Investigation of strength properties of laminated glass with different bonding materials

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Abstract

One of the most promising construction materials of the new millennium is laminated glass with all its remarkable capabilities and possibilities. With infrastructure projects progress, especially in regions with climatic effects of destructive force, the problem of durable and safe glazing application arises very intensively.

Now we meet especially urgent question about the use of durable and safe glazing with the development of infrastructure projects, especially in regions prone to climatic destructive forces.
Testing Center of the Glass Research Institute continues to conduct a series of tests to determine strength characteristics when the static centrally symmetric bending is coupled with climatic tests on the impact of external factors. We studied different types of laminated glass samples, consisting of at least two float glass layers and laminated, for example, with polymer film or polymer composition (different thicknesses). The test results were processed by different methods, such as: STF 05.12.1978 (determination of the averaged data in production-run) and EN12606: 2002 (determination of confidence intervals of destructive stress at fracture probability 0.1%). Tests showed that the use of modern films can increase the strength of glass by 2.5 times or more on various parameters, in comparison with traditional. In particular, we note that the innovative materials are light, more moisture-resistance and less vulnerable to damage to the edges of laminated glass sheets. We can conclude that a new generation high-films become an alternative to both traditional polyvinylbutyral film (PVB) and the bonding with glue.

Introduction and problem statement

Today sheet laminated glass in building is used as construction material wider. Glass sizes in use are increasing. New fields of application are appearing, for example: glass ceilings, beams, columns, coverings, translucent enclosures, façade systems and many other constructions. In recent years tendencies appeared in Russia that business-oriented projects concentrated around high-rise buildings with laminated glass application. Such buildings have raised requirements both in safety and architectural attractiveness. Special safety glazing is the laminated glass, consisting at least two float-glass layers, laminated with polymer film or polymer composition. Laminate layer can be sheet material, for example, PVB (polyvinylbutyral) film, or pitch with subsequent hardening. Laminated glass has some residual bearing capacity when glass layer is broken. Of cause the question of strength properties of such glass is extremely important because of listed above reasons.

For determination of the modern glass strength properties, we provided series of experiments in the testing centre of the Glass Research Institute. These experiments included samples of laminated glass with various laminating film types and thickness: polyvinylbutyral (PVB) film, new ionoplastic film, thermoreactive film on the basis of ethylenevinylacetate and photohardenable composition.

Experimental procedure

During this work for the strength limit (breaking stress) estimation authors used method of strength limit determination with static centrosymmetrical bending of the samples according to STP 12-5-78 [2] similar to EN 1288-5:2000 “Glass in building - Determination of the bending strength of glass - Part 5: Coaxial double ring test on flat specimens with small test surface areas”.

The obtained bending tests results were processed according to several techniques, including:
- STP 12-5-78 mentioned above. This method is based on the measurement of the breakage stress during bending of ring-supported sample, which is loaded by the ring-shaped forcer in alignment with support. After the measurement ultimate strength of the sample was calculated.

− EN12603:2002 “Glass in building. Procedures for goodness of fit and confidence intervals for Weibull distributed glass strength data”.

In the discussing experiments total number of samples was 104. The samples included laminated glasses with the different films and, for comparison, monolithic flat glass. See Table 1 for details.

Table 1 – The experimental samples

Film type	Film thickness, mm	Quantity of the samples	Glass construction, mm
Polyvinylbutyral (PVB) film	1.52	20	4-1.52-4
Ionoplastic film	1.52	18	4-1.52-4
	0.89	6	4-0.89-4
Photohardenable composition	1.60	20	3.8-1.6-3.8
Thermoreactive film on the basis of ethylenevinylacetate with high ratio of three-dimensional intermolecular bonds	0.50	20	6.0-0.5-6.0
Monolithic flat glass	--	20	6

Before tests all samples were observed for lack of external appearance defects.

All tests were conducted on the experimental setup with our old dependable testing machine FP 100/1, which can load up to 10 force tone. During the experiment thickness of the sample (mm), breakage load (kN) and deflection in mm were measured.

Post-processing of observations

As mentioned earlier, measurement results were processed according to STP 12-5-78 and EN 12603:2002 (E). According to the method from 8.4.1 subsection of latter standard we calculated confidence interval. Table 2 contains average data and confidence intervals for breakage stress with breakage probability of 0.1% in production-run.

Table 2 – Average test results and confidence interval of breakage stress in production-run

Film type	Film thickness, mm	Average strength, MPa	Standard deviation, MPa	Variation coefficient, %	Strength (breakage stress), MPa	Confidence interval (max-min), MPa	
PVB	1.52	17.63	5.82	33.02%	**2.26**	**4.47**	**0.71**
Ionoplast	1.52	44.92	10.89	24.24%	**10.66**	**17.63**	**4.52**
	0.89	42.48	13.89	32.70%	**3.54**	**13.33**	**0.06**
Photoharden able composition	1.6	**11.68**	**3.87**	**33.12%**	**1.53**	**3.01**	**0.49**
Film on the basis of ethylenevinyl acetate	0.5	**19.66**	**4.18**	**21.27%**	**6.81**	**9.69**	**3.74**
Monolithic glass	--	**53.77**	**22.21**	**41.30%**	4.65	10.68	1.08

Analysis of results

Table 2 contains average strength from calculations according to the following formula:

$$\sigma_i = 0{,}426 \frac{P_i}{h_i^2}$$

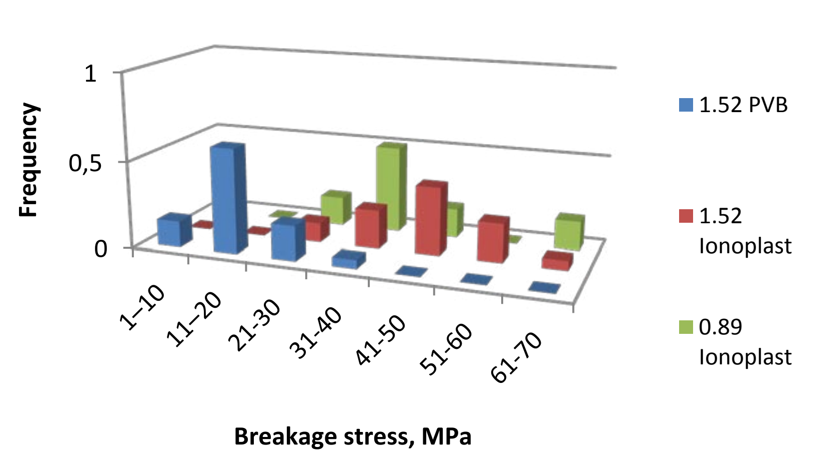
where σ_i is ultimate strength for centrosymmetrical bending of i -th sample, kgf/mm^2;

P_i is breakage stress of i -th sample, kgf;

h_i is thickness of i-th sample, mm.

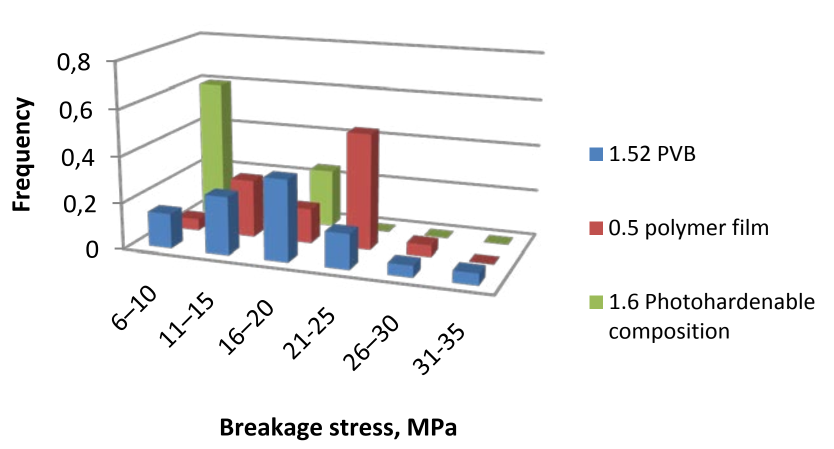
Our tests shows that ionoplast layer can increase strength of the laminated glass more than 2.5 times compared to classical PVB-film in various indices. Average strength of ionoplast-based laminates exceeds numbers of model maximum allowable stress for calculations of monolithic flat glass products. It can be seen that higher than classical PVB-film strength was shown not only for samples with 1.52-mm ionoplast layer, but samples with ionoplast thickness of 0.89 mm were also more durable than PVB samples (See Figure 1). But total quantity of 0.89-mm samples was insufficient to reliable estimation of their strength confidence interval.

Figure 1 Frequency diagram for the breakage stress (44 samples)



Samples with thermoreactive film on the basis of ethylenevinylacetate have medium strength, their strength is higher than calculating numbers for annealed glass but lower than maximum allowable stress for calculation of tempered glass products. Also we can see that strength of the 0.5-mm ethylenevinylacetate film samples is higher than samples with 1.52-mm PVB-film and 1.6-mm photohardenable composition (See Figure 2). But ethylenevinylacetate film showed lower results than ionoplast film. Samples with photohardenable composition showed worst strength properties with highest scatter of results for the composite materials in our tests.

Figure 2 Frequency diagram for the breakage stress (60 samples)



In the obtained results we can see relation between variation coefficient of the ultimate strength and the laminating film type and thickness. Variation coefficient is lower for the modern films even with lesser thicknesses comparing to PVB-film.

Other practical positive properties of the ionoplast-laminated glass are weight, which is 10% lower, density of the laminating layer, which is 5 times higher, higher moisture resistance and lower risk of the edge breakage for the laminated glass. So we think that we have enough reasons to say that discussed modern film types are real alternative to traditional PVB-film or glueing.

Comparing with monolithic flat glass under equal loads, ionoplastic laminated glass can be matched with the flat glass of the same thickness in tolerance limits, but the PVB-film laminated glass has to be twice the thickness of the comparable flat glass. Reference value of the flat glass strength from GOST 111-2001 and EN 572-1:2004 is 15 MPa, that is lower than obtained numbers. Therefore, in preliminary design calculations for the laminated glass one can use reference value.

Conclusions

Glass as construction material takes enhanced attention because of its possibilities to raise optical transparency in architectural environment and to diversify space and imaginative qualities.

In the scope of the glass mechanical properties analysis program our laboratory in the Glass Research Institute made a series of the presented experiments for detection of dependence between strength properties and types and thickness of the laminating layer. It was found that modern composite materials has some advantages comparing to traditional lamination techniques.

Relations between breaking stress in glass and presence of non-breakage defects of appearance were not found in the discussed experiments.

Due to actuality of the laminated and monolith glass strength properties problem, it is necessary to continue theoretical and experimental research to include structure of the glass investigation and to test samples number by order of magnitude greater.

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