Fused glass deposition modelling: numerical simulation of thermal and residual stresses due to additive manufacturing of glass on a glass base plate

Kerstin Thiele*[1], Philipp Chhadeh[1], Peter Hof[1], Jens Schneider[1], Ulrich Knaack[1], Matthias Oechsner[1], and Matthias Seel[1]

[1]TU Darmstadt – Germany

Abstract

A glass 3D printer is being created at Technical University Darmstadt, which uses the fused deposition modeling process to print glass onto a base plate of glass, see (Seel M. M., et al., 2018; Seel M. , et al., 2018). The aim is to develop novel joints and reinforcements for use in glass facades in the construction industry. The focus is on soda-lime silicate glass according to (DIN EN 572 - 1, 2011) and borosilicate glass according to (DIN EN 1748 - 1 - 1, 2004), which are mainly used in the construction industry.
Current research activities are in the area of development of printable solutions for glass facades, process development, and development of methods to investigate the failure mechanisms and component load bearing capacities of the printed complex geometries. In this paper, the focus is on numerical simulation of thermal mechanical stresses and residual mechanical stresses remaining in the glass components. The aim of these investigations is a deep understanding of the process of additive manufacturing of glass including the knowledge of the influencing parameters as well as the prevention of glass breakage during manufacturing or shortly after. The research is based on the existing numerical simulations of the thermal tempering process of flat glass, see (Pour-Moghaddam, 2020; Aronen, 2012).

For the numerical simulation, the process of additive manufacturing of glass on a base plate of glass is divided into 4 steps. The first step is to heat the base plate as homogeneously as possible to a temperature close to the annealing point of the used glass. In the second step, the local heating of the joining zone is investigated. In the joining area, where base plate and glass filament will join, a viscosity between 104 dPa s and 106 dPa s is desired. In the third step, the deposition of the first filament row of molten glass onto the base plate is investigated. In the last step, the deposition of several filament layers is investigated. The thermal boundary conditions are to be defined for each step. These are mandatory for a realistic simulation of the stresses. The engineering approach chosen here with the assumptions made to simplify the thermal material parameters as well as the thermal boundary conditions regarding radiation, convection and heat conduction is explained.

The numerical simulation is divided into a thermal transient and a static mechanical numerical simulation. First, the temperatures are determined. Based on the time and local distribution of the temperatures, the thermal and residual stresses can then be calculated in a second step. Stress-optical measurement methods provide information about the residual

*Speaker

stresses in the glass. The residual stresses determined in this non-destructive way can be compared with the calculated stresses from the simulation.

References

Aronen, A. (2012). *Modelling of Deformations and Stresses in Glass Tempering.* Tampere University of Technology.

DIN EN 1748 - 1 - 1. (2004). *Glas im Bauwesen - Spezielle Basiserzeugnisse - Borosilicatgläser - Teil 1-1: Definitionen und allgemeine physikalische und mechanische Eigenschaften.*

DIN EN 572 - 1. (2011). *Glas im Bauwesen – Basiserzeugnisse aus Kalk-Natronsilicatglas - Teil 1: Definitionen und allgemeine physikalische und mechanische Eigenschaften.*

Pour-Moghaddam, N. (2020). *On the fracture behaviour and the fracture pattern morphology of tempered soda-lime glass.* Technische Universität Darmstadt: Springer Vieweg Wiesbaden.

Seel, M. M., Akerboom, R., Knaack, U., Oechsner, M., Hof, P., & Schneider, J. (2018). Fused glass deposition modelling for applications in the built environment. *Materialwiss. Werkstofftechn., 49*, 870-880. doi:10.1002/mawe.201800075

Seel, M., Akerboom, R., Knaack, U., Oechsner, M., Hof, P., & Schneider, J. (2018). Additive Manufacturing of Glass Components - Exploring the Potential of Glass Connections by Fused Deposition Modeling. *Challenging Glass Conference Proceedings*, 381-388.

Keywords: Additive manufacturing glass, numerical simulation, residual stresses, heat transfer