Hygro-mechanical modelling of glutin-based bond lines in wooden cultural heritage

Daniel Konopka[*†], Erik V. Bachtiar[†‡], Peter Niemz[‡], and Michael Kaliske[†]

[†]Institute for Structural Analysis, Technische Universität Dresden, 01062 Dresden, Germany,
michael.kaliske@tu-dresden.de,
[‡]Institute for Building Material, ETH Zurich, 8093 Zürich, Switzerland

A comprehensive modelling of the transient hygro-mechanical behaviour of complex wooden structures by the finite element method is targeted. New methods and material models for glutin-based bond lines are developed, since bond lines proved to have significant influence on moisture transport and fracture behaviour. The modelling of wood is based on previous research on three-dimensional orthotropic elastic, plastic and fracture formulation on the mechanical side, and on multi-Fick'ian moisture transport formulation on the hygric side. The coupled monolithic description of transient hygro-mechanical behaviour of wood is based on previous research (see [1]).

By the contribution, a new multi-Fick'ian hygro-mechanical model for glutin-based bond lines [2] is presented. A cohesive element model is modified by adding features to simulate the mechanical behaviour of and the moisture transport in the joint. The joint, which includes one layer of adhesive and two layers of interphase zones, is simplified by using a single layer of cohesive elements. The material properties of the adhesive, the interphase zones and both wooden adherents are assigned to the cohesive element. Thus, the bond line will fail, for instance, by exceeding the minimum strength with respect to material, direction and moisture content. This method decreases computational effort with a reduced number of material and element layers, while still maintaining the reliability of the model. The investigated glues are gelatine-based adhesives, which are often used in wooden cultural heritage objects found in museums and collections. Further references on the basing experimental investigations of the hygro-mechanical properties of gelatine-based adhesives and the element and material formulations are described comprehensively in [2].

The new bond line model is validated by numerical investigations of two wood species, based on own and further experimental studies available in the literature. The simulated specimens contain a single bond line of animal adhesive. Hygro-mechanical shear tests (Figure 1) and diffusion experiments are simulated and compared to the experiments. The validations show that under mechanical loading, the numerical simulation of fracture under tension and shear is in good agreement with the experimental results. However, the numerical results of transient moisture transport are less precise. The reason is primarily due to the incomplete experimental data, which serve as input parameters into the simulation.

Finally, the methods are applied to the hygro-mechanical structural analysis of wooden cultural heritage objects at changing ambient relative humidity. The barrier effect of the bond lines leads to large moisture gradients and internal hygro-expansional constraints at the adhesive layers. The results show the high potential of cracks around the bond line.

The new bond line model enables to consider the influence of adhesive layers on fracture behaviour and resistance on moisture transport within structural analysis of wooden cultural heritage objects. Further experimental research on hygro-mechanical fracture behaviour and moisture transport in all members of the investigated structures are required to enhance the accuracy of the simulation results. Keeping in mind that every model is limited, simulation results can help conservators to evaluate constructions, detect overloaded structural members in a non-destructive way and with that develop conservation measures and define climate conditions.

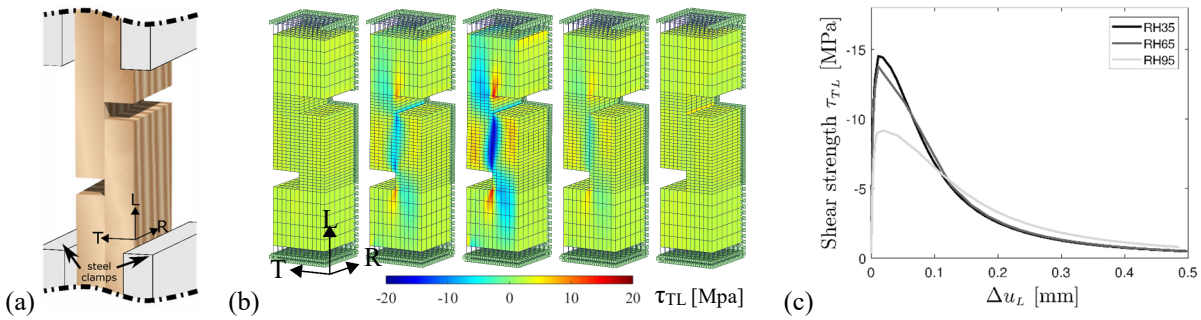

Figure 1: Shear test of adhesive-wood joints (glutin-based glue and European beech): (a) experimental setup; (b) shear stress (τ_{TL}) propagation (from left to right): initial (u_L=0 mm), elastic, peak before failure (u_L=0.196 mm), directly after failure, final condition (u_L=0.5 mm); (c) dependency of the shear stress on moisture [MC_{beech}(RH): 6.8%(35%), 12.1%(65%), 23.8%(95%)] [2]

References

[1] D. Konopka, M. Kaliske: Transient multi-Fickian hygro-mechanical analysis of wood. *Computers and Structures*, 197 (2018), 12–27.
[2] E.V. Bachtiar, D. Konopka, B. Schmidt, M. Kaliske, P. Niemz: Hygro-mechanical analysis of wood-adhesive joint. *Engineering Structures*, submitted (2018).

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