Hidden Connection of Laminated Glass Panes No. TH 03010175 of the Technology Agency of the Czech Republic (TAČR). The authors would like to thank OGB s.r.o company for the cooperation and providing of the samples.

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ISBN 978-94-6366-296-3, www.challengingglass.com

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