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Deformation Properties of Laminated Glass Subjected to Increased Temperature

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Abstract: Shear interaction of laminated glass belongs to the essential characteristics of this material. The impact of increased temperature on deformation properties was tested within investigation of basic mechanical properties on laminated glass plates. Samples of laminated glass with sizes of 120 x 1100 mm, subjected to four-point bending load, were exposed to the effect of gradual increasing temperature up to approximately 65 °C in a thermal chamber. The progress of deformation was continuously recorded by measuring device during temperature rise and subsequent cooling. In total five kinds of interlayers were tested. In this paper the obtained experimental results are compared to numerical FE analysis and degree of interaction of particular kind of interlayer is evaluated.

Introduction

Tests of the effect of increased temperature on strain characters of laminated glass samples were performed within research project in the Klokner Institute. In total 6 of various samples of laminated glass, which were joined by four differently used foils, were made. The measurements of laminated glass samples, thickness 5 + 5 mm, were designed in order to fit the capacity of thermal chamber, i.e. 120 x 1100 mm. These formations were verified: EVA SAFE 5.5.2 (double foil of ethylenvinylacetat), EVA SAFE 5.5.1 (simple foil), EVA LAM 5.5.2 (double foil), EVA LAM 5.5.1 (simple foil), STR 5.5.2, AHV 5.1.5. (simple foil of resin).

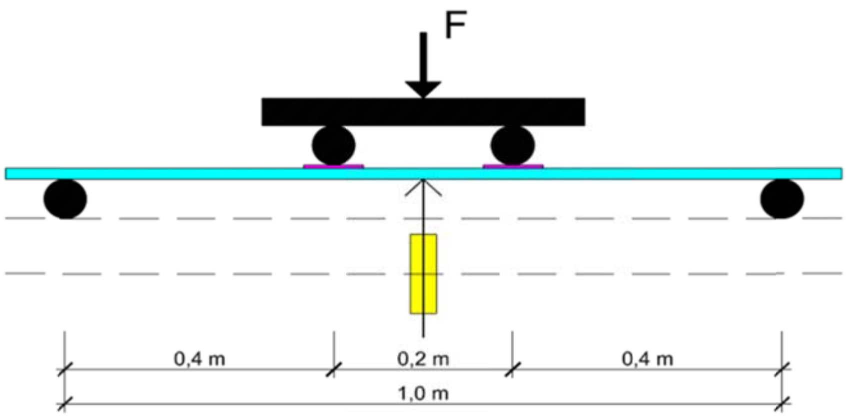

Fig. 1: Arrangement of four-point bend test

Test itself was carried out in a thermal chamber with its inner dimensions of 1250 x 550 mm, h = 350 mm. At first the impact of constant load on the samples of laminated glass was examined in the thermal chamber, which was carried out in accordance of four-point bend (refer to: Fig. 1), with subsequent even increasing of the temperature up to approximately 65 ^{o} C. After reaching required temperature, this temperature was maintained until strain stabilization after which cooling down of the samples followed.

The process of the test was continuously recorded with the help of data logger. Temperature and deflection in the center of the span were primarily measured. The influence of interaction of individual layers of laminated glass and the process of deformation in time is evaluated out of recorded sags. This article deals with different deformational characters of individual foils, which join layers of laminated glass during the impact of higher temperature. The final results of the experiment are accompanied and commented with sag of laminated glass common calculation method consequently compared with numerical FE analysis.

Fig. 2: Arrangement of four-point bend test in thermal chamber

Experimental part

Experimental part consists of measured results interpretation and the choice of accompanying calculation of degree of interaction of individual samples of laminated glass. If we assume that the glass deflection is ideally flexible, it is possible to use three different calculation methods. First, most common method (M1) to specify deflection of laminated glass is based on considering individual laminated glass layers as individual not interacting parts mutually moving on each other. This method is used today mainly for its simplicity and safety which we bring neglecting the interaction of individual layers into calculation, because it is necessary to consider certain degree of interaction between individual layers of laminated glass. On contrary there is the second method (M2) which assumes that the individual layers of laminated glass perfectly interact with each other and create compact unit. This method is in terms of calculating even easier than the first one, but despite the fact, the assumption of perfect interaction used in calculation; it is also on the dangerous side. It is not possible to say that the foil will function as glass itself. Here, I would like to mention the third possible calculating method (M3), which combines previous methods. So-called cross-sectional height which is depended on material characteristics of used foil influences the calculation of deflection of laminated glass (modulus if elasticity and modulus of elasticity in shear). This method is far more complicated, but it corresponds to most real behavior of laminated glass.

Topic of this article is to define the deformation characteristics of laminated glass at increased temperatures. It is necessary to define three basic input parameters, i.e. load time and temperature. In our case we investigated characteristics with regard to short-constant size with only one variable – temperature over time. Method M3 is used to assess the degree of interaction between individual foils, where we consider two load steps. The first is the time for settling since the load interacting, the second is the final deflection after temperature elevation to approximately 65 ^{o} C. Deflection calculation which is assumed as perfectly flexible was carried out according to equation (refer with: Eq. 1), from which the effective height (refer with: Eq. 2) was deducted during both load steps. The output for definition of laminated glass individual layers interaction is effective height.

$$\delta_{exp} = \frac{F.c}{24.E.I}.(3.l^2 - 4.c^2);\ I = \frac{1}{12}.b.h_{ef}^3 \qquad Eq.1$$

$$h_{ef} = \sqrt[3]{\frac{F.c.(3.l^2 - 4.c^2)}{2.E.b.\delta_{exp}}} \qquad Eq.2$$

The actual course of testing in thermal chamber was continuously recorded using data logger. Consequent outputs, i.e. the process of deformation in time due to temperature change can be interpreted graphically. As an example there are graphs showing laminated glass with EVA SAFE 5.5.2 foil (refer to: Fig. 3, Fig. 4). Every foil was examined in three samples, so the result is interpreted as three figures average.

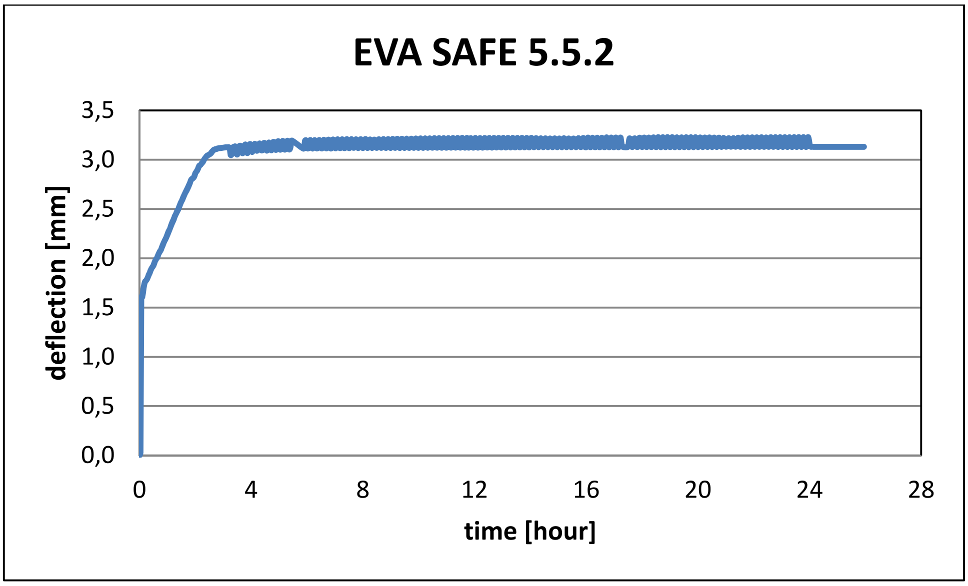

Fig. 3: The deflection development in time

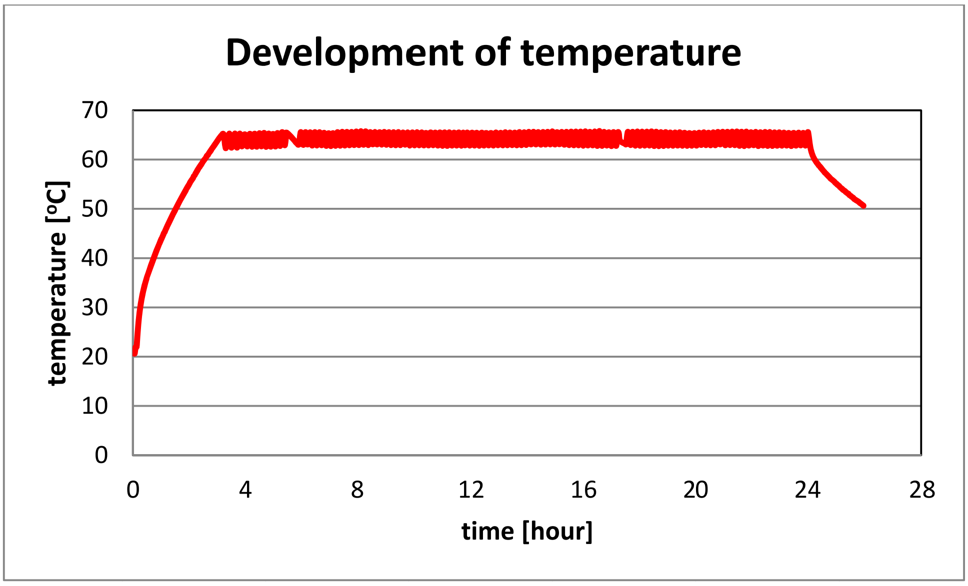

Fig. 4: The temperature development in time

Numerical FE analysis

The main purpose of the numerical analysis was a comparison of the calculated and measured results. For computer simulation was selected glass EVA SAFE 5.5.2. (foil made of ethylenvinylacetat).

Calculation was performed in ATENA software made by Červenka Consulting Company. Model is made of *Shell Concrete - Steel material* composed of two layers of glass (divided each into 4 layers) with an inserted contact surface between them. For the contact surface was used *3D interface material* with corresponding properties to real foil material. For meshing of the glass layers the hexahedra elements were used. In first five steps the structure was gradually loaded by its own weight and by static load of weights (5930 g). The deflection in the middle of the span, corresponds to the step no. 5, is approximately 1,8 mm.

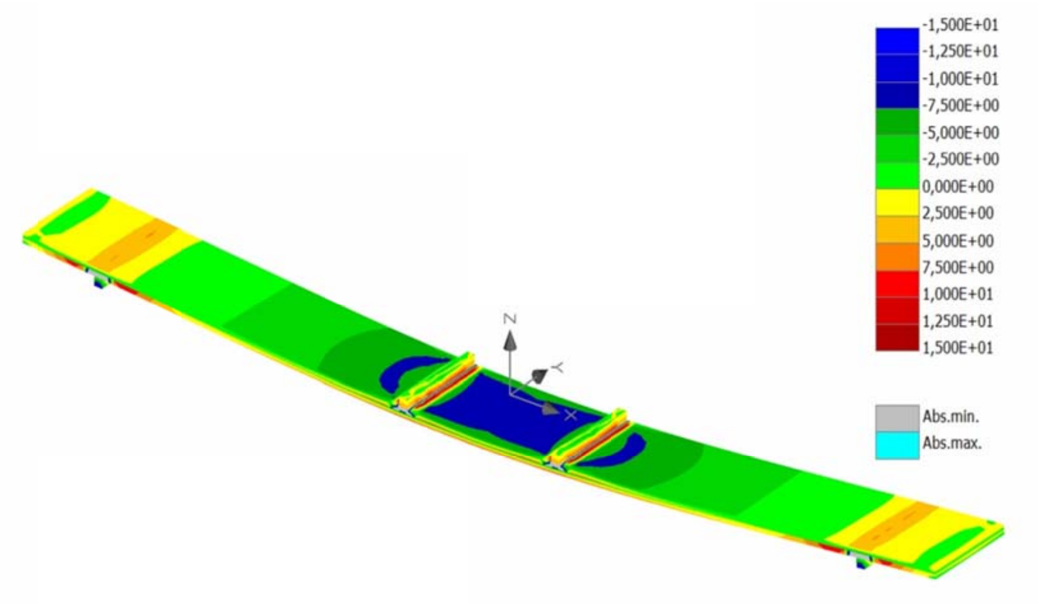

Fig. 5: Stress sigma xx corresponding to the step no. 50 of loading, view from the upper side

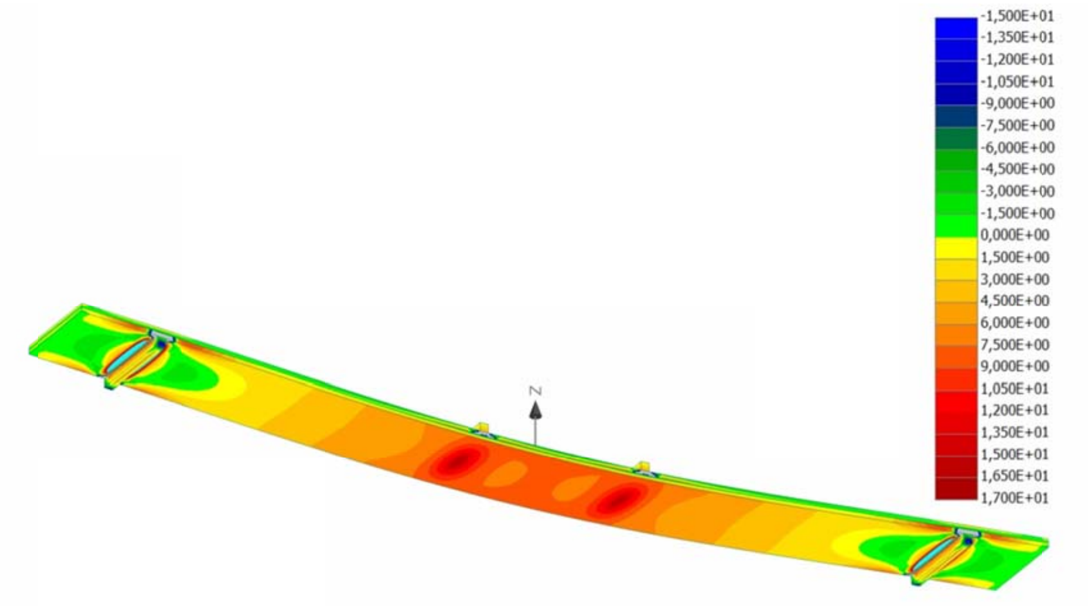

Fig. 6: Stress sigma xx corresponding to the step no. 50 of loading, view from the under side

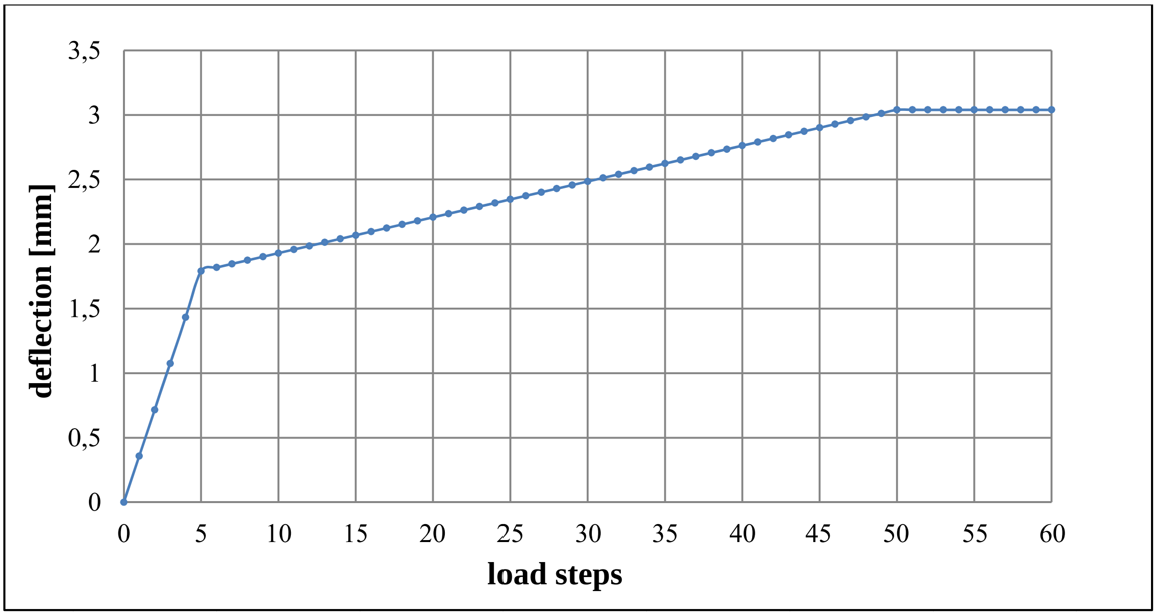

Fig. 7: Load steps/deflection diagram

In following steps (5 - 50) the structure was loaded by increasing of the temperature up to 70 ° C. The deflection was increased to about 3,1 mm (refer to: Fig. 7). In the steps 50 - 60 a constant temperature of 70 ° C was kept and the deflection was already constant. The values of the stress sigma xx are presented on Fig. 5, 6. The growth of the deflection that corresponds to the increasing of the temperature is caused by changing of the shear modulus of inserted foil.

Comparison of results and conclusion

The evaluation of the effect of increasing temperature of the deformational properties laminated glass is interpreted in the table (refer to: Table 1), where experimentally measured figures of deflection $\delta_{1,\ exp.}$ a $\delta_{2,\ exp.}$ [mm] after load force F [kN] without the effect of temperature and consequently after a temperature load, which are finally compared with deflections $\delta_{2,\ FE\ analysis}$ a $\delta_{2,}$

FE analysis [mm] specified by numerical computer analysis. Degree of interaction is evaluated by changing effective height between two loading steps expressed in percentage.

Table 1: Summary evaluation of the deformation characteristics of laminated glass

Marked samples for test in thermal chamber	Experimentally determined value of deflection		Numerically determined value of deflection		Change of effective height (determined according to experiment)			
	$\delta_{1,exp}$	$\delta_{2,exp}$	$\delta_{1,FE\ analysis}$	$\delta_{2,FE\ analysis}$	$h_{ef,1}$	$h_{ef,2}$	Δh_{ef}	p
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[%]
EVA SAFE 5.5.2	1,74	3,15	1,80	3,10	9,78	8,02	1,76	17,96
EVA SAFE 5.5.1	1,68	2,60	-	-	9,89	8,56	1,33	13,47
EVA LAM 5.5.2	1,97	8,09	-	-	9,38	5,86	3,52	37,57
EVA LAM 5.5.1	1,87	7,60	-	-	9,54	5,98	3,56	37,28
STR 5.5.2	2,97	7,95	-	-	8,19	5,89	2,29	28,01
AHV 5.1.5	5,14	5,94	-	-	6,81	6,49	0,32	4,68

The table shows that increasing of the temperature leads to loss of shear interaction between the layers of laminated glass, which is ensured with the help of different kinds of foils used. The results show that the assuming the effect of increased temperature is best to use an interlayer (foil) AHV which is „infused” foil of the resin based. This kind of interlayer shows smallest loss shear interaction.

Thanks

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