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Estimating the Flexural Strength of Float Glass

BOUŠKA Petr[1,a], BITTNER Tomáš[1,b], ELIÁŠOVÁ Martina[2,c], ŠPAČEK Miroslav[3,d], VOKÁČ Miroslav[1,e] and MANDLÍK Tomáš[1,f]

[1]CTU in Prague, Klokner Institute, Šolínova 7, 166 08 Praha 6, Czech Republic

[2]CTU in Prague, Faculty of Civil Engineering, Thákurova 7,166 29 Praha 6, Czech Republic

[3]Habena, Ltd., Korunní 60, 120 00 Praha 2, Czech Republic

[a]petr.bouska@klok.cvut.cz, [b]tomas.bittner@klok.cvut.cz, [c]eliasova@fsv.cvut.cz, [d]m.spacek@habena.cz, [e]miroslav.vokac@klok.cvut.cz, [f]tomas.mandlik@klok.cvut.cz

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Abstract. A series of simple and laminated glass tests were carried out under laboratory conditions at the Klokner Institute. The test specimens comprised panes made from float glass with dimensions of 1.1 x 0.36 m. The paper contains experimentally determined characteristic values of flexural strength and estimated design values related to commonly used glass.

Introduction

In recent decades, the use of glass in construction has been increasing, not only because of increasing interest from designers but also due to the technical potential of glazing technology. Reasons for using this material include its optical properties, its high durability and its resistance to climatic effects.

However, no normative documents that would determine reliable structural design values for these structures have yet been issued. The European standard that has been prepared by the European Committee for Standardization (CEN / TC 129) is only a draft.

The paper shows the computational characteristics derived according to prEN 16612 [1], and compares them with the results of tests of the flexural strength of sheet glass carried out in 2012 on samples of glass available in the Czech Republic. Float glass is a basic starting material for treatment by other special techniques.

Float Glass

Float glass is produced by melting recycled glass, silica sand, potash and soda lime in a kiln and floating it on a bed of molten tin. The molten mixture slowly solidifies on the molten surface, and after an annealing process the internal stresses are reduced during the cooling process. This technological process was patented by A. Pilkington in the 1960s, and most of world production of float glass is produced using this method. The basic glass format is 3.21 x 6.0 m, and is intended for further processing. Sheet glass with dimensions of 3.21 x 18.0 m can nowadays be produced in this way.

Computational Characteristics According to Draft prEN 16612

Glass materials under a load behave entirely elastically, without any plastic deformation. Glass is a brittle material, and sudden failure can occur. Failure of glass occurs in tension, and the tensile strength is strongly affected by surface microcracks. The theoretical strength of glass is high, but the real strength is reduced by surface imperfections, which also affect the long-term corrosion and the mechanical properties of the material [2]. When designing, it is therefore necessary to take into account an appropriate safety factor.

The basic properties of soda lime float glass are stated in EN 572-1 [3], which specifies the chemical composition, the optical and mechanical properties. The stated values are: density 2500 kg/m^3, modulus of elasticity 70 GPa, Poisson's ratio 0.22, and characteristic flexural strength 45 MPa. Standard EN 1288-3 [4] specifies the four-point bending test on a glass sheet sample with dimensions of 1100 x 360 mm, on supports at a distance of 1000 mm, loaded by a pair of forces acting at a distance of 200 mm.

Experimental Specification for the Bending Strength of Float Glass

Under laboratory conditions according to the method described in [4], tests were carried out on a total of 7 sets of specimens with a nominal thickness of 4, 5, 6, 8, 10, 12, 15 mm. Each set consisted of 9 samples with unworked edges (cut edge). The flexural strength for each test sample was derived from the experimental data. Figs. 1 and 2 show test specimens before the test and broken glass after the test.

Table 1 shows the basic statistical characteristics of flexural strength. The mean value is in the range from 48.9 to 59.2 MPa, the standard deviation is in the range from 2.8 to 6.4 MPa, and the coefficient of variation does not exceed a value of 0.11.

Table 1. Statistical characteristics of flexural strength.

Nominal thickness [mm]	4	5	6	8	10	12	15
Mean [MPa]	56.5	59.2	58.0	58.7	52.0	51.2	48.9
Std. dev. [MPa]	6.41	2.83	4.79	5.54	5.85	4.96	3.16
Coef. of var.	0.11	0.05	0.08	0.09	0.11	0.10	0.06

Fig. 1. Glass in the testing machine.

Fig. 2. Broken glass after the test.

The basic statistical characteristics of the flexural strength for each test sample were derived from the experimental data. Assuming that this data can be merged into a single statistical set, a characteristic material strength value can be determined: the value is not significantly

different for the normal statistical distribution (50.4 MPa) and for the log-normal distribution, (49.7 MPa).
The probability density, a histogram and the distribution function of the flexural strength of glass are plotted in Fig. 3. The black line represents the normal distribution and the red line represents the log-normal distribution.

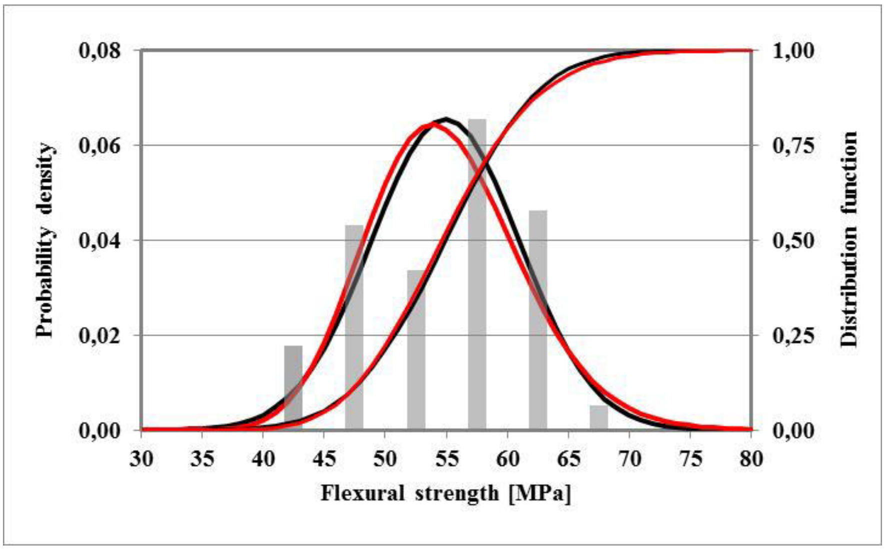

Fig. 3. The probability density, a histogram and the distribution function of the flexural strength of glass.

The characteristic design values for float glass were estimated from the experimental flexural strength. Design values for the strength for float glass material were derived from the characteristic strength, and depend on the material partial factor for float glass, on the glass surface profile factor and on the load duration factor. The allowable stress determined on annealed glass for a uniformly distributed load according to the standards [1,7] and also derived from experimental data, is shown in Table 2. According to the standards the design value for the strength *fg;d* of annealed glass material stress has been proposed using the formula

$$f_{g;d} = k_{mod} \, . \, k_{sp} \, . \, f_{g;k} \, . \, (\gamma_{M;k})^{-1} \qquad (1)$$

where
$f_{g;k}$ is the characteristic value of the flexural strength,
$\gamma_{M;k}$ is the material partial factor for annealed glass,
k_{sp} is the factor for the glass surface profile,
k_{mod} is the factor for the load duration.

An important parameter when assessing static glass structures is the thickness of the glass and the allowable tolerance. The basic statistical characteristics of the thickness of the tested glass are presented in Table 3. The average sample thickness value is mostly lower than the nominal value, and does not exceed the standard value [3].

Table 2. Characteristic and design value of flexural stress.

Flexural strength [MPa]		prEN 13474-3	prEN 16612	Normal distribution	Log-norm distribution
Characteristic value *fg;d*		45.0	45.0	44.9	45.2
Design value *fg;k*	Wind	18.8	18.5	18.5	18.6
	Snow	9.4	11.0	11.0	11.1
	Dead load	7.0	7.3	7.2	7.3

Table 3. Statistical characteristics of the specimen thickness.

Nominal thickness [mm]	4	5	6	8	10	12	15
Tolerance [mm]	± 0.2	± 0.2	± 0.2	± 0.3	± 0.3	± 0.3	± 0.5
Mean [mm]	-0.15	-0.15	-0.12	-0.18	-0.08	0.02	-0.26
Std. dev. [mm]	0.02	0.05	0.04	0.06	0.04	0.12	0.11

The draft of prEN16612 was drawn up by Technical Committee CEN/TC 129, and it has not yet been ratified by CEN as a European Standard. If the material partial factors are not determined in the National Annex, the recommended values given in the European standards should be used.

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