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Numerical Modeling of Timber Structures under Varying Humidity Conditions

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Abstract : Timber structures may be exposed to various environmental conditions during their service life. Often, the structures have to resist extreme changes in the relative humidity of surrounding air, with simultaneously carrying the loads. Wood material response for this load case is seen as increasing deformation of the timber structure. Relative humidity variations cause moisture changes in timber and consequently shrinkage and swelling of the material. Moisture changes and loads acting together result in mechano-sorptive creep, while sustained load gives viscoelastic creep. In some cases, magnitude of the mechano-sorptive strain can be about five times the elastic strain already at low stress levels. Therefore, analyzing mechano-sorptive creep and its influence on timber structures' long-term behavior is of high importance. Relatively many one-dimensional rheological models for rheological behavior of wood can be found in literature, while a number of models coupling creep response in each material direction is limited. In this study, mathematical formulation of a coupled two-dimensional mechano-sorptive model and its application to the experimental results are presented. The mechano-sorptive model constitutes of a moisture transport model and a mechanical model. Variation of the moisture content in wood is modelled by multi-Fickian moisture transport model. The model accounts for processes of the bound-water and water-vapor diffusion in wood, that are coupled through sorption hysteresis. Sorption defines a nonlinear relation between moisture content and relative humidity. Multi-Fickian moisture transport model is able to accurately predict unique, non-uniform moisture content field within the timber member over time. Calculated moisture content in timber members is used as an input to the mechanical analysis. In the mechanical analysis, the total strain is assumed to be a sum of the elastic strain, viscoelastic strain, mechano-sorptive strain, and strain due to shrinkage and swelling. Mechano-sorptive response is modelled by so-called spring-dashpot type of a model, that proved to be suitable for describing creep of wood. Mechano-sorptive strain is dependent on change of moisture content. The model includes mechano-sorptive material parameters that have to be calibrated to the experimental results. The calibration is made to the experiments carried out on wooden blocks subjected to uniaxial compressive loaded in tangential direction and varying humidity conditions. The moisture and the mechanical model are implemented in a finite element software. The calibration procedure gives the required, distinctive set of mechano-sorptive material parameters. The analysis shows that mechano-sorptive strain in transverse direction is present, though its magnitude and variation are substantially lower than the mechano-sorptive strain in the direction of loading. The presented mechano-sorptive model enables observing real temporal and spatial distribution of the moisture-induced strains and stresses in timber members. Since the model's suitability for predicting mechano-sorptive strains is shown and the required material parameters are obtained, a comprehensive advanced analysis of the stress-strain state in timber structures, including connections subjected to constant load and varying humidity is possible.

Keywords : mechanical analysis, mechano-sorptive creep, moisture transport model, timber
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