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A 3D coupled moisture-stress numerical analysis for timber structures

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ABSTRACT

The mechanical response of wood in presence of moisture changes is a fundamental topic for both the safety and the serviceability of timber structures. It is assumed that stresses in the plane perpendicular to the grain direction govern the strength of glulam beams during changing environmental conditions. Also the strength of timber joints in the cross grain direction is influenced by moisture induced deformations. In general, the combination of moisture history and mechanical loading is important in service conditions. In the last decade, several material models based on experiments in both service and drying conditions under different mechanical loads and humidity distributions were proposed ([1], [2], [3], [4]). However, the material models cited above were formulated for 1D and 2D problems only.

This paper presents a 3D coupled moisture-stress numerical analysis for timber structures based on a constitutive viscoelastic-mechanosorptive creep model composed of five deformation mechanisms: instant elastic response, hygroexpansion, viscoelastic creep, recoverable mechanosorptive creep and irrecoverable mechanosorption (see Figure 1). As proposed in [4], the mathematical model is defined starting from the Helmholtz free energy expressed in function of temperature T, moisture content u, total strain tensor ε, elemental viscoelastic strain tensor ε_i^{ve} and mechanosorptive strain tensor ε_j^{ms}:

$$\psi(T,u,\varepsilon,\varepsilon_i^{ve},\varepsilon_j^{ms}) = \phi(T,u) + \frac{1}{2}\varepsilon^e : \mathbf{C}_0 : \varepsilon^e + \frac{1}{2}\sum_{i=1}^{n}\varepsilon_i^{ve} : \mathbf{C}_i^{ve} : \varepsilon_i^{ve} + \frac{1}{2}\sum_{j=1}^{m}\varepsilon_j^{ms} : \mathbf{C}_j^{ms} : \varepsilon_j^{ms} \quad (1)$$

being $\varepsilon^e = (\varepsilon - \varepsilon^u - \sum_{i=1}^{n}\varepsilon_i^{ve} - \sum_{j=1}^{m}\varepsilon_j^{ms} - \varepsilon^{ms^{(irr)}})$ the elastic strain tensor where ε^u describes the strain due to hygroexpansion (see [4]) and $\varepsilon^{ms^{(irr)}}$ the irrecoverable part of the total mechanosorptive strain defined as in [3] for service temperatures. In expression (1), $\phi(T,u)$ represents the thermal energy while the stiffness tensors $\mathbf{C}_0$, $\mathbf{C}_i^{ve}$ and $\mathbf{C}_j^{ms}$ are, respectively, the elastic, the elemental viscoelastic and the elemental mechanosorptive tensor. The viscoelastic and recoverable mechanosorptive parts of the model are sums of Kelvin type elemental deformations. In particular, the 3D elemental viscoelastic matrices are defined on the basis of the viscoelastic compliance parameters for cross grain wood sections presented in [4] and the experimental results for wood parallel to grain reported in [1]. Instead, the 3D

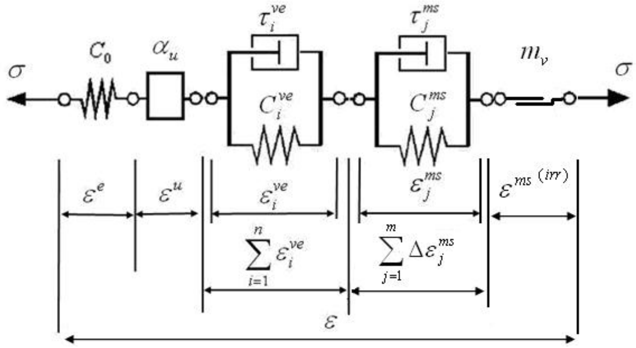

Figure 1: Rheological model. α_u: shrinkage coefficient; τ_i^{ve}, τ_j^{ms}, m_v: material parameters.

mechanosorptive matrices are defined on the basis of the experimental results for wood parallel to grain reported in [1] and the mechanosorptive recoverable and irrecoverable compliance parameters for cross grain wood proposed in [3]. The incremental-iterative algorithm for viscoelastic-mechanosorptive creep, implemented into the user subroutine UMAT of the FEM code Abaqus, is a variant of the one proposed in [5]. The following stress increment at the current time step $k+1$ is obtained:

$$\Delta\boldsymbol{\sigma}_{k+1} = \mathbf{C}_{\mathrm{T}} \left(\Delta\boldsymbol{\varepsilon}_{k+1} - \Delta\boldsymbol{\varepsilon}^{u}_{k+1} - \Delta\boldsymbol{\varepsilon}^{ms(irr)}_{k+1} + \sum_{i=1}^{n} \mathbf{R}_i^{ve}(\boldsymbol{\varepsilon}^{ve}_{i,k}, \boldsymbol{\sigma}_k) + \sum_{j=1}^{m} \mathbf{R}_j^{ms}(\boldsymbol{\varepsilon}^{ms}_{j,k}, \boldsymbol{\sigma}_k) \right) \quad (2)$$

where $\mathbf{C}_{\mathrm{T}} = \left(\mathbf{C}_0^{-1} + \sum_{i=1}^{n} \mathbf{C}_i^{ve^{-1}} + \sum_{j=1}^{m} \mathbf{C}_j^{ms^{-1}} \right)^{-1}$ represents the tangent operator of the whole model while $\mathbf{R}_i^{ve}$ and $\mathbf{R}_j^{ms}$ are functions of stress and elemental strain at the previous step (see [5]). Finally, the equations needed to describe the moisture flow across the structure (see references in [4]), are implemented into the Abaqus user subroutine DFLUX. Then, a coupled moisture-stress gradient analysis is performed under different loads and moisture changes by using the Abaqus Standard program and the analogy with the available thermal-displacement analysis. The proposed approach is validated by analyzing some of the structures described in [2], [3] and [6] and comparing the computational results with the reported experimental data.

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