Strength properties study for flat glass with various thicknesses, sizes and test methods

Natalia A. Chmykhova, Scientist, OAO Glass Research Institute, Dushinskaya street 7, 111024, Moscow, Russia, island.n@gmail.com
Alexander G. Chesnokov, Head of the standardization and testing department, OAO Glass Research Institute, Dushinskaya street 7, 111024, Moscow, Russia, agchesnokov@glassresearch.ru
Stanislav A. Chesnokov, Scientist, OAO Glass Research Institute, Dushinskaya street 7, 111024, Moscow, Russia, sachesnokov@glassresearch.ru

Keywords
1 = fracture stress 2 = centrosymmetrical bending 3 = Weibull distribution

Abstract

Glass application in building has a rapid development all over the world during last century. New types of glass are developing, glass areas are increasing and new types of glass constructions are designing. Therefore, strength research is very important, because mechanical strength is the key factor of many glass applications. Glass Research Institute Testing laboratory is carrying out large-scale test session for the strength properties estimation by various techniques. We use such methods as three-point bending, four-point bending in lateral static bending, static central-symmetric bending. We are analyzing dependence of float glass strength properties from glass thickness, visual appearance indicators, residual stress, edge finishing. Sample pool includes about 1000 glass samples of different types, with thicknesses in range from 3 to 12 mm, short size length from 360 to 1100 mm, various edge conditions etc. Testing results are processed by the following techniques: STP 12-5-78 (averaging data in batch), STP 12-4-78, EN 1288-3:2000 (equivalent to GOST 1.13.041-2.016.11) and EN 12603:2002 (GOST 1.13.041-2.019.11) (determination of the breakage stress confidence intervals with 0.1% breakage probability). We find a number of interesting conclusions during our test data processing.

Introduction and problem statement

Today application fields of the various building glass types are developing very rapidly. Using glass as a construction material needs to glass areas increasing. In the glazing projects there are two possible but objectionable options: either overestimated glass thicknesses and underestimated calculation strength or inversely understated glass thicknesses and overstated strength. We think that strength properties of the glass problem is very pressing question in this connection.
For the determination of the modern glass mechanical characteristics, OAO Glass Research Institute Testing Center is carrying out large-scale investigation of the different glass types specimens. We use various types of loading and glasses with wide range of quality, state of the surfaces and edges, cut quality, presence of defects in glass.

Experimental procedure

Authors are using the following test techniques for ultimate strength (rupture stress) of glass estimation:
- 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”. This method is based on the breakage load measurement during deflection of the ring-supported specimen loaded by axial shaping ring and the calculation of the ultimate strength after that. We are marking it as CSB.
- STP 12-4-78 [1] “Inorganic glass. Glass crystal materials. Refractories. Method for ultimate strength determination in lateral static bending”. 3-point and 4-point loading techniques are used and marked 3pB.
- EN 1288-3:2000 [4] “Glass in building - Determination of the bending strength of glass - Part 3: Test with specimen supported at two points (four point bending)” (marked 4pB).
- EN 1288-5:2000 [5] “Glass in building - Determination of the bending strength of glass - Part 5: Coaxial double ring test on flat specimens with small test surface areas” (marked 2AR).

Our plan includes the tests for the specimens listed in Table 1.

Table 1

Product type	Thickness, mm	Length, mm	Width, mm	Amount	Tested	Test type
Plain float glass	3	100	100	400		2AR
		1000	360	40		4pB
		1000	1000	16		CSB
Plain float glass	4	400	400	120	40*	CSB
					40*	3pB
					40*	4pB
		1100	360	80	40*	CSB
					40*	4pB
		100	100	400	173*	2AR
		1000	360	40	40*	4pB
		1000	1000	52		4pB/CSB
Plain float glass with edge processing		1000	1000	36	36*	CSB
Plain float glass	5	100	100	400		2AR
		1000	360	40		4pB
		1000	1000	16		CSB
	6	100	100	400	25*	2AR
		1000	360	40		4pB
		1000	1000	16		CSB
	8	100	100	400		2AR
		1000	360	40		4pB
		1000	1000	16		CSB
	10	100	100	400		2AR
		1000	360	40		4pB
		1000	1000	16		CSB
Clear float glass	12	100	100	400		2AR
		1000	360	40		4pB
		1000	1000	16		CSB
* – tested on the moment of submission specimens						

Works started from check of all specimens for visual appearance defects, edge state and residual stresses in glass before testing.
All tests use two experimental machines: test stand FP 100/1 with 100 kN load limit and test stand FP 10 with 10 kN load limit.
The tests include measurements of specimen thickness (mm), breakage load (kN), deflection (mm), time to breakage (s). In addition, we are always fixing area of the breakage start.

Post-processing of the observations

Obtained measurement results were processed according to test techniques listed above and according to EN 12603:2002 [3] “Glass in building. Procedures for goodness of fit and confidence intervals for Weibull distributed glass strength data”. Confidence interval calculation used techniques from the section 8.4.1 of this standard. Table 2 consists of average data and confidence intervals for the breakage stress with 0.1% breakage probability in production-run.

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

Specimen mark (Thickness / sizes / test type)	Amount of specimens	Test Technique	Average strength, MPa	Standard deviation, MPa	Variation coefficient, %	Strength (breakage stress), MPa	Confidence interval (min-max), MPa	
4mm 400x400 CSB	40		71.00	40.26	56.70%	2.35	0.73	5.44
4mm 400x400 3pB	40	STP 12-4-78	9.59	1.78	18.53%	3.05	2.02	4.07
4mm 400x400 4pB Ls=360 Lb=75	20	STP 12-4-78	11.94	3.09	25.87%	2.12	0.79	3.79
		GOST 1.13.041-2.016.11	57.35	14.67	25.58%	10.38	3.89	18.41
4mm 400x400 4pB Ls=360 Lb=200	23	STP 12-4-78	19.51	5.06	25.94%	3.49	1.45	6.02
		GOST 1.13.041-2.016.11	52.67	13.49	25.62%	9.63	4.03	16.48
4mm 1100x360 4pB Ls=1000 Lb=200	40	STP 12-4-78	3.41	0.89	26.06%	0.68	0.39	1.02
		GOST 1.13.041-2.016.11	50.46	11.84	23.47%	11.81	7.16	17.04
4mm 1000x360 4pB Ls=910 Lb=182	40	GOST 1.13.041-2.016.11	70.50	22.76	32.29%	10.77	5.42	17.30
4mm 1100x360 CSB	40		101.24	61.93	61.17%	2.19	0.58	5.62
4mm 1000x1000 CSB Processed edge	36		55.69	16.91	30.36%	10.61	5.85	16.38
4mm 100x100 2AR	173		224.16	86.03	38.38%	24.81	17.98	32.86
6mm 100x100 2AR	25		147.68	58.05	39.31%	15.96	5.77	31.10
4mm 280x330 CSB ([7])	20	Tin side	92.39	27.49	29.75%	17.81	4.47	35.43
		Side without tin	52.99	13.19	24.88%	12.41	2.77	24.05
		Both sides	74.66	29.58	39.63%	6.5	1.7	14.56
6mm 280x330 CSB ([7])	20	Tin side	63.58	26.62	41.86%	5.61	0.54	16.06
		Side without tin	42.86	7.64	17.82%	14.06	4.12	23.51
		Both sides	53.77	22.21	41.30%	4.65	1.08	10.68
6mm 1000x1000 ([9])	741		71.35	17.17	24.06%			
4mm 80x80 CSB ([6])	30		127.08	44.15	34.74%	13.22	4.96	25.01

We showed earlier [7] that tested strength of the tin side and side without tin of the float glass has statistical difference. Therefore, here we use average strength of both sides' numbers.

Analysis of results

Our tests showed that strength of the 6 mm thick glass is lower by the same comparing to 4 mm thick glass in the tests by same technique. We did not find any dependence between breakage stress in glass and visual appearance defects presence, edge quality or residual stresses in glass before test. In the same time, we can note high dispersion of the breakage stresses between specimens. Variation coefficient was about 40% in the both cases. It might be supposed that ribbon shaping technology can effect on the dependence of the glass strength from its thickness, so thicker glass has lower strength than thinner one.
Also it worth to mention that on the smaller specimens measured strength parameters are higher than for the bigger specimens.

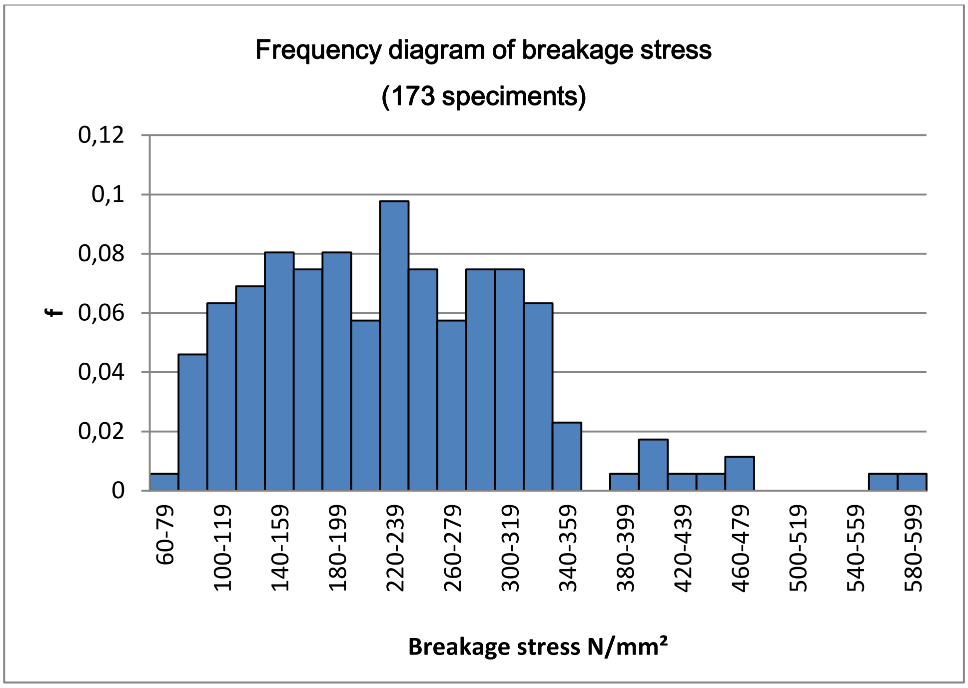

Figure 1. Frequency diagram of breakage stress

Dependence of the glass strength from temperature

Our laboratory is carrying out various researches. In particular, we want to show the results of the examination of laminated glass specimens under different temperature. The laminated glass specimens consisted of two layers of 3 mm clear float glass and new strengthened PVB film with thickness of 0.7 mm. 62 specimens with 400×400 mm sizes were available.
Obtained results you can see in Table 3.

Table 3
Average test results and confidence interval of breakage stress in production-run for the laminated glass

Specimen mark		Average strength, MPa	Standard deviation, MPa	Variation coefficient, %	Strength (breakage stress), MPa	Confidence interval (min-max), MPa	
t=+40°C		25.54	6.23	24.41%	4.71	1.59	8.63
t=+20°C		41.74	10.07	24.12%	11.01	5.35	17.24
t=-40°C		49.65	14.85	29.91%	7.97	2.90	14.66
PVB [8]	1.52 mm thick	17.63	5.82	33.02%	2.26	0.71	4.47
Ionoplastic protection film [8]	1.52 mm thick	44.92	10.89	24.24%	10.66	4.52	17.63
	0.89 mm thick	42.48	13.89	32.70%	3.54	0.06	13.33

The tests showed that laminated glass strength decreasing with temperature grow i.e. with temperature decreasing strength grows. This result has good agreement with the theory. As you can see, average glass strength under t=-40°C temperature is two times higher than for the specimens under t=+40°C temperature. When we compared these results with the older results for the specimens with the different films from [8], when test were carried out under room temperature, we found that new strengthened PVB is two times stronger than classic PVB of 1.52 mm thickness. Actually, we found that new laminated glass could be compared to ionoplastic-laminated glass with 0.89 mm thick film even it included thinner glass layers.
So one of our results is that new high-performance next-generation PVB film becomes the real alternative both to the well-known with a good account ionomeric film and to the traditional PVB film.

Conclusions

Construction applications of the glass make for increased interest for its properties investigation. Anyone involved now understands that glass application as a construction material allows optical permeability increasing, space- and image-bearing properties variety.
In the context of the glass mechanical properties research program Glass Research Institute laboratory is carrying out series of the experiments aimed to find dependencies of the strength characteristics from various parameters.
At the moment, we did not find statistically significant dependency between rupture stress in glass and visual appearance defect presence. Dispersion of the breakage stress between specimens is very high that is the reason to continue research to reveal technological parameters and glass characteristics effecting its strength. Glass strength estimation techniques require refinement both in theoretical and experimental part.

References

[1] STP 12-4-78 “Inorganic glass. Glass crystal materials. Refractories. Method for ultimate strength determination in lateral static bending”.
[2] STP 12-5-78 “Inorganic glass. Method for determination of ultimate strength by centrosymmetrical bending”
[3] EN12603:2002 “Glass in building. Procedures for goodness of fit and confidence intervals for Weibull distributed glass strength data.”
[4] EN 1288-3 2000. “Glazing in building - Determination of the bending strength of glass - Part 3 Test with specimen supported at two points (four point bending)”
[5] EN 1288-5 2000. “Glazing in building - Determination of the bending strength of glass - Part 5 Coaxial double ring test on flat specimens with small test surface areas”
[6] N. Kodratieva, V. Zubkov, A. Chesnokov, S. Chesnokov. Analysis of the Flat Glass Strength Properties. "Glass Processing Days. Conference Proceedings 17 to 20 June 2005", Tampere, Finland, p. 527-529.
[7] N. Chmykhova, A. Chesnokov, S. Chesnokov. Experimental study of strength properties for the modern glass. "Glass Processing Days. 2009", Tampere, Finland, p. 845-848.
[8] N. Chmykhova, A. Chesnokov, S. Chesnokov. Investigation of strength properties of laminated glass with different bonding materials. "Glass Processing Days. 2011", Tampere, Finland, p. 252-254.
[9] Design of glass panes bending strength. / An overview of prEN13474 and the work of CEN/TC129/WG8 from which it was developed.

2013