Smart by nature – New perspectives on wood

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Abstract

In timber engineering, material is required simply to be rather than to do. With a different engineering philosophy however, wooden components can be considered as functional: components can be required to do things, to undergo purposeful changes. To be effective, small, well controllable changes in stimulus like moisture should result in significant and reproducible system changes. Hybrid multi-species wood components under climatic changes are studied to demonstrate the potential of such smart systems. With a non-linear material model that comprehends elastic, plastic, hygric, visco-elastic and mechano-sorptive components of the strain tensor [1] of the moisture dependent materials, we find optimal configurations and assess the hygro-fatigue behavior of the bio-activated components.

1 Rheological Models for Wood

When thinking of smart materials, mainly the ingenious of man-designed materials comes to our minds, not even thinking about nature where material functionalization is observed to gain an evolutionary advantage over competitors [2]. For plant tissue, such as wood, the reaction towards moisture is the main driving force that for some species results in excessive deformations and basically changes of all mechanical and hygric properties, in other words strong non-linear sclero- and rheonomous behavior. What sounds like a nightmare for wood engineers and carpenters is the fundament of bio-actuated structures, where pieces of different wood species are combined in various ways to stimulate bending, twisting or other deformations upon alteration of the ambient relative humidity. Systems based on this principle have the potential for a revolution in façade engineering, since they require neither electrical control nor do they add to the carbon footprint of future buildings.

When combining different species with different material orientations like spruce in L- and beech in T-direction by adhesive bonding e.g. with Polyurethane (PUR), the response of shape distortions with respect to moisture changes can be maximized. The response of a wood element is however a combination of the elastic strain increments for the orthotropic body ($E_{L,R,T}$, $G_{LR,LT,RT}$, $\nu_{LR,LT,RT}$), the plastic strain increment that can form for compressive load increments and from moisture increments, as well as the creep and mechano-sorptive strain increments all add up, following the total strain concept. To make matter worse, all material parameters exhibit a pronounced dependence on moisture w. The same is true for the utilized PUR adhesive, with the simplification of isotropy, J2 plasticity with isotropic hardening, linear viscoelasticity and without mechano-sorptivity. Since the moisture field needs to be calculated, also moisture dependent diffusivity constants are utilized for wood and adhesives. A detailed model description of the implementation as a user material in ABAQUS can be found in Ref. [1].

2 Generic Smart Hybrid Wood Structures

Two cases were studied: (1) the free bending of bilayer samples (Figure) and (2) snapping of longitudinally restrained and pre-bent bilayers. Strips of length L=120mm, width b=20mm and various thickness ranging from 0.2-4mm were cut from boards of spruce with the fiber direction parallel to the long sample axis and beech with the fiber direction perpendicular to the long axis of the strips with an inclination of the annual rings of 20-25°. Samples were conditioned at 65% RH / 20°C prior to bonding with the PUR adhesive HB-S309 (Purbond, Germany). During the relative humidity changes the wood moisture content is monitored and deflections are tracked. The response of systems with different layer thickness ratios and pre-bending uh is simulated with respect to environmental changes, including hygro-fatigue.

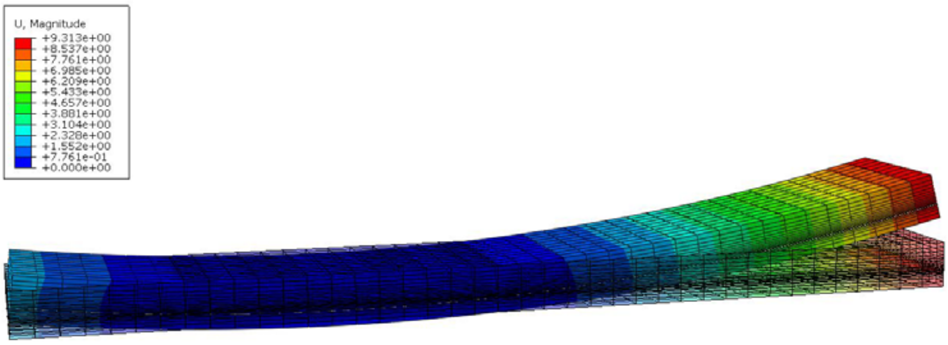

Figure: Deflection of a spruce-beech bi-layer due to moisture changes.

3 Conclusion and Outlook

By calculating the true stress and deformation state, one obtains a history dependent moisture-stress analysis under changing climatic condition. The comparison of the numerical predictions with detailed experiments on bi-layered systems of beech and spruce under changing environment shows good agreement. This is true for free bending, as well as for snapping of pre-curved bi-layers. The simulations exhibit the importance of non-linear simulations, since plastic strains develop mainly in beech wood and mechano-sorptive strains build up over several moisture cycles, altering the performance characteristics with time. We show how wood components can play an active part in the way a smart structure or architecture works without the need for energy consuming active electronic control.

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References

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