Control and optimization of the sag bending process in glass windscreen design

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Abstract

Complex glass shapes with good optical quality are now commonly used by car designers to augment the aesthetic appearence and to improve aerodynamics of the car windscreen. At the same time the technical glass specification has been made more complex by incorporation of thermal and mechanical properties. Complex shapes must be achieved together with these performance characteristics. In this work numerical algorithms have been developed to simulate the forming process. Without heating control the standard sag bending process results in shapes with poor optical quality With controlled simulated heating a good match between required and possible shapes could be obtained in terms of cross curvature at the centerline. However for some shapes an inversion in curvature values occurs at the top and at the bottom corners of the windscreen. An optimal control algorithm is needed to achieve a compromise among the requirements.

In order to simulate the behavior of the glass during the sag process an initial linear elastic model is proposed. This model is based on the minimization of the elastic energy over constraints imposed by the frame. This leads to a variational inequality which can be solved by a numerical algorithm through a Lagrangian multiplier technique. A FEM simulation of this model shows the experimentally observed lift at the corners. Over this model we seek an optimization of the temperature distribution. The optimization is based on the minimization of a functional representing the error, in a suitable space, between the desired and the actual shape. Different penalty terms are added to the functional to improve the numerical scheme. At this stage the optimal temperature distribution is tested in a viscous-elastic model. The glass is described as a maxwellian fluid and the presence of the viscous term relaxes the stresses generated in the elastic model. The importance of the viscous term can be evaluated in the final stage and compared with the experimental data. Mathematical theory of this model and numerical results are discussed in this paper.