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▶ To cite this version:

Cédric Montero, Joseph Gril. From wood hygromechanical interactions to timber structure longevity. EUROMECH Colloquium 556, May 2015, Dresden, Germany. hal-01159803

HAL Id: hal-01159803
https://hal.science/hal-01159803

Submitted on 11 Jun 2015

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From wood hygromechanical interactions to timber structure longevity

C. Montero and J. Gril
Laboratory of Mechanics and Civil Engineering
University of Montpellier
860 rue de Saint Priest 34000-Montpellier, France
E-mail: cedric.montero@um2.fr

Architects face nowadays the challenge of raising buildings edifices matching functionality of structural design, sustainable raw materials, thrifty energy consumption and aesthetic integration within surrounding environment influenced by human culture and civil engineering heritage considerations. They often specify wood for various reasons: cost, ecological issues, design versatility, construction facilities, etc. To improve timber structures, material engineers develop innovative wood products allowing to overcome dimensional and mechanical limits imposed by trees with e.g. longer span capabilities, higher dimensional stability, or higher strength to weight ratio.

In all these aspects, the question of life expectancy of wood based materials and timber structures is of major importance for building safety and one of the major obstacle in people's mind for investment. Wood material achievements have to be designed with an expected long term viability that englobes several topics such as detailing construction considerations or even durability issues of termites and fungi resistance as well as aesthetic issues on colour changes in wood due to weathering – but, as a first step, the longevity of wood inherent mechanical performance.

To investigate the longevity of mechanical performance of wood, micro-mechanical considerations on wood microstructure have to be highlighted. Wood is made of a variable multi-scale arrangement of cellulose (highly crystalline polymer) embedded in a matrix of lignin and hemicelluloses (amorphous polymers) [1]. This organization within the cell-wall, in addition to arrangements of fibres and functional tissues at different scales, determines wood/moisture interactions through diffusion processes, time-dependency of mechanical properties, and a coupling between both phenomena.

To quantify the evolution of the deformation of wood according to moisture content variations, we performed bending tests experiments on small spruce samples placed in a controlled hygrothermal environment. The time-dependent compliance was calculated as the ratio of measured strain to imposed flexural stress, and divided by the instantaneous compliance to derive a relative compliance. Its evolution at high moisture content between 1 day and 1 week of loading was linear with respect to the logarithm of time. This observation of such a constitutive law have lead some authors to over-estimate long term behaviour [11-12] and is not consistent with wood material leading to infinite deformation of the material at larger time scales and never observed into heritage timber structures. Therefore a rheological approach can be proposed to provide a better prediction of wood viscoelastic behaviour. During successive moisture cycle we observed a significant change of the viscoelastic kinetics and a relative compliance increment demonstrating the coupling of deformations mechanisms.

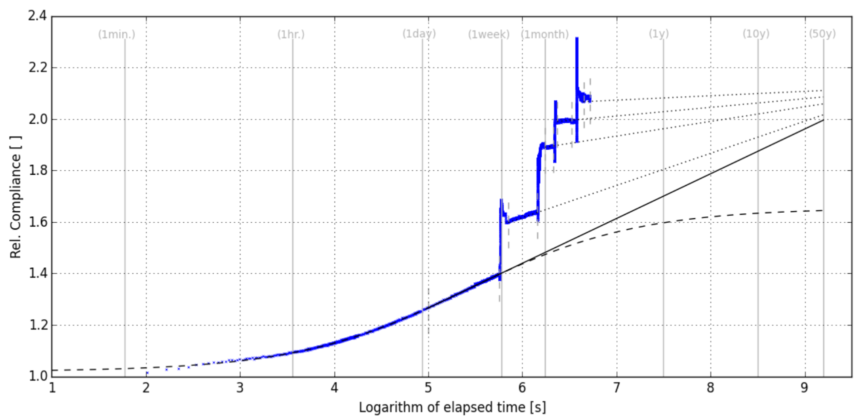

Fig 1. Relative compliance evolution with time along longitudinal direction from 4 point bending experiment on spruce specimens (L = 100 mm x R = 10 mm, T = 2 mm, mean air-dry density 482 kg/m^3). From loading to 1 week at 25°C +/- 0.5°C, viscoelastic creep at approx. 26% moisture content with linear model (–) and sigmoid model extrapolation (- - -) followed by 4 cycles of moisture change (…) down to 12% moisture content.

With such a description the comparison to EN1995 Eurocode 5 (EC5) standard is almost straightforward with a description of Serviceability Limit State based onto a k_{def} deflection coefficient. The relative compliance evolution is comparable to 1+ k_{def} factor. For a solid timber used at constant high moisture content (equivalent to a service class 3) the EC5 standard predicts a relative compliance of 3.0. Based on our results (see fig.1) the evolution toward a relative compliance can be predicted between 1.6 and 2.0 at 50 years based on various rheological hypotheses. The maximum relative compliance observed is set at 2.3.

In massive wood beams the larger dimensions of the element on both section and length induced lower diffusion of moisture within the element compared to our analysis. Moreover our experiment has been performed in extreme high conditions of moisture content compared to classical service class 3 conditions. Those two observations should lead to a lower observation of relative compliance evolution and consequently to a larger difference with prediction.

For a deeper investigation of these phenomena, experimentations are presently being planed to extend to different wood species with sufficient account of wood variability, in order to seek micro-mechanical explanations of these coupled mechanical behaviours. As a perspective of this work experimentations based on in-situ structural health monitoring of wood structures will be performed, combined with numerical approaches to investigate the internal behaviour of a beam.

This presentation will be the opportunity to present an overview on hygromechanical couplings of wood and recent experimental results focused on timber structure applications. Some scientific actions will also be proposed to investigate that field to improve the realization of architectural structure and the preservation of civil engineering heritage buildings.

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