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An integrated simulation for the whole forming process of the picture tube panel

Yun Zhang *, Zhigao Huang, Fen Liu

College of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan, Hubei 430074, People's Republic of China

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Abstract

An integrated model for the whole forming operation of the picture tube panel is developed in this paper, which couples the behaviors of glass and mold. The molten glass is modeled by an incompressible Newtonian liquid undergoing flow. And a three-dimensional finite element method is used to perform the simulation of the fluid and heat flow. A local one-dimensional transient analysis in the thickness direction is adopted for the part cooling stage after pressing, which employs the finite-difference method. The mold heat transfer is established by boundary conditions analysis and its numerical implementation is a three-dimensional boundary element method. The glass and mold simulations are coupled by matching the temperature and heat flux on the glass-mold interface. For residual stresses analysis, a thermo-rheologically simple viscoelastic material model is introduced to consider the stresses relaxation effect and to describe the mechanical behavior according to the temperature change. The shrinkage of formed parts induced by the residual stresses is calculated based on the theory of shells, represented as an assembly of flat elements formed by combining the constant strain and the discrete Kirchhoff triangular elements. A thermoelastic model is presented to predict the deformation of the mold blocks during pressing, which is based on the steady mold temperature field and thermoelastic boundary element method.

Keywords: Picture tube panel; Numerical simulation; Glass pressing; Residual stresses

1. Introduction

The picture tube panel is the upper component of electronic products such as TV sets and computers, which is produced by the glass pressing operation. Basically, each cycle of the process consists of three major stages: gob forming, pressing, and air formers cooling. In forming, molten glass is pressed into a relatively cold mold. After pressing, heat transfer at the mold surface and air formers cooling eventually result in a solid part. Traditionally in the development period of this process, various process conditions are often selected by experienced engineers, or based on reference handbooks, and later improved and fine-tuned by trial-and-error on the shop floor. This method depends highly on the experience of molding operators and could potentially be costly and time

* Corresponding author. Tel.: +86 27 87543492.
E-mail address: lihust2000@yahoo.com.cn (Y. Zhang).

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consuming. Interrupting the continuous forming cycle to conduct a series of experiments would be disruptive and also factory floor experimentation is not always a viable option due to the very hostile environment.

As a result of the market competition, the producers face the challenge of shortening development period and improving products quality. To improve the mold design and process control in the picture tube panel production, it is desirable to have an analysis tool for optimization. By employing simulation tools, engineers can quickly qualify final design without physically committing machine time. Furthermore, through numerically evaluating alternative designs, engineering know-how can be developed quickly and more cost-effectively compared to trials on the shop floor.

In recent years, with the availability of powerful computers, simulation models have been developed to gain a better understanding of, and subsequently improve, glass pressing process. Some models have been developed to simulate the glass flow, heat transfer, mold cooling, etc. For example, Cesar de Sa [1] presented a finite element method to the simulation of glass forming processes, which could provide both the glass and temperature distribution at each instant of the forming process. Cormeau et al. [2] modeled the glass blowing process and provided the preliminary results of a numerical simulation. Humpherys [3] presented a simplified mathematical model for axial-symmetrical pressing. Li et al. [4] used a commercial simulation program DEFORM™ to model the picture tube panel forming process, especially the glass flow during pressing. Camp et al. [5] developed a software system for the simulation of the process steps that are required for the production of TV panels, including gob forming, pressing, cooling and annealing. As for residual stresses simulation, Narayanaswamy and Gardon [6] proposed a thermorheologically simple viscoelastic material model to calculate transient stresses. Chabrand et al. [7] dealt with the mechanical and numerical modeling of the thermal tempering of a thermoviscoelastic material by using Maxwell model. Mauch and Jackle [8] used the framework of the theory of thermoviscoelasticity to model the Gardon and Narayanaswamy theory of annealing and tempering of glass in a unifying way, considering the effect of isothermal pressure relaxation in addition to the relaxation of shear stress. In recent years, the research group of Prof. Zhou performed a wide range of studies for the forming process of picture tube panels, including glass pressing [9], part cooling [10], mold cooling [11], residual stresses [12,13], part shrinkage [14], mold deformation [15], etc.

Although computer simulation of glass pressing process has been a popular research topic, most of existing investigations only focused on one aspect of the problem. However, the final solid part is obtained at the end of a series of coupled fluid and heat-transfer processes. There are many interrelated factors involved in the pressing process, all of which affect the formed parts quality. For example, the heat transfer and fluid flow within molten glass are interrelated because the glass viscosity is strongly temperature dependent; the mold cooling is of great importance because the temperature distribution on its surface is the boundary condition of pressing and part cooling; and the mold deformation can also affect the geometric shape and dimensional precision of the formed part.

Based on the simulation modules developed by the Prof. Zhou's research group, this paper presents an integrated and coupled simulation for the whole forming process of the picture tube panel, from the glass pressing to part shrinkage. For the glass pressing, a three-dimensional finite element model is used to deal with the fluid and heat flow. The part cooling is simulated by the finite-difference method. A boundary element method is employed to analyze the mold temperature during the pressing process, which considers the heat transfer from the glass, coolant, and ambient air. The part and mold simulations are coupled by the temperature distribution on the glass-mold interface. By taking the effects of pressure and temperature history during the forming process into account, the calculation of residual stresses uses a thermorheologically simple thermoviscoelastic material model. The model for the analysis of shrinkage is proposed based on the theory of shells, as an assembly of flat elements. The numerical model for mold deformation is based on a three-dimensional thermoelastic boundary element formulation.

2. Physical modeling

2.1. Description of the forming process

The forming process of the picture tube panel is periodic (cyclic) and all process steps are carried out on an 11-station carousel that indexes two stations at each gob drop, as shown in Fig. 1. That is, the glass panel