Simulation of the integral forming process of TV-panels

Gerard Haagh, Dries Hegen, Maurice Limpens, and Olaf Op den Camp
TNO Glass Technology, P.O. Box 595, 5600 AN Eindhoven, The Netherlands

A simulation program has been developed as a design and optimisation aid for the integral forming process of TV-screens. The program consists of modules that allow for full 3D simulations of spout and gobber, gob forming, pressing, cooling and annealing. The modules are based on the finite element method, in which advanced techniques have been employed to model the glass free surfaces and the moving objects (e.g., the gobber, spanker and plunger) while keeping the computation times at an acceptable level. Other features include thermal effects (including radiation) in both the glass and the tools, temperature-dependent material properties (such as the glass viscosity) and thermal stresses. Interaction between modules makes it possible to impose the resulting thermal state of the tools from a cycle as the initial condition for a subsequent cycle. The program can be used to simulate the TV-screen pressing process as a whole, or focus on a particular step of the process that needs to be optimised.

Introduction

The requirements and tolerances on the quality of glass products are becoming increasingly stringent. As the quality of glass products is determined to a large extent by their forming processes, the design and optimisation of moulds and forming processes becomes more and more critical. Therefore, computer simulation tools have been developed to assist in improving the glass forming processes. For instance, for the production of TV-panels, simulation software helps the manufacturer to meet the requirements with respect to panel geometry (e.g., inner and outer curvature) and strength (e.g., the influence of residual stresses). It has been recognised by TV-panel manufacturers and simulation software developers that fully three-dimensional forming simulations are required to capture the relevant phenomena that determine the quality of the panel, such as non-uniform gob temperature, the position of the gob cut, and out-of-centre position of the gob in the mould. At present, a survey into the performance of software for 3D simulations of the pressing stage of a TV-panel is being carried out in TC-25, the ICG's Technical Committee on Modelling of Glass Forming.[1]

However, the quality of a glass TV-panel is not merely determined by the pressing step in the production line, but by the complete forming cycle, i.e. by all production steps from spout via gob forming, gob fall, pressing to cooling, as well as by the subsequent annealing process. Moreover, the forming steps are connected to each other in a physical sense, as they are carried out subsequently at a production turntable. Hence, the Glass Technology group at TNO has developed a simulation tool for the *complete* forming cycle of a TV-panel. It consists of a collection of software modules for the separate production steps as well as for the annealing step. The user can opt to simulate a single step in the forming cycle, two or more subsequent steps, or the forming cycle as a whole.

In this paper we will demonstrate how a glass manufacturer can benefit from the use of such a software tool by either simulating a complete forming process or by focusing on a single step in the cycle. The modules for the separate production steps are presented, as well as the Graphical User Interface to the software.

Overview of the forming simulation software

Although the separate software modules for the simulation of TV-panel forming focus on the specific issues of each step in the forming cycle, they have a number of characteristics in common:

- All modules employ the finite element method as the computational framework to solve the equations that describe the relevant physical processes.
- All modules have the option to carry out full 3D simulations; most modules also provide an option for 2D simulations to give the user a faster (but less detailed) insight into the characteristics of the process.
- All modules are based on a fixed mesh approach, which avoids the use of remeshing techniques that are exorbitantly expensive (time-consuming), especially for 3D simulations. The gob forming and pressing simulations require the tracking of free glass surfaces. This is dealt with by using a pseudo-concentration method, in which glass is treated as a chemical species with a concentration equal to unity, whereas the surrounding media (usually air) has a « glass concentration » equal to zero. By solving a convection equation for the glass concentration, the position and movement of the free glass surface can be computed throughout the process. [2]
- All modules can be operated from a single Graphical User Interface (GUI), which also takes care of the transfer of data between modules.
- The models in the simulation software are able to deal with temperature-dependent glass properties (density, viscosity, thermal properties, etc.)

The main characteristics of each module will be shortly discussed below.

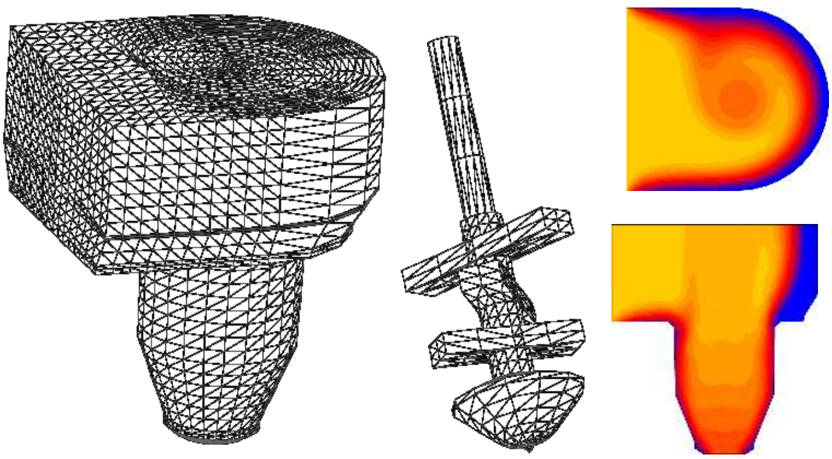

Figure 1: Discretisation of the spout (left) and gobber (centre), and temperature distributions in top view and centre cross-section (right).

Spout with gobber

The spout module allows for both 2D and 3D simulation of a spout with a moving (i.e., rotating and translating) gobber. Given the input from the feeder (e.g., from the TNO Feeder Model), the user can adjust the gobber movement and cycle time to obtain the desired gob weight. A sophisticated technique has been developed to account for the movement of the gobber in the fixed mesh, thereby obtaining a substantial reduction in computational time compared to remeshing techniques.[3] Thus, the gobber translates and rotates in the fixed mesh that is shown in Figure 1. The outflow from the spout is governed by the movement of the gobber, as well as by gravity. Internal heat radiation is taken into account.

Gob forming

Given the flow and temperature of the glass that leaves the spout (obtained from the spout module, or from data provided by the user), the shape, weight and temperature distribution of the gob can be determined by the gob forming module. Both internal and external radiation are taken into account. The user can choose to have the gob supported by a spanker during gob forming (see Figure 2). The gob is represented on a fixed mesh, in which the spanker movement is taken into account via a fictitious domain method. To couple the gob forming result to the pressing module, an optional tool is available that accounts for the gob fall.

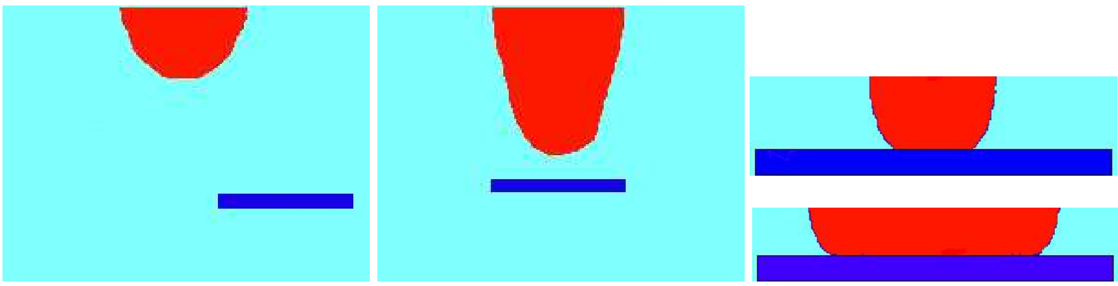

Figure 2: Gob shape and spanker movement during gob forming, and detailed view of gob-spanker contact.

Pressing

The pressing module, which allows for 2D and 3D simulations, forms the core of the forming simulation software; the 2D option has been designed for pressing simulations of axisymmetric articles (e.g., tableware). Whereas the calculation of the flow is limited to the glass, the temperature calculation is extended to the tools (mould, plunger and ring; see Figure 3). The initial tool temperatures can be taken from the previous cooling step. Moreover, the temperature calculation in the glass is coupled with an internal heat radiation model. An Arbitrary Lagrange-Euler (ALE) type of approach has been used to account for the plunger movement; hence, the mesh topology is retained during the pressing step and time-consuming remeshing is avoided.

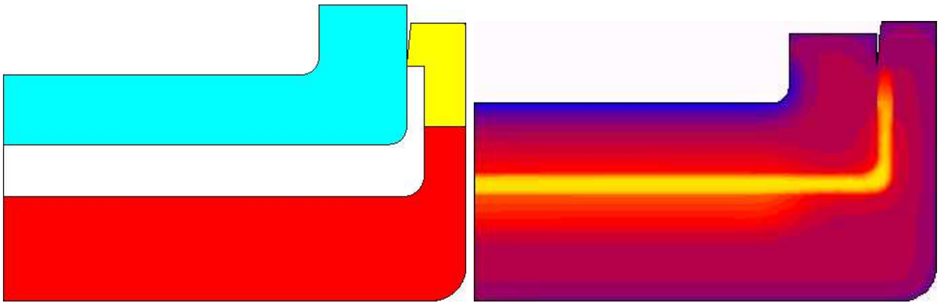

Figure 3: Cross-sectional view of a conventionalised configuration of mould, plunger, and ring (left) and temperature distribution in a TV-panel during pressing (right).

Cooling

The simulation of cooling is actually an extension of the pressing simulation: the ring and plunger are removed and the process conditions for cooling are applied to the panel and the mould. Both the temperature and the thermal deformations of the panel and the tools are computed (see Figure 4). The characteristics of forced cooling by air (via air formers) are calculated separately; the results are imposed as boundary conditions for the panel cooling process.

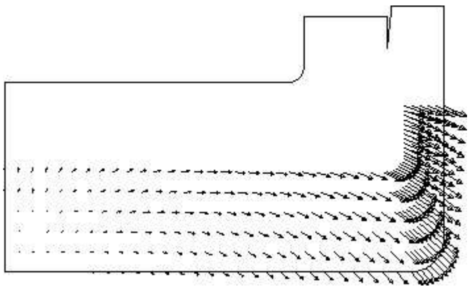

Figure 4: Mould deformation during cooling of a conventionalised TV-panel.

Annealing

The annealing module considers the panels as they move through an annealing lehr. Hence, they are subjected to prescribed temperatures in the different zones of the oven. The temperature distribution in the panels is calculated based on heat transfer (including radiation) to and from the oven and the conveyor belt.

Graphical User Interface

The Graphical User Interface (GUI) has been divided in a part for general input—i.e., input that applies to the complete forming cycle, such as glass properties and process timings—and a part for input that is specific for each module, such as geometrical parameters, process conditions and desired output. For each process step, the user can choose to define the initial conditions himself, or to take the output of any previous simulation as the initial condition for the next simulation. Hence, the forming simulation software combines user-friendliness with flexibility (see Figure 5).

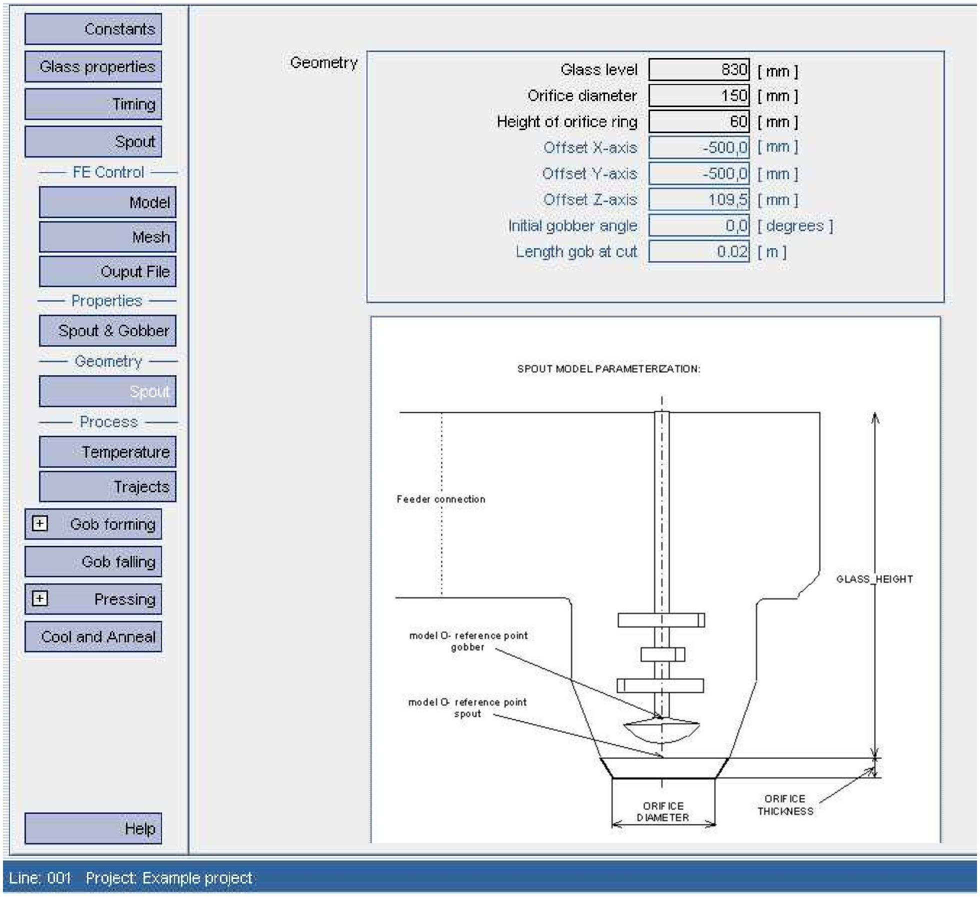

Figure 5: Specification of the spout and gobber geometry in the Graphical User Interface.

Applicability of the forming simulation software

The TNO glass forming simulation program enables the manufacturer of glass TV panels to predict the effects of changes in process settings (cycle times, tool temperatures, gobber velocity etc.) without interfering with the actual production process. Thus, forming simulations can help to answers questions as: What happens to the process and product if the glass temperature in the feeder slightly changes? How does the temperature distribution in the gob affect the filling behaviour of the mould during pressing, and can the gob cut be traced back? How sensitive is the pressing process to the position of the gob in the mould? Will the suggestions to change either the geometry or the thermal conditions of the mould have the desired effects on the product? Can the production speed be increased, and how should the process settings be modified then? Ultimately, the objective is that the interaction between process simulation and manufacturing experience will lead to one-time-right design and production.

The TNO glass forming simulation software has been validated with data from a TV-panel production plant and is currently being used to optimise a production line. The prediction of residual stresses—taking into account viscoelastic and structural relaxation—is currently implemented[4]. Moreover, the development of a module for the simulation of container glass forming by press/blow processes has been initiated.

---

[1] Homepage of TC-25 on the Internet: www.shef.ac.uk/uni/projects/icg/tc25.html

[2] Haagh, G.A.A.V. and Van de Vosse, F.N., International Journal for Numerical Methods in Fluids **28**, p. 1355-1369 (1998).

[3] Hegen, D. in *Proceedings of the 2nd International Colloquium on Modelling of Glass Forming and Tempering,* Valenciennes, France, 2002, p. 50-56.

[4] Haagh, G.A.A.V. in *Proceedings of the 2nd International Colloquium on Modelling of Glass Forming and Tempering,* Valenciennes, France, 2002, p. 241-246.