Glass Windscreen Forming Optimization by Finite Element Analysis Using COMSOL Multiphysics

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Abstract: Glass products are widely diffuse in the everyday reality. An interesting glass application field, from a technological point of view, is the transportation area.
The automotive industry always needs for more complex shape of windscreen in order to satisfy the request of new design. In the paper, a "common" windscreen forming process, for automotive application, is described. The results of a preliminary study, on the forming sheet glass process, are here shown. A first optimization step, in order to reduce the forming time, is also introduced.

Keywords: Viscous material, high temperature forming process, optimization process

1. Introduction

Glass products are widely diffuse in the everyday reality. Windows, doors, furniture parts, kitchenware, bottles etc., are few examples of goods made with glass. In the basic formulation, the glass is made by fusing of silica with a basic oxide [1].

An interesting glass application field, from a technological point of view, is the transportation area. In fact, during the last years, the design of vehicles is developed toward a major fantasy in the shapes [2]. This required for deeper studies in the manufacturing glass process, in particular in the forming process, where a windscreen is obtained from a "raw" sheet of glass.
In the paper, a "common" windscreen forming process, for automotive application, is described (see figure 1). Usually, when a change in the windscreen shape is decided from the designer, a series of trial and error manufacturing tests have be done, in order to obtain the expected final shape. Often, this means to stop the manufacturing line to carry out the forming tests with loss of money [2].

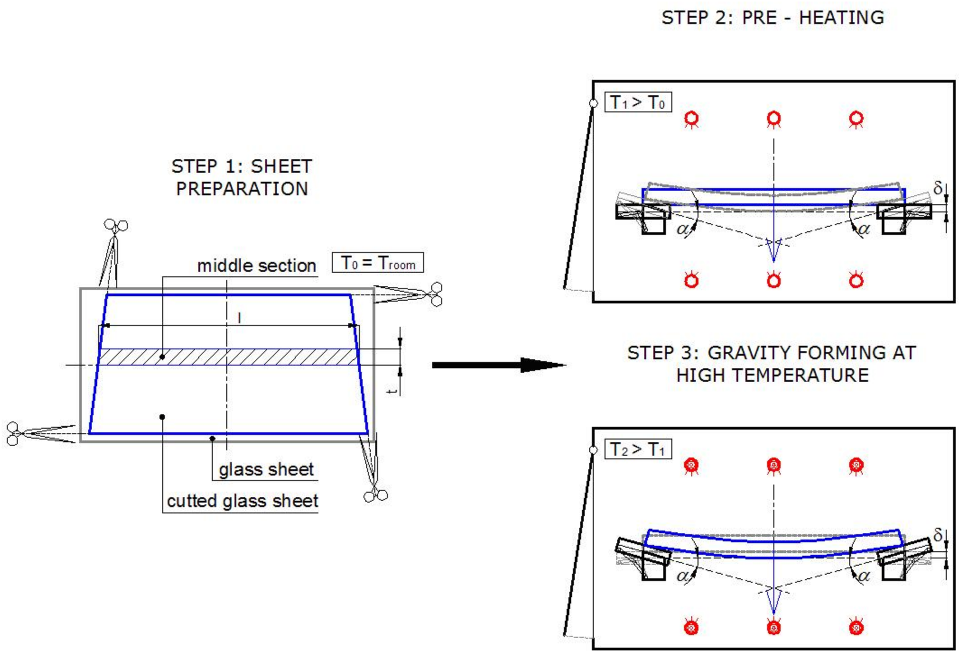

Figure 1 Traditional windscreen forming process.

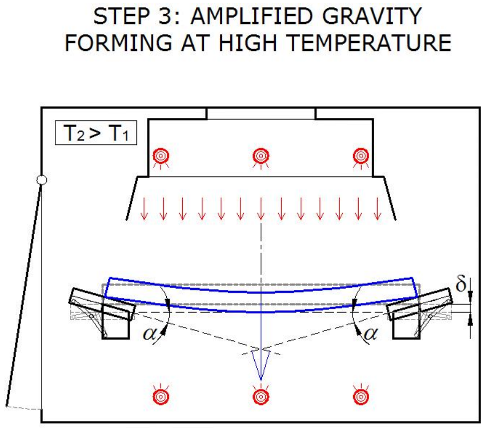

Figure 2 Modified windscreen forming process.

In this paper, the results of a preliminary study on the forming sheet glass process are shown. A first optimization study, in order to reduce the forming time, is also here presented (figure2) [3].

2. The constitutive relationships

The forming process of glass sheets into windscreens can be modelled by a stress-strain relationship accounting for the temperature. In [4], the relationship is described as follows [5, 6,7, 8, 9]:

$$\begin{cases} \sigma(t) = E_r \varepsilon(t) + \sum_{j=1}^{n} E_j \varepsilon_j(t) \\ \dfrac{d\varepsilon_j(t)}{dt} + \dfrac{E_j}{\eta_j}\varepsilon(t) = \dfrac{d\varepsilon(t)}{dt} \\ \varepsilon_j(0) = 0 \quad j = 1,2 \ldots n \\ \dot{\varepsilon}_c = \dfrac{3}{2}\dfrac{1}{3\eta}\sigma^d \end{cases} \qquad (1)$$

In the present study, the stain components are evaluated as follows:

$$\varepsilon(t) = f(\varepsilon_{el}(t), \varepsilon_c(t)) \qquad (2)$$

the ε_{el} are the viscoelastic strain components, while the ε_c are the creep strain components. η is the viscosity of the glass, defined as a material property depending on temperature [2].

In this study the system (1) is simplified by the following assumption: neglecting the pre-heating step, the forming process is modeled as in a steady state temperature condition.

The viscoelastic material constants in (1) are the same used in [8]. A shift factor was used to account the difference between the modeled process temperature and the test temperature.

3. Use of COMSOL Multiphysics

In the present study the secondary creep for the glass sheet forming is modelled in COMSOL Multiphysics 3.5a by using a coupled analysis. A 2D Structural Mechanical Module is coupled with a number of PDE Modules in a general form to perform a multiphysics analysis. In addition to the secondary creep, the PDE Modules allowed to consider the relaxation terms of the shear modulus, G(t), in the Prony series. This method made possible to consider the time dependent elastic phenomena.

Figure 3 shows the sheet geometry used in this study together with the 2D simplified subdomain.

Several simplifying assumptions were done in order to undertake simulations on a low performance laptop. The model does not consider the presence of a frame but it consider a symmetric boundary condition, in the middle, and a “zero” vertical displacement on the opposite tip (see figure 3). The mechanical analysis consider a 2D problem in a plane strain condition. This simplifies the final curvature of the windscreen shape.

Moreover, the model simulates an uniform temperature on the whole glass subdomain. The temperature is set on 600°C.

The time process is here evaluated as the time necessary to bend the glass sheet after the reaching of the thermal steady state condition.

Three load conditions were analyzed. The gravity load for which the glass sheet bends under the own weight. The 1,5 times gravity load and, finally, the 2 times gravity load. The aim is verify the time process reduction but also the increasing in the induced maximum stresses.

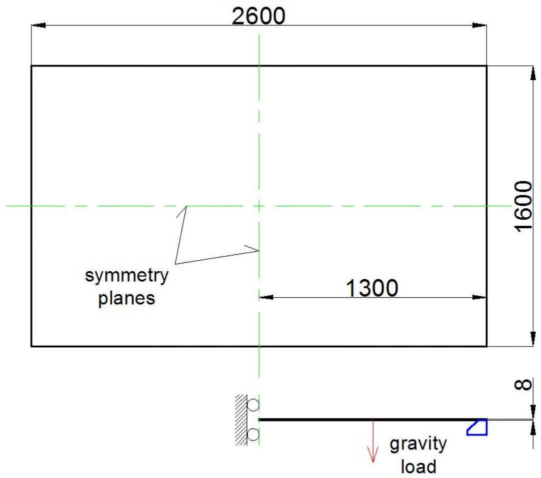

Figure 3 Analyzed windscreen geometry.

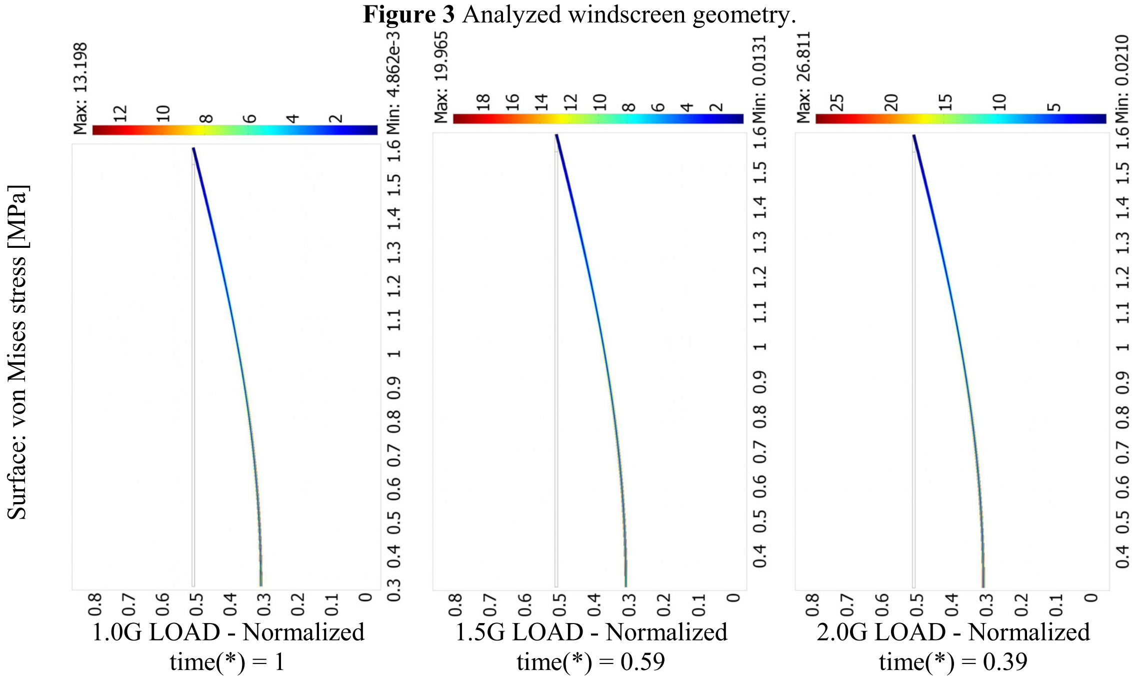

Figure 4 von Mises stresses distribution on deformed subdomain.

4. Results and discussion

In the simulations, the forming process ends when a preset middle deflection is reached. Here, the time process is the time needs to reach a deflection of 200 mm.

Normalization of computed values were considered for all load conditions in order to compare the results.

In the following were used the normalized bending time(*) as the ratio between the elapsed time process and the time process of the gravity load condition. The normalized load is the ratio between the applied load condition and the gravity load condition (sheet weight). The normalized von Mises stress is the ratio between the computed equivalent stress ratio and the maximum equivalent stress valued in the gravity load condition.

In figure 4, the von Mises stress distributions, on deformed subdomain, are showed. As expected, when the applied load is two times

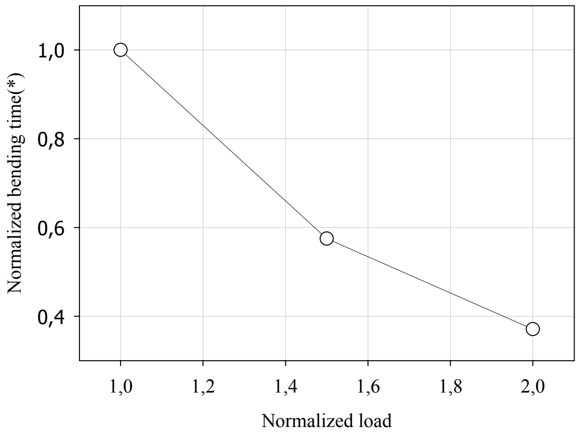

Figure 5a Bending time versus normalized load.

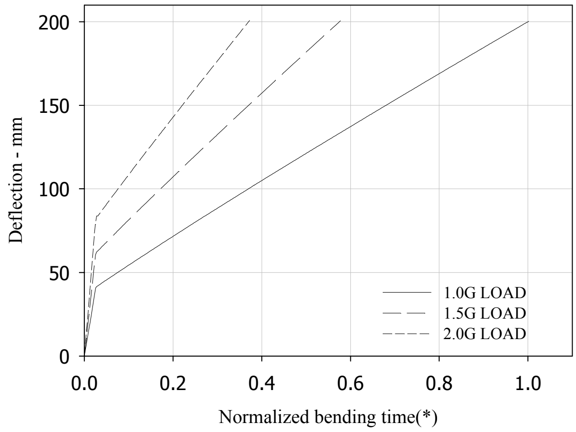

Figure 5b Deflection versus norm. bending time.

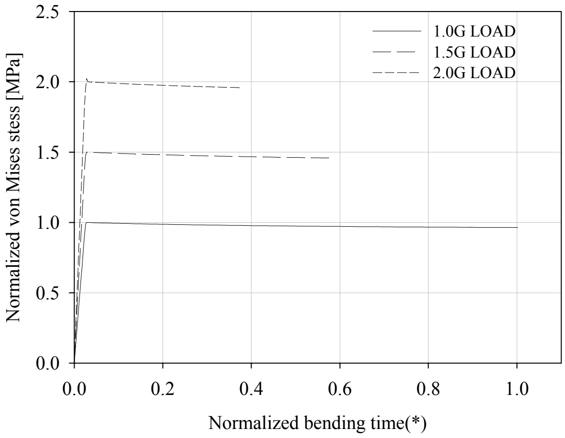

Figure 6a Norm. von Mises stress versus normalized bending time.

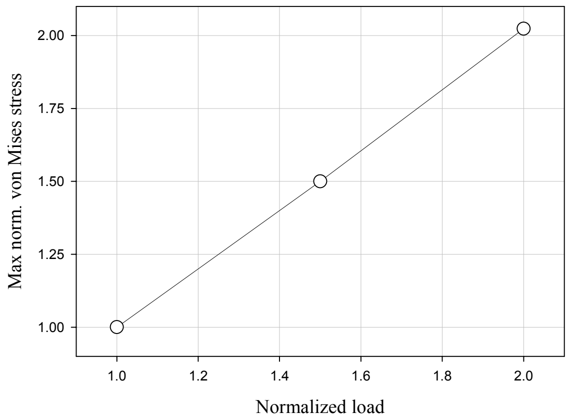

Figure 6b Max norm. von Mises stress versus norm. load.

the gravity load, the process is speeded up but the stresses are higher. The material could not withstand and it could break during the forming.

Comparison between the time process and the maximum stress during the forming process allow to value the "best" process parameter to carry out the forming process.

Figure 5a shows as the bending time reduces increasing the applied load during the process. In figure 5b, the deflection is plotted versus the normalized elapsed time. Here can be seen the slower bending process for the gravity load condition.

Figure 6a shows how the stresses increase during the initial bending process. Than, the stress magnitude drops thank to the viscous relaxation phenomena. It can be seen also the effect of higher applied load on the bending process, but as figure 6b confirms, the maximum stresses value increase with the applied load.

5. Conclusions

In this paper a preliminary approach, in order to optimize the windscreen high temperature forming process, was showed. COMSOL Multiphysics was a suitable tool to study the coupling of physical phenomena such as the structural creep and the viscous phenomena together with the thermal state. The computed results allow to study the "best" forming condition in order to speed up the production rate without compromise the windscreen integrity.

Further improvement have to be done to account the preheating step process, and a 3D model have to be carried out to consider more complex windscreen shapes.

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