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Investigation of Delamination Process in Adhesively Bonded Hardwood Elements under Changing Environmental Conditions

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Abstract : Application of engineered wood, especially in the form of glued-laminated timbers has increased significantly. Recent progress in plywood made of high strength and high stiffness hardwoods, like European beech, gives designers in general more freedom by increased dimensional stability and load-bearing capacity. However, the strong hygric dependence of basically all mechanical properties renders many innovative ideas futile. The tendency of hardwood for higher moisture sorption and swelling coefficients lead to significant residual stresses in glued-laminated configurations, cross-laminated patterns in particular. These stress fields cause initiation and evolution of cracks in the bond-lines resulting in: interfacial de-bonding, loss of structural integrity, and reduction of load-carrying capacity. Subsequently, delamination of glued-laminated timbers made of hardwood elements can be considered as the dominant failure mechanism in such composite elements. In addition, long-term creep and mechano-sorption under changing environmental conditions lead to loss of stiffness and can amplify delamination growth over the lifetime of a structure even after decades. In this study we investigate the delamination process of adhesively bonded hardwood (European beech) elements subjected to changing climatic conditions. To gain further insight into the long-term performance of adhesively bonded elements during the design phase of new products, the development and verification of an authentic moisture-dependent constitutive model for various species is of great significance. Since up to now, a comprehensive moisture-dependent rheological model comprising all possibly emerging deformation mechanisms was missing, a 3D orthotropic elasto-plastic, visco-elastic, mechano-sorptive material model for wood, with all material constants being defined as a function of moisture content, was developed. Apart from the solid wood adherends, adhesive layer also plays a crucial role in the generation and distribution of the interfacial stresses. Adhesive substance can be treated as a continuum layer constructed from finite elements, represented as a homogeneous and isotropic material. To obtain a realistic assessment on the mechanical performance of the adhesive layer and a detailed look at the interfacial stress distributions, a generic constitutive model including all potentially activated deformation modes, namely elastic, plastic, and visco-elastic creep was developed. We focused our studies on the three most common adhesive systems for structural timber engineering: one-component polyurethane adhesive (PUR), melamine-urea-formaldehyde (MUF), and phenol-resorcinol-formaldehyde (PRF). The corresponding numerical integration approaches, with additive decomposition of the total strain are implemented within the ABAQUS FEM environment by means of user subroutine UMAT. To predict the true stress state, we perform a history dependent sequential moisture-stress analysis using the developed material models for both wood substrate and adhesive layer. Prediction of the delamination process is founded on the fracture mechanical properties of the adhesive bond-line, measured under different levels of moisture content and application of the cohesive interface elements. Finally, we compare the numerical predictions with the experimental observations of de-bonding in glued-laminated samples under changing environmental conditions.

Keywords : engineered wood, adhesive, material model, FEM analysis, fracture mechanics, delamination
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