Experimental and numerical analysis of glass samples

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Abstract: A stress analysis of material is important for a design of safe and efficient constructions. The glass is very brittle material, but its mechanical properties allow its usage as structural material. The assembling of the material models for certain type of glass can be very helpful for assessment of safety of glass constructions, but also hanging products such as chandeliers, or decorative glass.

Keywords: glass; Charpy impact test, 3-point bend test, FEM, numerical analysis

1 Introduction

Numerical analysis of glass materials is very important and helpful way for design of safe and reliable products. For assembling of suitable glass material model different parameters are required. Some of them are possible to find in the literature, but for concrete type of glass they have to be experimentally determined. The glass is very brittle material and its testing due to this characteristic could be very difficult. For example testing of Young modulus by the help of standard tensile test is practically impossible. Therefore Charpy test and 3-point bend test were involved for determination of Young and bending modulus. For both tests FEM models were assembled.

2 Experiment

Two different glass samples marked as Type 1 and Type 2 were used in the experiment. For the determination of Young modulus and flexural modulus a 3-point bend test (Fig. 1 left) in accordance with standard ČSN ISO 14125 was used. Results are shown in table 1.

$$E_{to} = \frac{4F_{max}\,L^3}{3\pi A_{max} d^4} \text{ (1)},$$

$$E_o = \frac{L^3\,\Delta F}{\Delta s\,\pi d^4} \text{ (2)}.$$

Type 1						
Statistics	Amax	Fmax	σ	E_{to}	$E_{o\,(0,1mm)}$	$E_{o(0,2mm)}$
	mm	N	Mpa	Mpa	Mpa	Mpa
Average	0,21	520,50	94,19	47453,81	33405,30	35794,93
Deviation	0,02	108,89	18,12	8531,41	7729,35	7416,33
Variance	10,3%	20,9%	19,2%	18,0%	23,1%	20,7%
Type 2						
Average	0,17	464,84	72,57	42767,22	30106,18	29863,02
Deviation	0,05	193,11	23,63	5941,48	3684,57	3076,76
Variance	31,3%	41,5%	32,6%	13,9%	12,2%	10,3%

Table 1: Results of 3-point bend test

A distance between supports was set on 64 mm, a strain rate was 2 $mm.min^{-1}$. Test was done on dynamometer LabTest 2.050. Young modulus was calculated from formula (1). A bending modulus is calculated from the formula (2) for sample deformation of 0,1 and 0,2 mm.

Also Charpy test (Fig. 1 right) in accordance with standard ČSN EN ISO 179-1 was performed. The impact strength is determined from the formula (3) [1, 2].

$$H = \frac{E_c}{\frac{\pi d^2}{4}} \quad \left[\frac{J}{mm^2}\right] \text{ (3).}$$

The test was performed on a device LAB TEST® CHK 50J. The distance of supports was 62 mm, a pendulum velocity was 3,7 $m.s^{-1}$. Samples were without notches. Obtained results are in table 2.

	Type 1				Type 2			
	Diameter [mm]	Cross-section [mm^2]	Energy E [J]	Impact tenacity [J/mm^2]	Diameter [mm]	Cross-section [mm^2]	Energy E [J]	Impact tenacity [J/mm^2]
Average	9,637	73,22	0,423	0,0058	8,27	54,24	0,384	0,00719
Deviation	0,634	9,70	0,063	0,0007	0,837	10,31	0,07	0,001
Variance	0,402	94,12	0,004	4,43E-07	0,701	106,37	0,005	1,08E-06

Table 2: Results of Sharpy test

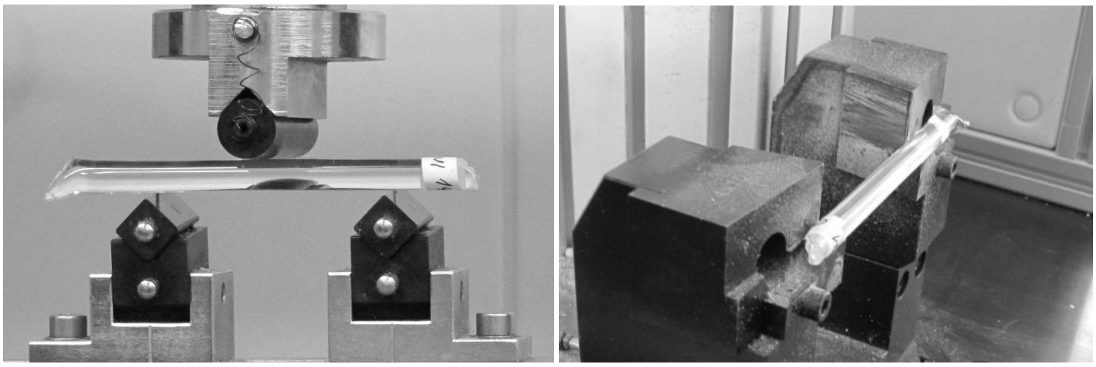

Fig. 1: Left – 3-point bend test; Right – Charpy test

The results were used for establishing of a material model of the glass material.

3 FEM model

FEM models were assembled for 3-point bend test and Charpy test. The CAD geometry was created in SolidWorks 2012 and it corresponds with real testing apparatus and samples. The geometries were imported to ANSYS software [3]. The basic geometry is created with two parts. The sample represents flexible part, supports and the indentor creates are rigid bodies. To the model contacts among the test sample, indentor and supports were introduced. A friction in contacts of individual parts was set on value 0,3. The FE mesh is created with 3D cubic elements. Boundary conditions are following: supports are fixed, the indentor in 3-point bending test is fixed, only in Z direction is allowed a displacement of 15 mm. The FE model of 3-point bending test with a mesh is shown in Fig. 2. The indentor representing Charpy pendulum can moves only in one direction with the velocity 3,7 $m.s^{-1}$. The model of Charpy test is shown in Fig. 5. FE models were optimized from point of view of material model parameters, thus model results are comparable with obtained experimental data.

3-point bend test shows stress in the structure under static loading (Fig. 3, 4), Charpy test indicates stress, energy and also failure of the glass under dynamical loading (Fig. 6, 7).

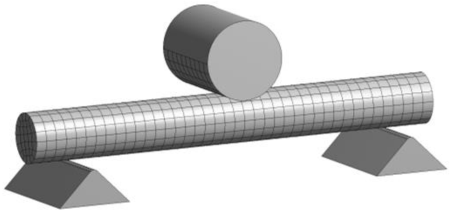

Fig. 2: Meshed geometry of 3-point bending test model

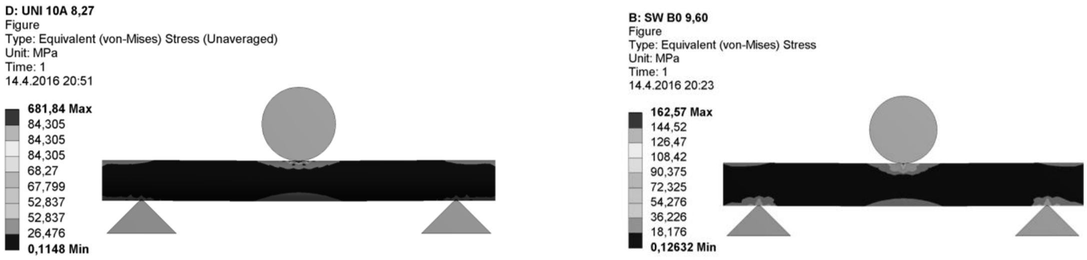

Fig. 3 and 4: Stress distribution in sample Type 1 and Type 2

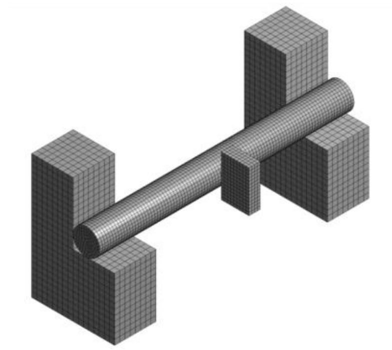

Fig. 5: Meshed geometry of Sharpy test model

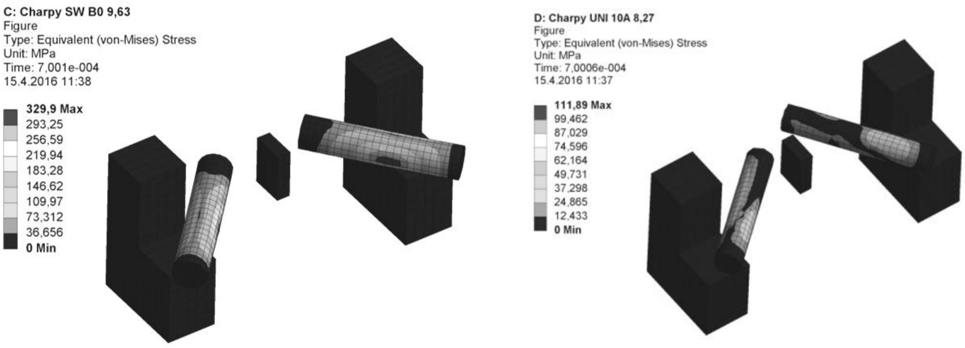

Fig. 6 and 7: Stress distribution during Sharpy test for Type 1 and Type 2 sample

4 Discussion

The model was created for a modeling of special glass products especially for decorative purposes. By the help of this material model was found for example maximal load capacity of glass bead chain that hangs in vertical direction (Fig. 8, 9). It is important to know how many beads threaded on a carrying wire can be used. It was determined by the maximal allowed stress acting on the lowest bead from the mass of another threaded beads and mass of the carrying wire. Also shape of a hole in the bead for more efficient distribution of the stress was designed by the help of this model. Another application was a determination of a tightening torque of plastic screw that fixes decorative glass plate. By the help of the model was also found optimized geometry of screw head.

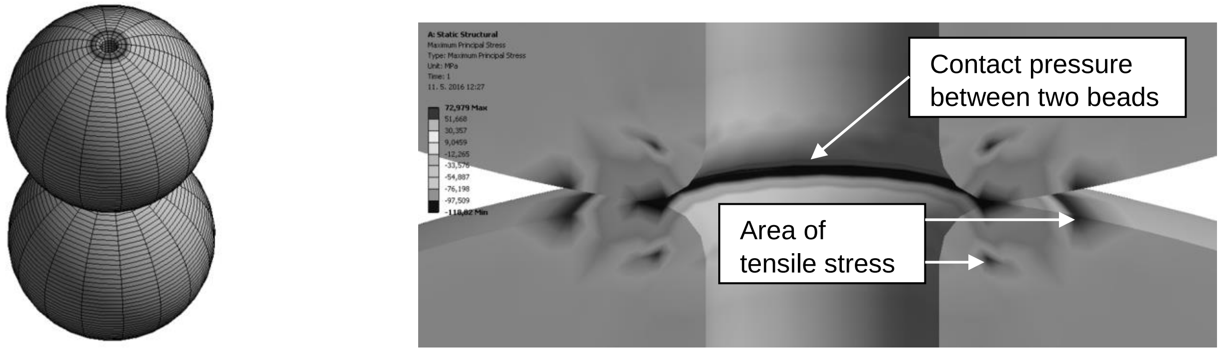

Fig. 8, 9: Model of beads pressed by the gravity force (left); a detail of contact pressure of two beads

5 Conclusion

Assembled FE models were optimized so that numerical analysis results correspond with experimental data. The models show critical stress that causes brittle fracture and crack propagation of the glass structure. Also energy during impact and propagation of stress was observed. The optimized models of these concrete types of the glass were used for stress analyses of glass products and assessment of a safety factor.

Acknowledgement

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References

[1] *ČSN ISO 14125: Fibre-reinforced plastic composites - Determination of flexural properties*. Opr.1. Praha: Český normalizační institut, 1999.

[2] *ČSN EN ISO 179-1: Plastics - Determination of Charpy impact properties - Part 1: Non-instrumented impact test*. A1 2011. Praha: Český normalizační institut, 2001.

[3] Lee, H.: *Finite element simulations with ANSYS Workbench 13*. SDC Publications, 2011, ISBN 978-1-58503-653-0