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NUMERICAL SIMULATION OF THE 3D GLASS SAGGING PROCESS

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Abstract: *The article deals with possibilities of using the tools for computer modelling in glass industry with the intention on the sagging process. Possibilities of usage are demonstrated in 3D-models of rectangular glass sheets supported by simple mould. Numerical outputs are compared with verifying experimental results under laboratory conditions. Mentioned analysis allows identifying individual stages of the sagging process. Results of sensitivity analysis of chosen parameters are submitted in brief in the end of the article.*

Keywords: ***Glass, forming, sagging, bending, slumping.***

1. Introduction

Glass sagging process is ranked among the expanded glass technologies. It is used firstly for windscreen production; known is also a usage for a production of spherical optical elements and complex building elements, but also in an art glass manufacture. Glass sagging is a relatively complex technological process (Hyre, 2002), whereas its principle is based on the glass temperature dependence on rheological properties. The principle of the method is notorious – glass sheet placed on a frame changes its shape under the influence of the gravity force at a given temperature corresponding to a viscosity under the deformation point (10^{10} Pas).

2. Experiment

For the purpose to analyze basic parameters of the glass sheet sagging process a special fixture, simple ring symmetrical along both vertical planes, has been projected. Samples of the glass sheet made of clear float soda-lime glass has been put on the ring and subsequently they have been inserted together to a preheated laboratory furnace, in which sample has been heated up to the working temperature.

As soon as the temperature in the whole cross section of the glass sheet exceeds the deformation point sagging process starts. After the defined period of time (10, 20 and 40 minutes) the frame with the sagged sample was taken out of the laboratory furnace and annealed by the air. Consequently, the deflection along three basic curves (see Fig. 2) was evaluated by means of a special gauging device with an optical laser sensor.

3. Virtual model

The flat glass gravity process is a complex couple thermo-mechanical problem characterized with strong interaction between the heat transfer and the viscous flow of the molten glass. Basic phenomena of the forming process are the distribution and the course of temperature fields in the sheet being shaped as well as viscosity changes with temperature.

Considering the thickness of analyzed glass samples, there was used an effective conductivity and the heat transfer in the system were realized by means of external subroutine. Geometrical characteristics were chosen according to the experimental model (Fig. 1), material properties of shaped glass were described through the rigid plastic model. The ring mould is assumed to be rigid.

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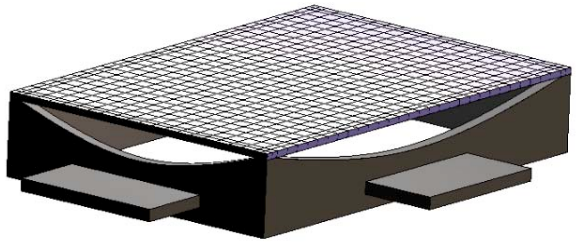

Fig. 1: FEM model - frame with glass

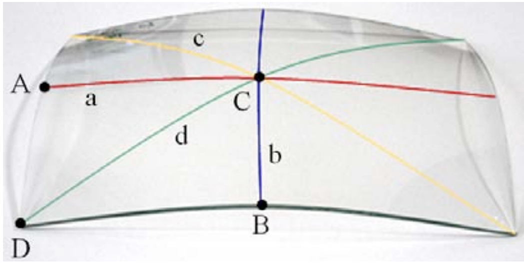

Fig. 2: Sample with measured lines and points

4. Results of virtual modelling

Numerical model allowed analyzing the course of the glass gravity bending process. The sagging process itself consists of three different stages (see Fig. 3). The sagging speed in the first stage (and approximately in the second stage as well) of two blanks with various thickness is set by the square ratio of their thickness. Distribution of displacements among curves in the time of 2400 s for glass thickness of 2.1 mm is showed in Fig. 4. The displacement behaviour along curves is in really high equality with realized experiments, maximal deviation is under 1 %.

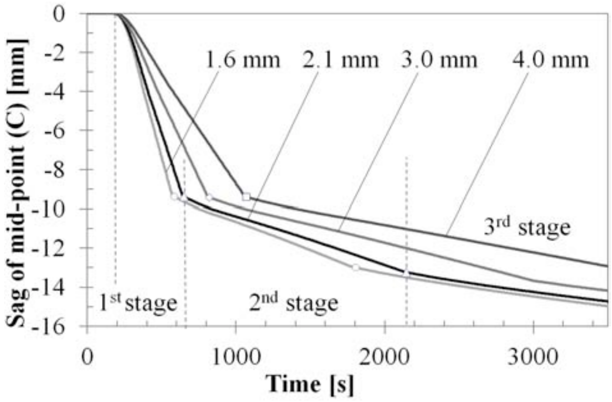

Fig. 3: Development of maximum displacement

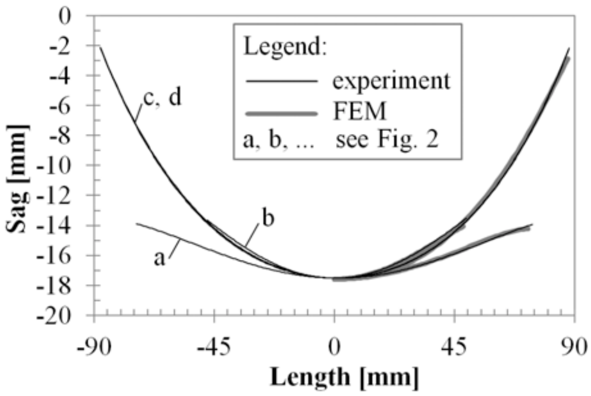

Fig. 4: Sample deflection along basic curves

The sagging rate change in the gravity centre due to the change in the thickness of glass sheet can be described by equation (1), generally, whereas for the 1st stage of the sagging process coefficient $c(l_l,l_t)$ is equal to 1.

$$v_2(z) = c(l_l, l_t)\frac{h_1^2}{h_2^2}v_1(z)\,, \tag{1}$$

where: $v_i(z)$ - sagging speed of the sample gravity centre in vertical direction, h_i - sample thickness, $c(l_l,\, l_t)$ - geometrical coefficient, l - support distance along longitudinal (l_l) and transversal (l_t) axis.

5. Conclusions

In the paper a computer analysis of sagging process is presented. Comparison of numerical results with experiment validated the reliability of the numerical model. The sagging process on 3D support rings itself proceeds in three different stages and sagging rate decreases relatively markedly with the stiffness increase due to change of boundary conditions. Maximum sagging rate (at the sample gravity centre) changes linearly with the viscosity and with the square ratio of sample thickness.

Acknowledgement

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References

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