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FLAT GLASS GRAVITY SAGGING

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Summary: *In the submitted paper is presented survey of reached knowledge about flat glass gravity forming process. For the research was used physical analog modeling method. Realized experiments were focused on sensitivity of glass sample response on local and general changes of forming process parameters.*

1. Introduction

The flat glass gravity sagging technology is mainly used in automotive industry for windscreen production and next for aspherical optical element production. This paper is focused on problem with windscreen production, however with more general applicability. The car design development has brought extreme requirements as for shapes of windscreens, and also it has put in great demands on their shape accuracy. Thus, manufacturers have been pressurized into knowing their production process more deeply (Salenius, 1997). Principle of the technology is based on the dependence of glass rheological properties, especially viscosity, on temperature. Glass sheets placed on a frame change their shapes only under the influence of the gravity force at a given temperature (600 - 620 °C). The final shape is obtained through an interaction between the glass sheet, exposed to the viscous flow due to gravity forces, and the frame.

2. Windscreen manufacture

The initial step is to cut out sheets having required shapes from the flat glass ribbon. After grinding in of edges and printing of glass sheets, a pair of intermediate products is placed over the frame (Fig. 1).

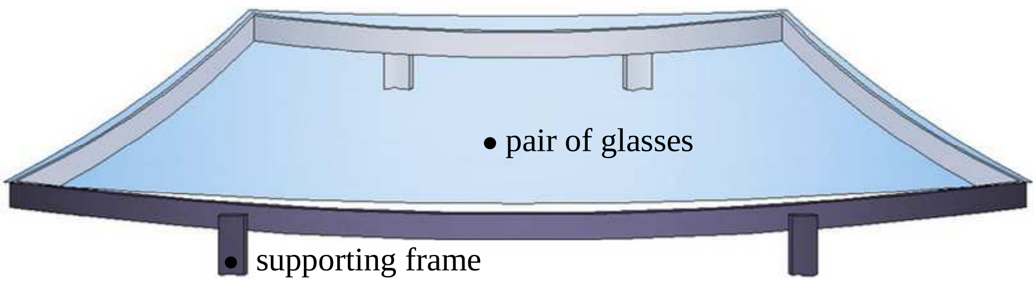

Fig. 1: Supporting frame with placed glasses

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After carrying-in supporting frame with glass sheets to a forming kiln, the forming cycle runs about 20 min. Sheets forming is controlled by a defined course of temperature fields within the kiln and a temperature regime is adjusted for the product given shape on the basis of empirical experience. The final shape (Fig. 2) is obtained through an interaction between the glass sheet, exposed to the viscous flow due to gravity forces, and the frame. Controlled annealing of intermediate products having shapes required and subsequent taking-out of the kiln are final stages of the forming cycle.

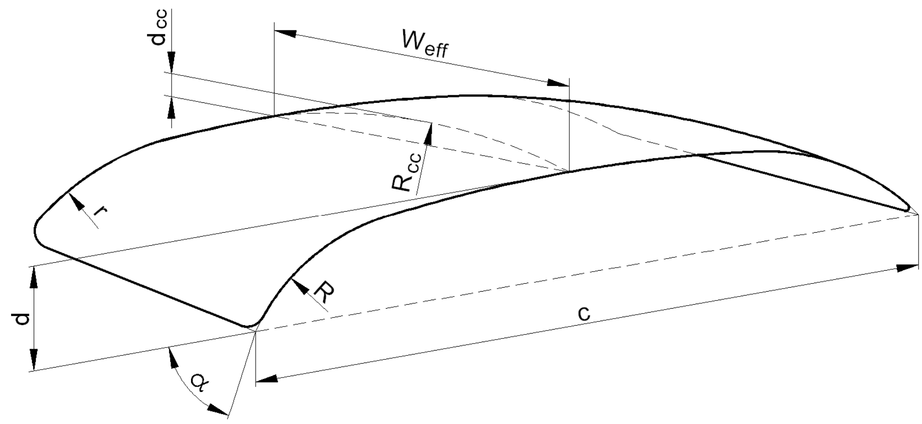


Fig. 2: Overview of basic parameters defining final windscreen shapes

3. Analysis of the process

The forming process and also quality of output production are affected by many factors whose effect is necessary to evaluate complexly with a view to their interaction. During glass sheets gravity forming, the dominant role play in particular temperature dependences of rheological and thermo-mechanical properties of the material formed, especially viscosity, thermal conductivity and nature of heat transfer. It is also necessary to pay advanced attention to thermal characteristics of mentioned properties. From technological point of view it is possible to summarize the factors affecting the forming process and consequently the production yield and also the quality of production into few basic points given in Fig. 3.

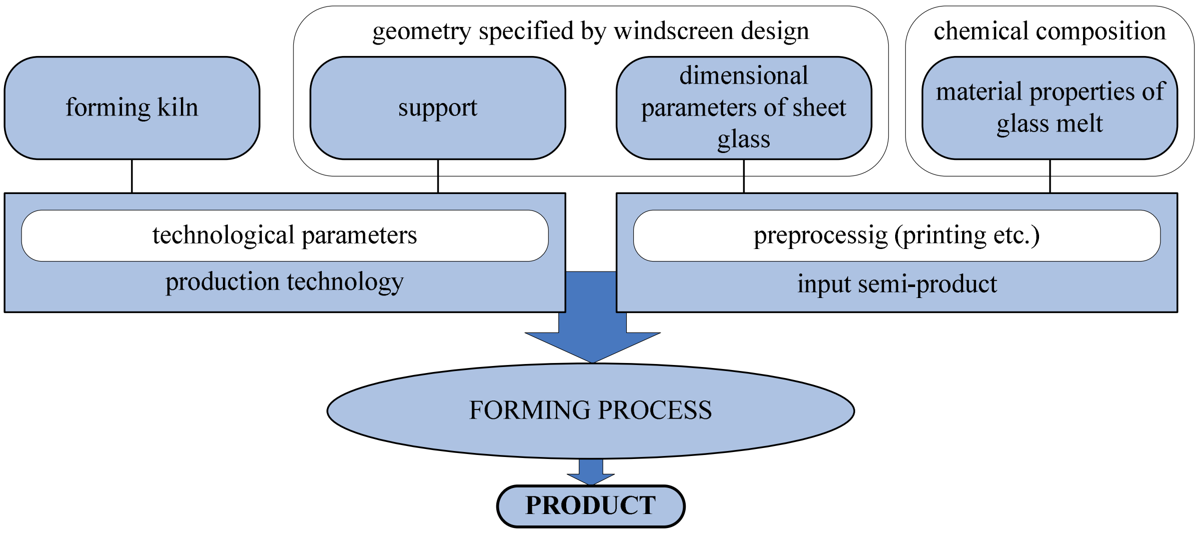


Fig. 3: Basic factors of the forming process

The main effect has the applied production technology, especially process equipment, and mainly properties of a formed glass melt and eventually a glass printing. Technological parameters setting of the production process is mainly defined by geometry of the final product, possibilities of the forming equipment and solution of the sagging support.
From the physical point of view the flat glass gravity forming is complex thermo-mechanical process with dominant relation between heat transfer and deformation behaviour of the formed material, where the temperature is the control parameter of the whole forming process. Complicated process of thermal transmittance at flat glass gravity sagging is shown on Fig. 4 (Hottel, 1979).

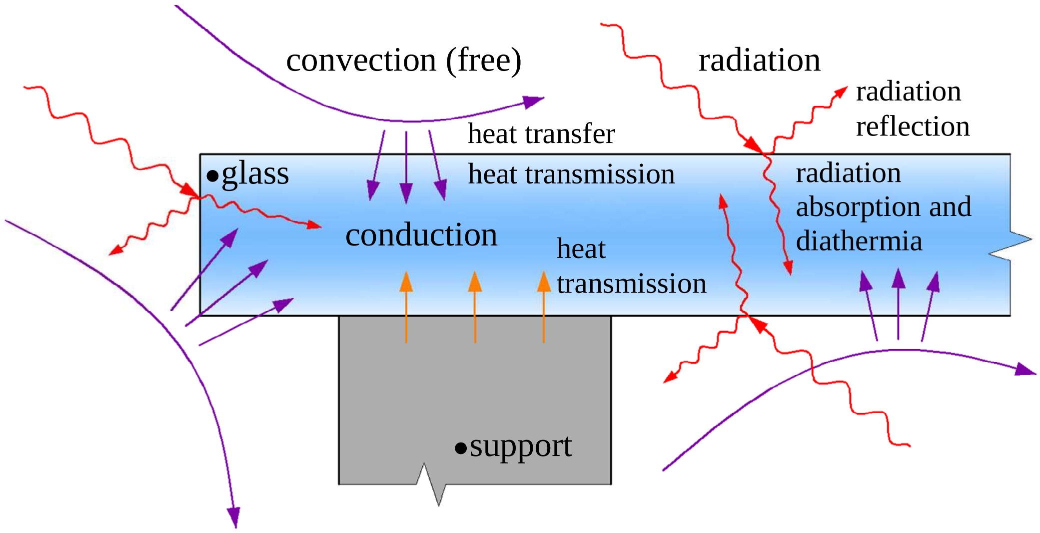


Fig. 4: Thermal transmittance at flat glass gravity forming process

4. Physical analog modeling

The best way for understanding and following optimalization of the gravity forming process and also essential part of presented research is physical analog modeling. Measurements were carried out on an experimental device based on a special kiln (Fig. 5). The design of this laboratory kiln having a built-in electric drive in the stem allows a distance between the upper heating and frame to be set up smoothly. The supporting frame is placed on the frame with plugs. When shifting the frame, the sample distance from the kiln hearth can be modified. Handling test samples in the kiln space is realized through opening door in the kiln front. The kiln is heated by the pair of independently controllable elements which are located in the working chamber roof and bottom. Maximum working temperature of the kiln is 800 °C.

Deflection of the (cold) sample formed is measured by means of a special gauging device, where the sample intrinsic deflection is gauged by an optical laser sensor (Starý, 2005).

For experiments carried out, samples of clear, alternatively green, glass (by AGC) 40x180 with thickness of 2.1 mm, alternatively 1.6 or 3.85 mm, were used. Default setting of the laboratory kiln is: the temperature of 630 °C, heating from the top only, 150 mm distance between the mould and spirals (Starý, 2007). Measuring data of the sample courses are trimmed and alignmented with the defined zero thereby are obtained profiles of the glass external surface. Next related series of points are approximated by polynomial curve of the fourth order (De Boor, 1978). When describing courses of partially (asymmetrical) printed glasses, it was necessary to use the polynomial curve of the sixth order.

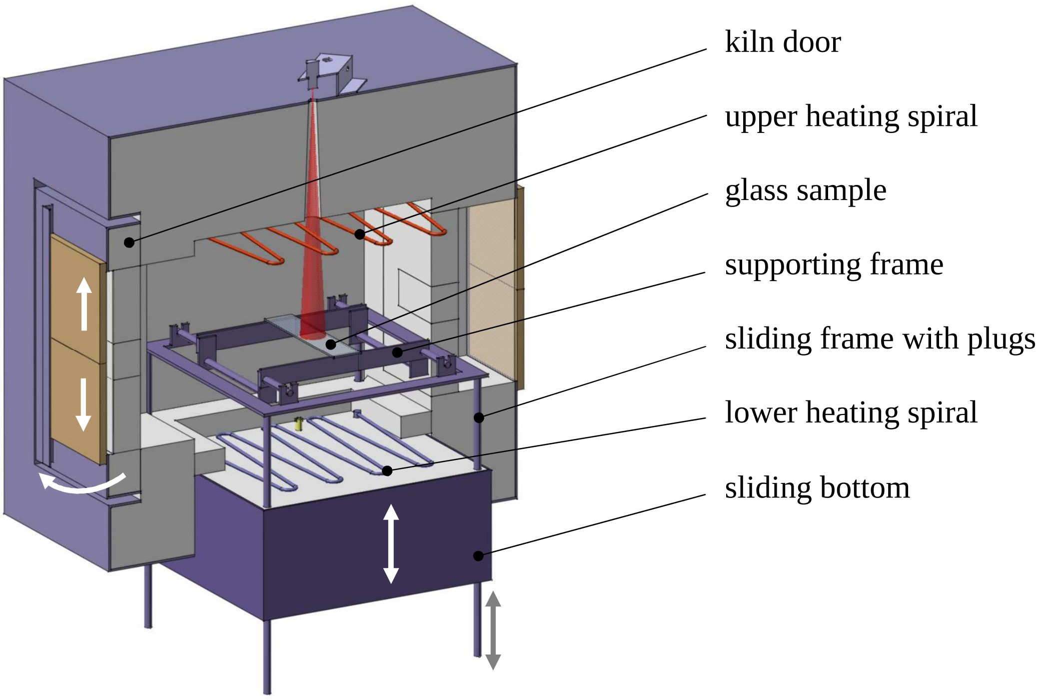


Fig. 5: Broken-out section of the laboratory kiln with a carried-in sample

5. Experimental results

The primary laboratory data output, also time development of the sample deflection, is shown in Fig. 6. This example presents default laboratory setting and sample thickness of 2.1 mm in the time range 150 – 480 s.

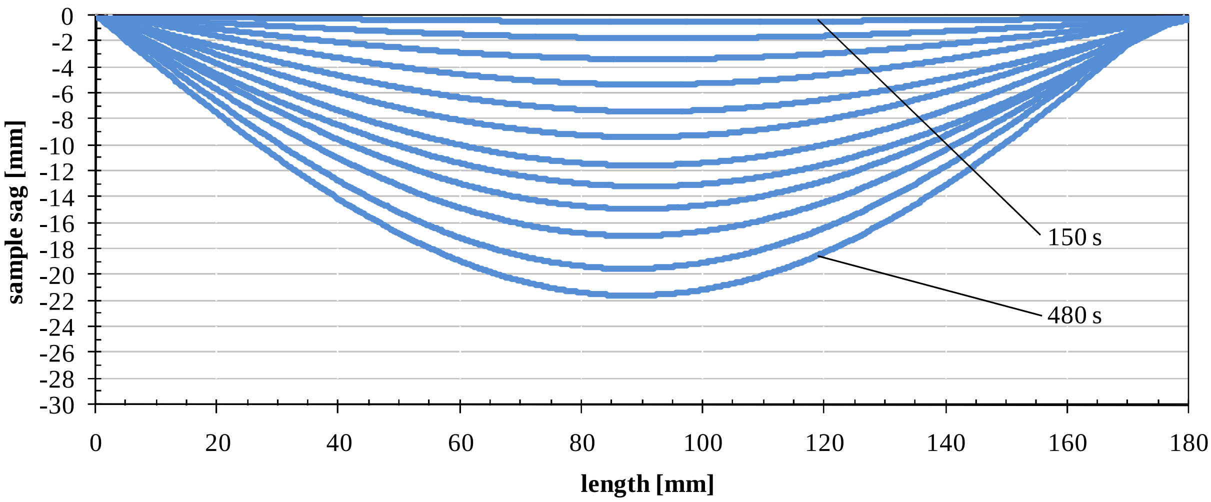


Fig. 6: Time development in the sag course of glass sample with thickness 2.1 mm

Interesting partial output is represented by summary of the steel shades effect, which is shown in Fig. 8. Local surface temperature of the samples is changed by modification of shading glass in the forming kiln thereby consequently the sample deformation. The shades are placed horizontal under the formed glass sample (Fig. 7). Default characteristic of the shades is: material of 11 343 (commercial steel), thickness of 2 mm.

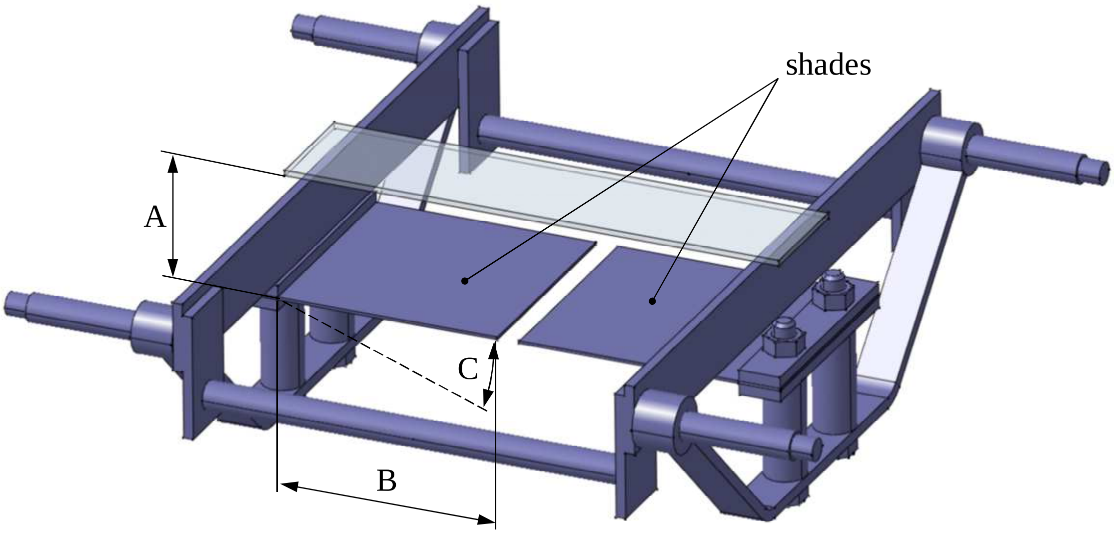


Fig. 7: Model of the laboratory frame equipped with horizontal steel shades

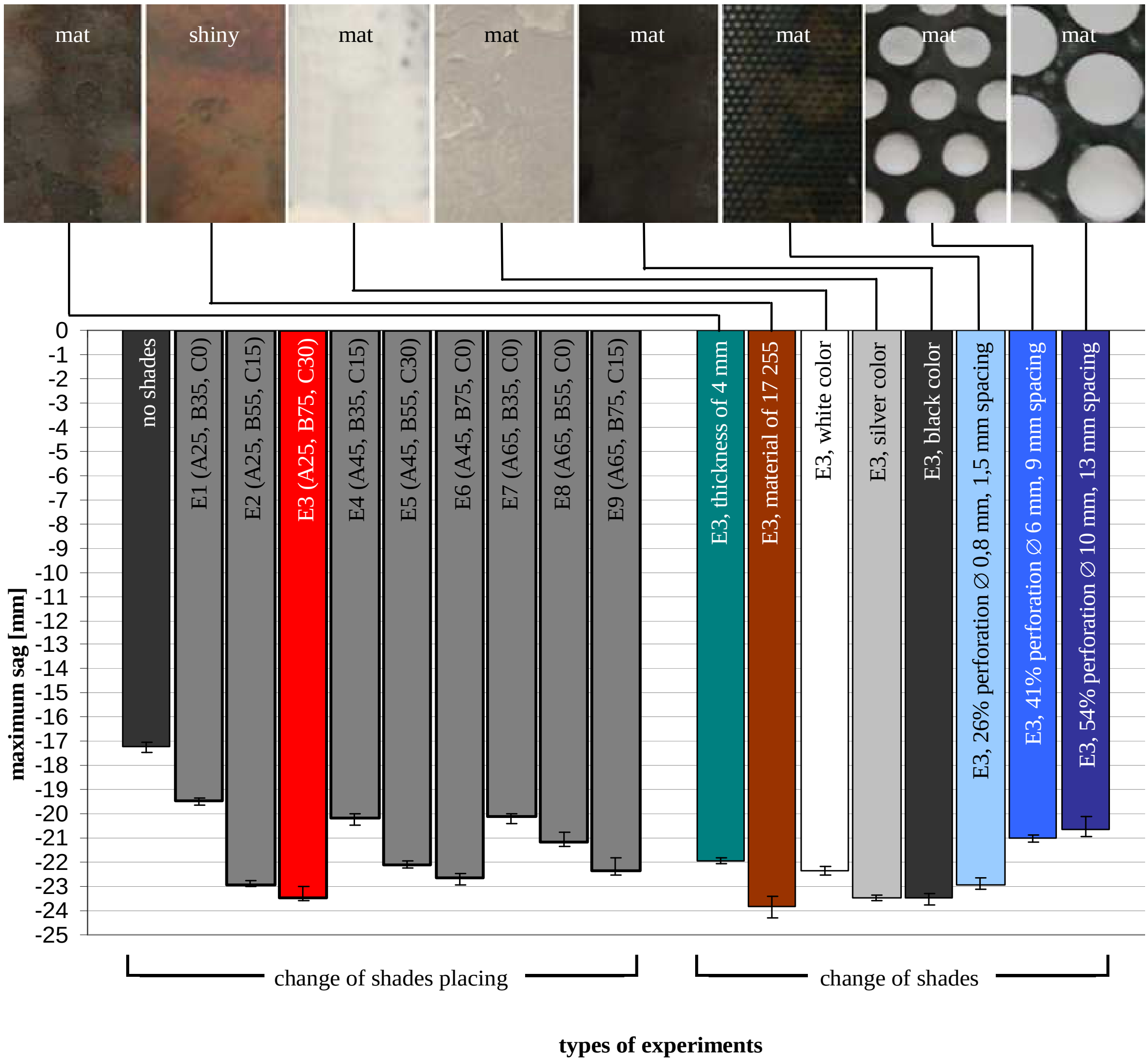


Fig. 8: Confrontation in maximum sag of samples for different setting shades

The main experimental data output is time development in maximum sag of samples. The summary is shown in the graphic form in Fig. 9 and next in Tab. 1.

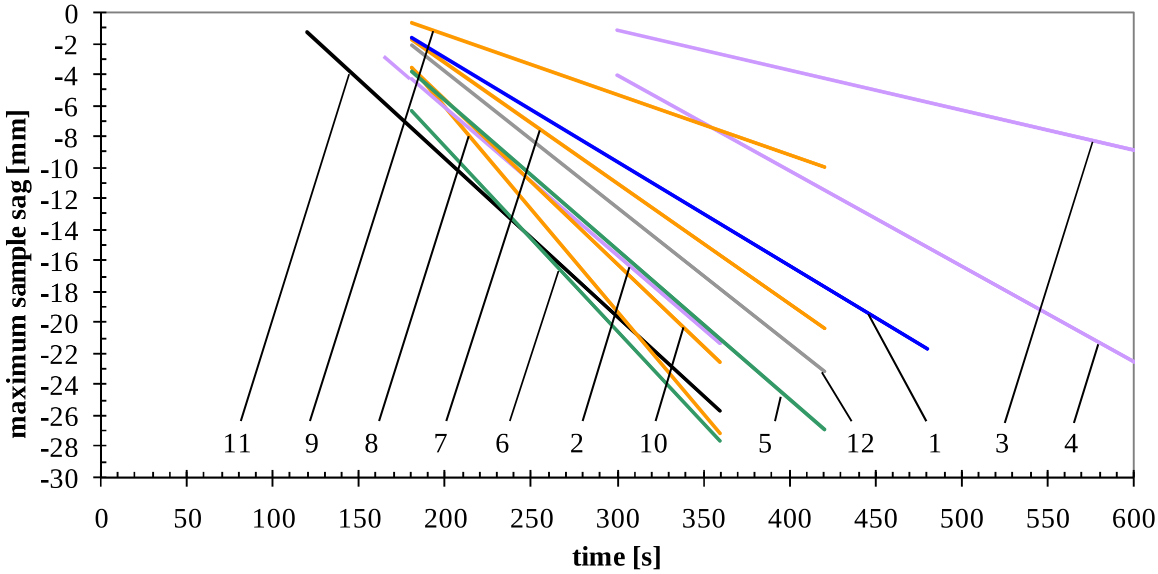
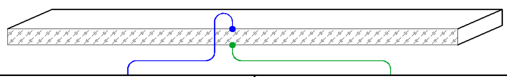


Fig. 9: Summary of time development in maximum sag of samples

Legend: 1 – default setting (below only chance is specified), 2 – glass thickness of 1.6 mm, 3 – glass thickness of 3.85 mm, 4 – double-glass (2.1+2.1 mm), 5 – green glass FGN0, 6 – green glass FGN5, 7 – lower heating (630 °C), 8 – (upper) heating of 640 °C, 9 – (upper) heating of 620 °C, 10 – sample distance from the kiln hearth 75 mm, 11 – full-printed (black) upper sides of samples, 12 – shades (Fig. 7) under sample/frame placed

Tab. 1: Summary of sample surface temperatures and speeds of the maximum sags

Setting characterization	Stagnation surface temperature [°C]		Steady sagging speed of samples [μm·s^{-1}]
Default: glass thickness 2.1 mm, glass type FCL0, upper heating 630 °C, distance between sample and heating 150 mm	 Centre of upper sample side	Centre of lower sample side	
Default setting (1)	**621**	**613**	**66**
Glass thickness 1.6 mm (2)	621 (-)	613 (-)	95 (+44 %)
Glass thickness 3.85 mm (3)	621 (-)	613 (-)	26 (-61 %)
Double-glass 2.1+2.1 mm (4)	621 (-)	613 (-)	62 (-6 %)
Glass type FGN0 (5)	-	-	96 (+45 %)
Glass type FGN5 (6)	623 (+2)	619 (+6)	118 (+79 %)
Lower heating 630 °C (7)	-	-	78 (+18 %)
Upper heating 640 °C (8)	632 (+11)	622 (+9)	131 (+98 %)
Upper heating 620 °C (9)	613 (-8)	605 (-8)	39 (-41 %)
Glass-heating dist. 75 mm (10)	-	-	106 (+61 %)
Full-printed glass (11)	625 (+4)	611 (-2)	103 (+56 %)
Horizontal shades (12)	622 (+1)	620 (+7)	88 (+33 %)

5.1. Discus of results

Speed of the sample heating is mainly influenced by glass thickness, chemical constitution, convection in the kiln and eventually glass printing. Increasing glass thickness naturally causes decreasing sample heating speed. Glass chemical constitution, effect was tested by glass color defined by Fe_2O_3 content, influences especially intensity of radiation absorption. Increasing Fe_2O_3 content causes increasing sample heating speed. Black mat printing deposited on the glass surface absorbs more radiant energy than clear glass, which is the cause of higher sheet heating speed. Deformation speed is given by sheet geometric characteristic and mainly by distribution of local temperatures in the sheet. Temperature of the glass sample is given by its properties (chemistry, thickness, printing, etc.) as well as by system properties (temperature and position of heating elements, etc.). Decreasing glass thickness (and also increasing temperature) causes increasing speed of the sample sag. Temperature profile in glass sample, documented by difference between foreside and bottom of sample surface temperature, is mainly influenced by radiation rate (range of glass printing) and by distribution of air temperature in the kiln (upper/lower heating, shades placing, etc.).

Conclusions

The study submitted gives the overview of results as for the gravity forming of float glass. The influence of sever factors on the glass sag courses was evaluated in detail. In particular, new knowledge was obtained concerning the effect of the printing and shades placing which can contribute to higher quality and optimalization of automotive glass.

Acknowledgement

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