Natalia A. Chmykhova
Alexander G. Chesnokov
Stanislav A. Chesnokov
Glass Research Institute
Moscow, Russia

Strength properties study for flat glass

with various thicknesses, sizes and test methods

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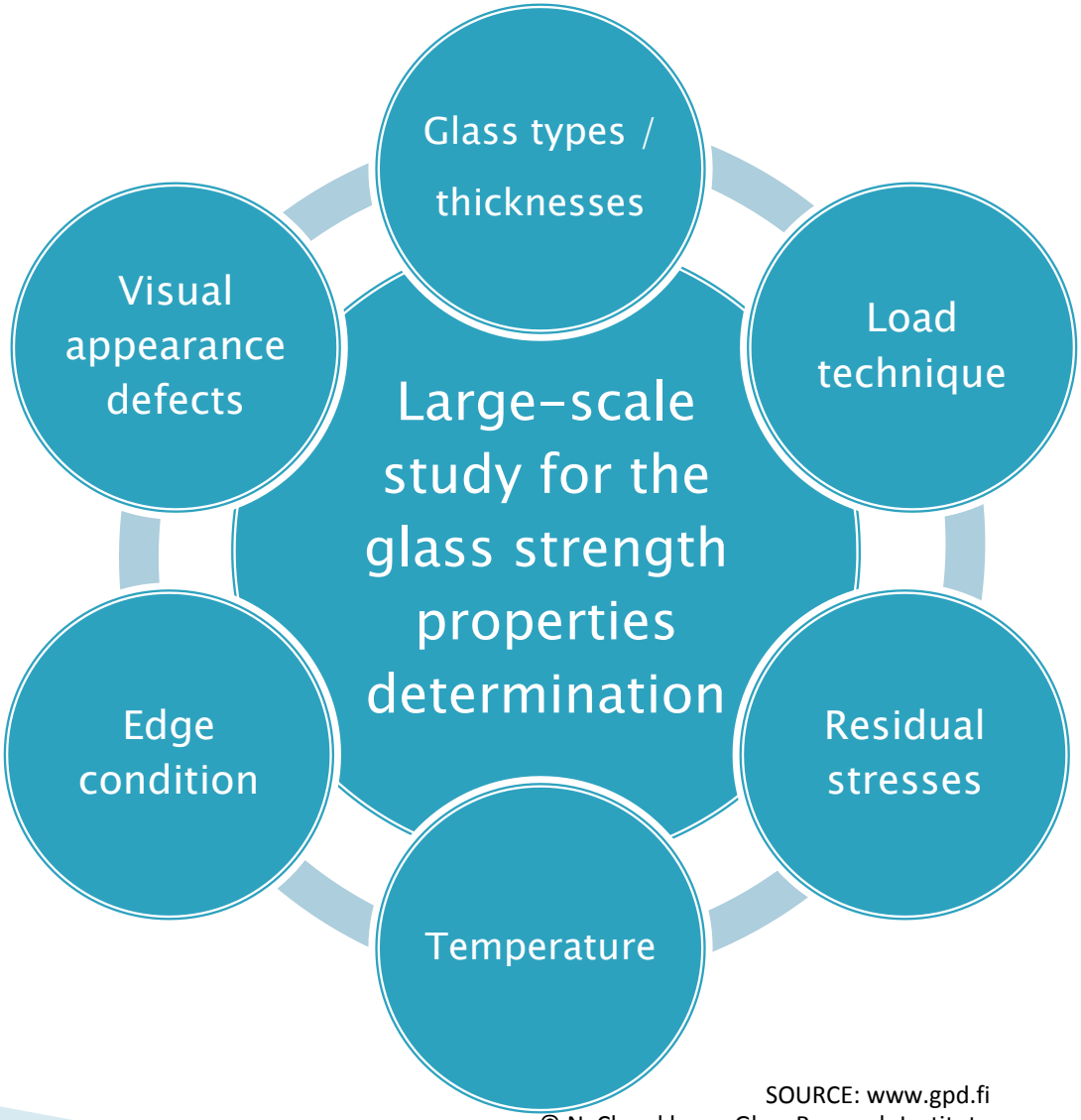
Introduction & problem statement

Application fields of the various glass types are expanding

Glass areas in applications are increasing

Glass strength properties problem is VERY RELEVANT



SOURCE: www.gpd.fi

Test methods (techniques)

- **STP 12-5-78** *"Inorganic glass. Method of strength limit determination with static centrosymmetrical bending"*. similar to EN 1288-5:2000 (We are marking it as **CSB**.)
- **STP 12-4-78** *"Inorganic glass. Glass crystal materials. Refractories. Method for ultimate strength determination in lateral static bending"*. 3-point and 4-point loading techniques are used (marked **3pB**.)
- **EN 1288-3:2000** *"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** *"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**).

SOURCE: www.gpd.fi

Experimental procedure (Plan)

Product type	Thickness, mm	Width x Length, mm	Amount
Plain float glass	3	100x100; 360x1000; 1000x1000	456
Plain float glass	4	100x100; 400x400; 360x1000; 360x1100; 1000x1000	692
Plain float glass with edge processing	4	1000x1000	36
Plain float glass	5	100x100; 360x1000; 1000x1000	456
Plain float glass	6	100x100; 360x1000; 1000x1000	456
Plain float glass	8	100x100; 360x1000; 1000x1000	456
Plain float glass	10	100x100; 360x1000; 1000x1000	456
Clear float glass	12	100x100; 360x1000; 1000x1000	456

SOURCE: www.gpd.fi

Experimental procedure (Tested)

Product type	Thickness, mm	Width x Length, mm	Tested amount	Test type
Plain float glass	4	400x400	40 40 40	CSB 3pB 4pB
		360x1100	40 40	CSB 4pB
		100x100	187	2AR
		360x1000	40	4pB
*with edge processing	4	1000x1000	36	CSB
Plain float glass	6	100x100	214	2AR

CSB – static centrosymmetrical bending
3pB – three point bending
4pB – four point bending
2AR – coaxial double ring bending

SOURCE: www.gpd.fi

Experimental procedure

Works started (before testing) from check of all specimens for:

- visual appearance defects
- edge state
- residual stresses in glass

Testing specimens had to meet corresponding standards.

Experimental machines:

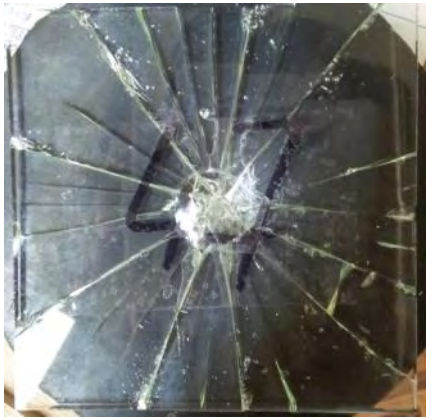
- test stand FP 100/1 with 100 kN load limit
- test stand FP 10 with 10 kN load limit

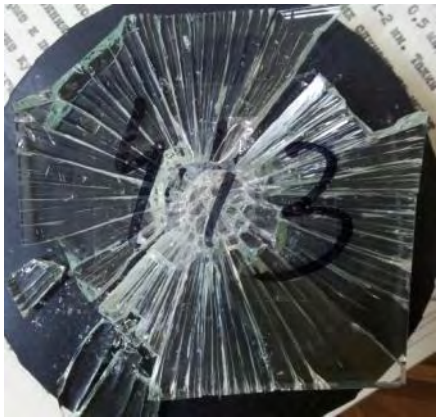
The tests include measurements of:

- ✓ specimen thickness, mm.
- ✓ breakage load, kN.
- ✓ Deflection, mm.
- ✓ time to breakage, s.
- ✓ fixing area of the breakage start

SOURCE: www.gpd.fi

Experimental procedure





SOURCE: www.gpd.fi

Post-processing of the observations

Obtained measurement results were processed according to test techniques listed above and according to ***EN 12603:2002*** *"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.

Following table consists of average data and confidence intervals for the breakage stress with 0.1% breakage probability in production-run.

SOURCE: www.gpd.fi

Post-processing of the observations

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	187		220,47	85,86	38,94%	23,19	17,04	30,64
6mm 100x100 2AR	214		167,19	52,83	31,60%	26,19	20,63	32,54
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

SOURCE: www.gpd.fi

Post-processing of the observations

We showed earlier 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.

Specimen mark (Thickness / sizes / test type)	Amount of specimens	Side	Average strength, MPa	Standard deviation, MPa	Variation coefficient, %	Strength (breakage stress), MPa	Confidence interval (min-max), MPa	
4mm 280x330 CSB	20	Tin side	92,39	27,49	29,75%	17,81	35,43	4,47
		Side without tin	52,99	13,19	24,88%	12,41	24,05	2,77
		Both sides	74,66	29,58	39,63%	6,5	14,56	1,7
6mm 280x330 CSB	20	Tin side	63,58	26,62	41,86%	5,61	16,06	0,54
		Side without tin	42,86	7,64	17,82%	14,06	23,51	4,12
		Both sides	53,77	22,21	41,30%	4,65	10,68	1,08

[7] N. Chmykhova, A. Chesnokov, S. Chesnokov. Experimental study of strength properties for the modern glass. GPD-2009, Tampere, Finland.

Post-processing of the observations

Specimen mark (Thickness / sizes / test type)	Average strength, MPa	Standard deviation, MPa	Variation coefficient, %	Strength (breakage stress), MPa	Confidence interval (min-max), MPa	
4mm 400x400 CSB	71,00	40,26	56,70%	2,35	0,73	5,44
4mm 400x400 4pB Ls=360 Lb=75	57,35	14,67	25,58%	10,38	3,89	18,41
4mm 400x400 4pB Ls=360 Lb=200	52,67	13,49	25,62%	9,63	4,03	16,48
4mm 1100x360 4pB Ls=1000 Lb=200	50,46	11,84	23,47%	11,81	7,16	17,04
4mm 1000x360 4pB Ls=910 Lb=182	70,50	22,76	32,29%	10,77	5,42	17,30
4mm 1100x360 CSB	101,24	61,93	61,17%	2,19	0,58	5,62
4mm 1000x1000 CSB Processed edge	55,69	16,91	30,36%	10,61	5,85	16,38
4mm 100x100 2AR	220,47	85,86	38,94%	23,19	17,04	30,64
6mm 100x100 2AR	167,19	52,83	31,60%	26,19	20,63	32,54
4mm 280x330 CSB [7]	74,66	29,58	39,63%	6,5	1,7	14,56
6mm 280x330 CSB [7]	53,77	22,21	41,30%	4,65	1,08	10,68
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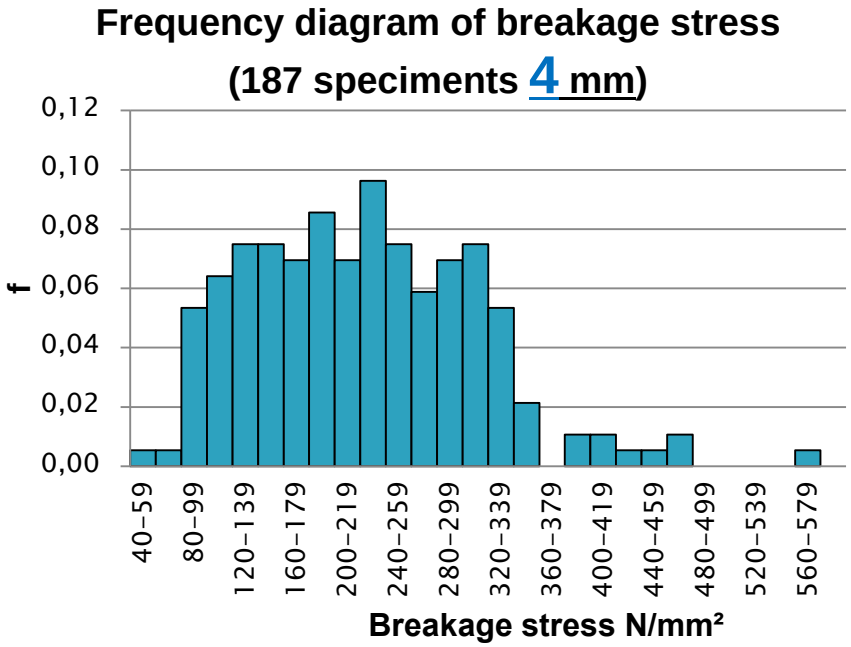
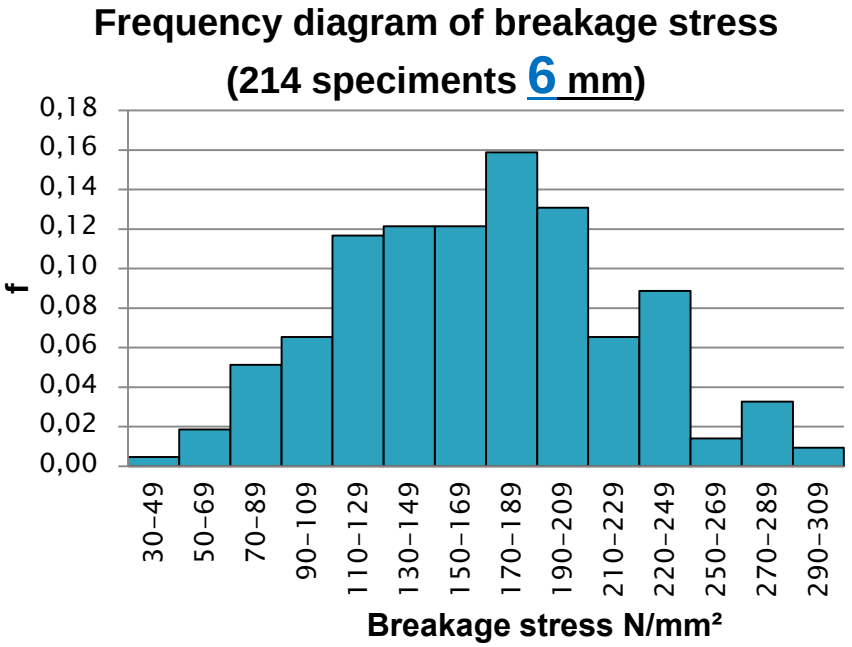
6mm 1000x1000 [9]	71,35	17,17	24,06%			

SOURCE: www.gpd.fi

Post-processing of the observations





SOURCE: www.gpd.fi

Analysis of results

- Strength of the 6 mm thick glass is lower 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 (mentioned defects satisfied requirements of the corresponding standards), 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.

Dependence of the glass strength from temperature

Average test results and confidence interval of breakage stress in production-run for the laminated glass specimens consisted of two layers of 3 mm clear float glass and **new strengthened branding PVB film** with thickness of 0.7 mm. 62 specimens with 400×400 mm sizes were available.

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

[8] N. Chmykhova, A. Chesnokov, S. Chesnokov. Investigation of strength properties of laminated glass with different bonding materials. GPD-2011, Tampere, Finland.

Dependence of the glass strength from temperature Analysis of results

- New strengthened branding 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.
- Laminated glass strength decreasing with temperature grow i.e. with temperature decreasing strength grows. Average glass strength under t=-40°C temperature is two times higher than for the specimens under t=+40°C temperature.
- 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.

SOURCE: www.gpd.fi

Conclusions

- 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 (if the defects are below of the requirements level of the corresponding standard). 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

- STP 12-4-78; STP 12-5-78
- EN12603:2002; EN 1288-3 2000; EN 1288-5 2000

- [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.

Thank you for your attention!

Contact info:

OAO «Glass Research Institute»
111024, Moscow, Russia, Dushinskaya str., 7
+7 495 363-9687, 361-1502 (phone)
+7 495 363-9688 (fax)
Web: www.glassinfo.ru
E-mail: ic.steklo@mail.ru