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Analysis of the influence of humidity during the production of safety glass on its quality

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Abstract: The production of safety glass is a multi-stage process and as such has a number of parameters that affect the final quality of the glass. The article presents an analysis of the influence of one of the production parameters on the results of the impact test. The object of the experiment was laminated safety glass with PVB foil of different humidity. This glass was tested in accordance with the ČSN EN 356 standard.

Keywords: safety glass, humidity, PVB foil, quality, testing

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Introduction

Safety glass is a special type of glass that is used to minimize damage either in a car accident or after external aggressive interference with the glass of buildings (Badalassi et al., 2014). It is designed so that upon impact, the glass breaks into small pieces that remain together thanks to the presence of a special foil. Safety glass can be divided according to the type of production into several categories. One type of glass is tempered glass, which has high bending strength, is very resistant to impacts and has high chemical and thermal resistance. Another is thermally tempered glass, which

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is also resistant to thermal and mechanical stress and is used mainly for interior and exterior doors of buildings. The third category is laminated glass, which consists of two or more layers of glass and one or more PVB foils (Zhou et al., 2023). The conductivity of polyvinyl butyral is very low, which is why it is used for applications such as safety glass. The adhesion of PVB foil is affected by several factors. Mineralized water is used before applying the foil to the glass pane. If demineralization and insufficient cleaning occurs, the adhesion of the PVB foil to the glass is reduced. Adhesion is also affected by the moisture content in the PVB foil and the relative humidity of the surrounding air (Aggromito et al., 2022). Laminated safety glass is used mainly in the automotive industry and serves primarily to protect the safety of people in traffic environments (estav, 2025).

Laminated safety glass is the most widely used type of safety glass in the automotive and construction industries. It is used in automobiles primarily for windshields, where it serves to protect the driver and passenger in the event of a collision thanks to an interlayer of PVB foil, which prevents the glass from shattering. In construction, it is used not only for doors and windows, but also for railings, roofs, shop windows, etc. (alfaglass, 2025). If the glass is damaged, the glass fragments adhere to the foil so as not to fall out and thus pose no health risk. The foil is also used to prevent burglary or the entry of people and objects through broken glass (Hooper et al., 2012). Laminated safety glass is also characterized by its high resistance to gunfire and explosions, penetration of people and objects, and finally its higher resistance to impacts. Thanks to polyvinyl butyral, which is used in the production of laminated safety glass, it also provides protection against ultraviolet radiation and has improved acoustic parameters compared to non-laminated glass. Last but not least, it provides increased thermal insulation and is also used for decorative purposes (Aggromito et al., 2022; Chen et al., 2022; Zacchei et al., 2023).

In terms of protection, we can divide laminated safety glass into three categories, the division results from the number of layers of foil between the layers of glass and the function of the safety glass. Basic protection: this is the lowest level of security, at least 2 PVB foil layers are used, the purpose is protection against manual attack. Medium protection: at least 4 PVB foil layers are used, its task is to prevent minor criminal activity. Enhanced protection: the aim of this level of protection is a higher level of security, where, due to increased demands on the safety of individuals, at least 6 PVB foil layers are used (alfaglass, 2025; estav, 2025). The above-mentioned types of glass are tested according to several relevant standards that were created in response to high demands on the safety and quality of safety glass. Of course, the safe use of glass panels in building structures depends on proper installation (Respondek, 2019). Assembly errors can lead to reduced performance or even structural damage (Chęciński & Respondek, 2020).

In the presented article, the "Drop Test" according to ČSN EN 356 was used to test the quality of safety glass. This European standard sets out the requirements and test methods for safety glazing, designed to withstand the action of force for a short period of time, which consists in delaying the entry of objects and/or people into the protected space. The standard classifies safety glazing products into categories of resistance to force, where glass is divided into classes: P1A - 33.2, P2A - 33.2, 44.2, P3A - 33.4, P4A - 33.4, 44.4, P5A - 44.6, which simulates the impact of a hard object on laminated glass and determines the resistance of glass to breakage. The method is used for testing glass intended for ground-level glazed parts of houses, commercial and administrative buildings, as well as shop windows. Other uses include: glass for detached houses, ground floor windows in commercial and administrative buildings, as well as for shops and warehouses with valuable goods, (estav, 2025).

The aim of this article is to analyze the influence of one of the production parameters of safety glass, namely humidity, on the resulting quality, using a drop test.

1. Materials and methods

The production of laminated safety glass is divided into individual phases: glass cleaning; application of PVB foil to the lower pane of glass; the upper pane of glass is placed on the PVB foil; pressing at high temperatures where it is passed over by a roller, which serves primarily to remove air bubbles and to pre-secure the connection between the glass and the PVB foil; loading on a stand; and curing in an autoclave at approx. 650 °C. The tested glass is a material with PVB foil in the range of 0.62 mm - 0.86 mm. 5 sheets of glass were prepared for one experiment, each of which was divided into 6 samples. The dimensions of the samples 300 × 300 mm were determined by the ČSN EN 356 standard. A drop test was performed on each of these samples, the success of which was evaluated according to the maximum drop height at which the ball does not pass through the glass. During sample preparation, the finished glass had to be relaxed for at least 12 hours. The prepared samples were then placed in a climate chamber, where the humidity was maintained at 40 % and the temperature at 18 °C for at least 4 hours, according to the standard. After preparation, the sample was placed in a stand, where an impact test was performed using a steel ball according to the ČSN EN 356 standard (Figs. 1 and 2).

The experimental samples differed in percentage humidity in the laminated glass and also in the drop height during the drop tests.

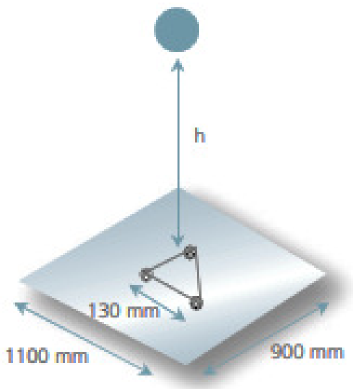

Fig. 1. Schematic of the drop test (Nováček, 2024)

Fig. 2. Unsuccessful (NOK) test result (Nováček, 2024)

2. Measured values

For the samples, attention was focused on the change in humidity in the laminated glass. The humidity was measured and found to be in accordance with the standard, in the range of 0.32 % - 0.75 %. The average humidity value in laminated glass in normal serial production is in the range of 0.34 % - 0.42 %. The experimental humidity values were chosen to be below the average humidity value, but also of values that exceeded the average percentage humidity in laminated glass within the framework of normal series production. The values were adjusted in such a way as to preserve the corporate secrecy of the presented results.

The first set of samples, which had an average PVB film thickness of 0.77 mm and an average humidity in the laminated glass of 0.33 %, were subjected to a drop test and the results are shown in Table 1.

Table 1. Drop test results: Ø PVB foil thickness: 0.77 mm; Ø humidity in laminated glass: 0.33 % (*own research*)

Glass number	1	2	3	4	5
Drop height	4 m	4.25 m	4.5 m	4.75 m	5 m
Sample 1	OK	OK	OK	NOK	OK
Sample 2	NOK	NOK	NOK	OK	NOK
Sample 3	OK	NOK	NOK	NOK	NOK
Sample 4	OK	NOK	NOK	NOK	NOK
Sample 5	OK	NOK	OK	NOK	NOK
Sample 6	NOK	NOK	NOK	NOK	NOK

For the first set of samples, a lower percentage humidity than the standard value for ordinary laminated glass was chosen. According to Table 1, we can see that the samples failed at the minimum height from which the steel ball was dropped. This was the reason for the gradual increase in humidity in the experimental material.

Therefore, another set of samples, which had the following experimental parameters: an average PVB foil thickness of 0.78 mm and an average humidity in the laminated glass of 0.35 %, were subjected to a drop test and the results are shown in Table 2.

From Table 2 it is clear that increasing the humidity led to better results compared to the previous experimental conditions. Thus, there is a clear trend that higher humidity in laminated glass has a positive effect on the strength of safety glass. This hypothesis needed to be confirmed by further experiments in which humidity values were increased while maintaining constant values of other parameters.

Therefore, another set of experimental samples, which had the following parameters: Ø PVB foil thickness: 0.77 mm; Ø humidity in laminated glass: 0.4 %, were tested. The results of the drop test are shown in Table 3.

Table 2. Drop test results: Ø PVB foil thickness: 0.78 mm; Ø humidity in laminated glass: 0.35 % (*own research*)

Glass number	1	2	3	4	5
Drop height	4 m	4.25 m	4.5 m	4.75 m	5 m
Sample 1	OK	OK	OK	OK	OK
Sample 2	OK	NOK	NOK	NOK	NOK
Sample 3	OK	NOK	NOK	NOK	NOK
Sample 4	OK	OK	OK	NOK	OK
Sample 5	OK	OK	OK	NOK	OK
Sample 6	OK	OK	OK	NOK	NOK

Table 3. Drop test results: Ø PVB foil thickness: 0.77 mm; Ø humidity in laminated glass: 0.4 % (*own research*)

Glass number	1	2	3	4	5
Drop height	4 m	4.25 m	4.5 m	4.75 m	5 m
Sample 1	OK	OK	OK	OK	NOK
Sample 2	OK	NOK	NOK	NOK	NOK
Sample 3	OK	NOK	OK	NOK	OK
Sample 4	OK	OK	NOK	NOK	NOK
Sample 5	OK	OK	OK	OK	NOK
Sample 6	NOK	NOK	OK	OK	NOK

Although the humidity value in the laminated glass was purposefully increased during this experiment, the results of the drop tests were worse than at lower humidity. It is evident (Table 3) that the steel ball passed through the glass already at the lowest tested drop height specified by the ČSN EN 356 standard, yet the experiment continued with a systematic increase in humidity while keeping the other parameters constant.

Table 4. Drop test results: Ø PVB foil thickness: 0.79 mm; Ø humidity in laminated glass: 0.44 % (*own research*)

Glass number	1	2	3	4	5
Drop height	4 m	4.25 m	4.5 m	4.75 m	5 m
Sample 1	OK	OK	OK	OK	NOK
Sample 2	OK	NOK	OK	OK	NOK
Sample 3	NOK	NOK	OK	OK	NOK
Sample 4	OK	NOK	OK	OK	NOK
Sample 5	OK	OK	OK	NOK	NOK
Sample 6	OK	NOK	OK	NOK	NOK

According to Table 4, it is clear that the steel ball passed through the glass from the minimum set height of 4 m. Given that the test results from a height of 4.5 meters were all satisfactory, it can be assumed that the samples that were used for the drop test from heights of 4 and 4.25 meters may have contained a crack or other defect that affected the results of the automotive safety glass.

Despite the above facts, the experiment continued with the following parameters: Ø PVB foil thickness: 0.78 mm; Ø humidity in laminated glass: 0.51 % (Table 5).

Table 5. Drop test results: Ø PVB foil thickness: 0.78 mm; Ø humidity in laminated glass: 0.51 % (*own research*)

Glass number	1	2	3	4	5
Drop height	4 m	4.25 m	4.5 m	4.75 m	5 m
Sample 1	OK	OK	OK	NOK	NOK
Sample 2	OK	OK	OK	OK	NOK
Sample 3	OK	OK	OK	NOK	OK
Sample 4	OK	OK	OK	NOK	NOK
Sample 5	OK	OK	OK	OK	OK
Sample 6	OK	OK	OK	OK	NOK

The results of the experiment under the specified conditions were the most successful so far. As can be seen in Table 5, the steel ball passed from the set height of 4.75 meters, which indicates that higher humidity in the laminated glass leads to better properties and safety of the glass than in the previous conditions, where the film humidity values were lower. This statement needed to be confirmed by another experiment. If similar results were to occur in further experiments, it would be necessary to normalize this value of humidity in laminated glass. Proposed testing conditions for the next series of samples: Ø PVB film thickness: 0.78 mm; Ø humidity in laminated glass: 0.6 % (Table 6).

Table 6. Drop test results: Ø PVB foil thickness: 0.78 mm; Ø humidity in laminated glass: 0.6 % (*own research*)

Glass number	1	2	3	4	5
Drop height	4 m	4.25 m	4.5 m	4.75 m	5 m
Sample 1	OK	OK	OK	OK	NOK
Sample 2	OK	OK	NOK	OK	NOK
Sample 3	OK	NOK	NOK	NOK	OK
Sample 4	OK	NOK	OK	OK	NOK
Sample 5	OK	OK	OK	OK	OK
Sample 6	OK	OK	OK	OK	OK

It is evident from the results (Table 6) that the steel ball passed through the glass from a height of 4.25 meters. Based on these results, it can be concluded that the percentage humidity in laminated glass is an important factor that affects the strength of automotive safety glass. In order to achieve successful results, the humidity in the laminated glass should be in the range of 0.44 % - 0.51 %. Within this range, we should be able to produce glass with the highest strength and resistance to penetration of foreign objects. Lower humidity values led to frequent occurrences of unsuccessful results, and the same was true for values above 0.51 % moisture. However, this statement still requires verification using several other independent tests to achieve its validity.

Conclusions

The article presents an analysis of the influence of humidity in the production of safety glass on the final quality using ČSN EN 356, specifically the impact test.

Humidity in laminated glass can affect the adhesive properties of the PVB foil and thus the overall strength of the glass. The samples were designed to test different humidity levels and their effect on safety glass and the glass of buildings. The results of these tested samples showed that humidity is an important factor that can positively affect the strength of safety glass and the glass of buildings. According to the results of the tested samples, higher humidity in the range of 0.51 % - 0.6 % brings the best results. This humidity level ensures optimal adhesion between the PVB foil and the glass, which increases the impact resistance of the glass. If we achieve optimal humidity, we can improve the cohesion between the PVB foil and the surface and thus the safety, which is the main function of safety glass.

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