Experimental measure of the memory strain of wood sample during drying

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Key words: mechano-sorption; viscoelasticity; wood drying; stress relaxation; beech; RT plan

Context and objectives

As the industrial drying of wood is a very high consuming stage the integration of renewable energies and heat recovery in the process could reduce its cost and environmental impact. Beside the traditional fuel boilers or nuclear electricity used as heat source, the renewable energy and energy recovery (EnR&R) are intermittent and often at a low exergy. These characteristics could have an important effect on the internal stress and deformation of the drying wood. If the viscoelasticity of the wood may be inhibited by the low temperature, the mechanosorptive creep could be activated by the cyclic variations of moisture content of wood. This mechanism could reduce internal stress, which allows a higher drying rate with no loss of dried product quality. The mechanosortive effect have been observed by Armstrong and Kingston (1960) and further studied until now. A rheological model of this phenomena has been proposed under several forms (Leicester 1971, Ranta-Maunus 1975, Grossman 1976, Hunt 1984, Bazant 1985, Colmar et al. 2014).

Several devices were built to measure the strain and stress of wood samples with moisture variations and under load. They were oriented for structural beams or for thin samples of wood, with load parallel to grain (Hunt 1984, Navi et al. 2002, Randriambololona 2003, Dubois et al. 2005) or perpendicular (Schniewind 1966, Toratti and Svensson 2000) to grain. The drying of originally wet wood under tensile load has been studied in the grain direction (Dubois et al. 2005). In this work, an original apparatus has been designed to evaluate the memory deformation during drying of a hardwood sample with constrained shrinkage in a direction perpendicular to the grain.

Material and methods

Apparatus and operation principle

The first apparatus consists of a two-pronged fork milled in a single aluminium plate with a thin prong that is considered as a cantilever beam, and a parallel thick prong that is seen as infinite rigid body (Fig. 1). A movable blocking member (the B-element in Fig.1) can be attached on the fork device to reduce the length between the fixed end and the free end of the cantilever beam. It thus modifying the stiffness of the beam. To easily analyse the relation between beam's deflection and loading the experiences have been made in the elastic domain. Only small deflections have been occurred, and the beam is considered slender as its length to height ratio is greater than 10; in such case the shear deformations were not taken into account and the mechanical analysis could be simplified. The fork force-displacement calibration curve has been established by measuring the displacement of the fork via a linear variation differential transducer (LVDT, C-element in Fig.1) for several known weights placed at the free end.

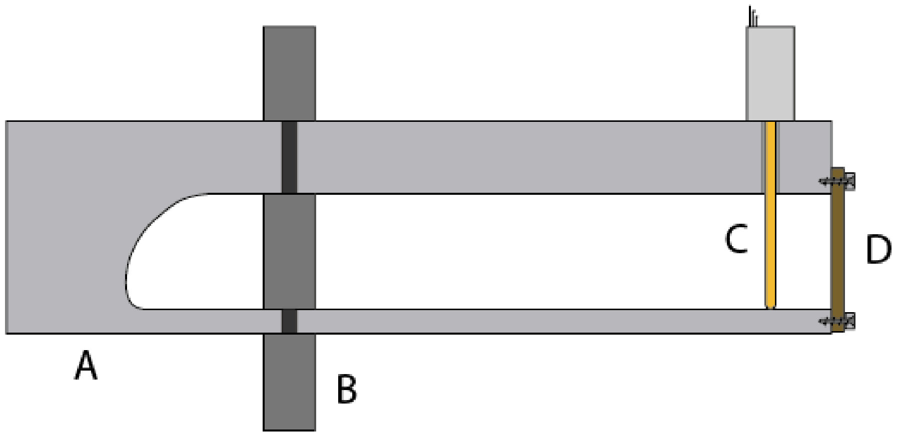

Fig. 1 : Schematic cut of the “Fork” apparatus composed of an aluminum fork (A), a movable blocking member (B), an LVDT (C) and a sample (D) screwed to the free end of the fork.

Clamps were screwed to the end of the beam and to the support to hold a wood sample (the D-element in Fig. 1). A thin rubber pad was placed between the sample and the clamps to maximize contact, even with dimensional variations of the sample. The other side of the sample is in contact with an abrasive sheet glued to the beam or support. No slippage of the sample was observed during the tests in this configuration.

As the moisture content of the wood sample changes, the wood material will shrink or swell, causing displacement of the end of the aluminium beam. The wood sample is then in a constrained shrinkage or swelling configuration. Measurement of beam displacement provides both the strain of the wood sample, and the force applied to the wood sample via the fork force-displacement calibration curve. One LVDT (OP/6/G from Solartron Metrology, UK) was used to measure the fork deformation (C-element in Fig.1).

In parallel with the fork test, another simple device with two additional LVDTs (DFg2.5 and DFg5 from Solartron) measures the swelling/shrinkage of the cross section of a twin wood sample. It allows to measure the section changes of the sample in a free shrinkage or free swelling configuration.

The experiment was placed in a climate chamber that controls humidity and temperature of the surrounding air.

In the tests presented in this work, the sample was placed and clamped on the fork device in the green state. As a result, a constrained shrinkage occurs during drying and the sample is subjected to tensile stress throughout the test. The conditions inside the climatic chamber were measured by an SHT85 (Sensirion, Switzerland). The signals coming from the LVDT was acquired by a Digital Acquisition Centrale 34970A (Keysight Technologies, California). The measurements were recorded in a PC program developed with Labview.

Wood sampling

Three twin samples were cut into a beech log in green state, which never entered the hygroscopic domain. The log was quarter sawn prior to the sample cut. The samples were 75 mm long in the radial direction, 10 mm wide in the tangential direction, and 3 mm thick in the longitudinal direction. Due to of the small length of the sample in the grain direction, it was assumed that there was no moisture gradient within the material. Indeed, the moisture transfer coefficient is much higher compared to that in the cross-grain direction.

The first of them has been reduced from both ends to have a length of 50 mm in the radial direction; it was the sample for free shrinkage and swelling measurement. It had the same length as the distance between the clamps of the fork in idle state. The second sample has been clamped in the fork test. The third sample has been tested on tensile device to determine the module of elasticity in green state. Then it was placed in the same climatic chamber with the other two samples.

Measure of strains

The swelling and shrinking coefficients were assumed to be the same for all twin samples. It was then possible to determine the stress inside the sample in the fork:

$$\sigma(t) = \frac{F(t)}{A(t)} \tag{1}$$

where $F(t)$ is the force applied to the sample at time *t* and $A(t)$ the area of the cross section of the wood sample at the same time *t* (TL plan). The latter is determined using the free shrinkage and swelling test bench, which gives the deformations of the TL plan during the experiment.

The strain in the radial direction to the sample section was considered as follows:

$$\varepsilon_{tot} = \varepsilon_{el} + \varepsilon_{shsw} + \varepsilon_{ms+ve} \tag{2}$$

The strain due to swelling and shrinkage ε_{shsw} was calculated using the following Eq. 3 :

$$\varepsilon_{shsw}(t) = \frac{\Delta l_{shsw}(t)}{l_{shsw,0}} \tag{3}$$

where Δl_{shsw} is the displacement of the twin sample in the radial direction and $l_{shsw,0}$ is the initial length of the twin sample in the radial direction.

The elastic strain ε_{el} is calculated with the one-dimensional form of Hooke's law as follows:

$$\varepsilon_{el}(t) = \frac{\sigma(t)}{E} \tag{4}$$

Where σ was calculated in Eq. 1 and E is the module of elasticity of the sample measured in air dried state, at the end of the experiment, by tensile test.

Since

$$\varepsilon_{tot}(t) = \frac{\Delta l(t)}{l_{tot,0}} \tag{5}$$

where $l_{tot,0}$ is the initial length of the sample between the fork clamps, and Δl the variation of the sample length.

It was then possible to isolate the memory strain ε_{ms+ve}, the strain due to viscoelastic and mechanosorptive behavior of the material from Eq. 2 and Eqs. 3, 4 and 5.

Results and discussion

The conditions applied (Fig. 2) were chosen to maximise the memory strain, in particular the mechanosorptive part due to the low temperature, which cannot activate the viscoelastic behaviour. Some cyclic moisture variations were applied, to obtain a stress relaxation, as well as moisture variations with some moisture content that had never been seen before.

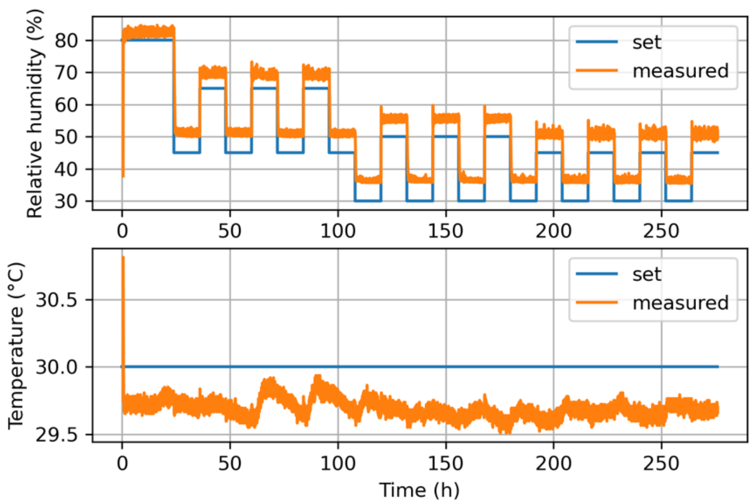

Fig. 2 : Evolution of the boundary conditions in the climate chamber

The different strains obtained are shown in Fig. 3. The shrinkage strain is the major contributor to the total deformation. Shrinkage is constrained by the fork, the total deformation of the sample is then lower, with a small amount of elastic strain and a large amount of memory strain. This strain seems to tend to a limit, that might take into account the mechanosorptive creep limit (Hunt and Shelton 1988). The moisture content step at around 100 hours was supposed to entail an important mechanosorptive deformation because the new MC had never been seen before, as between 0 and 40 hours, which is not the case.

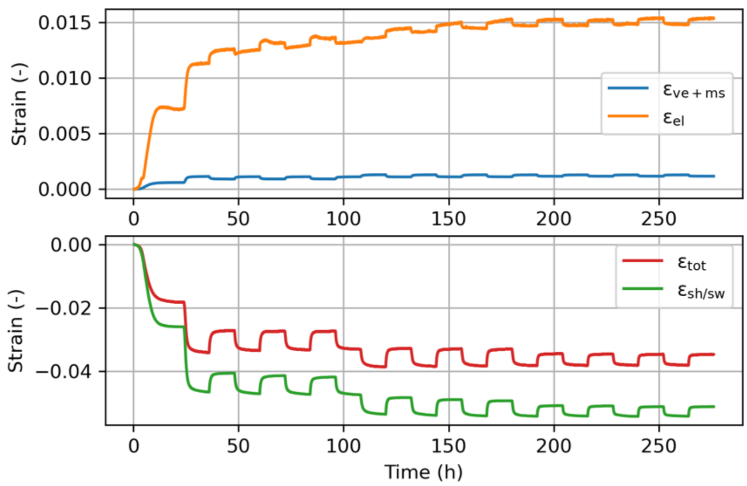

Fig. 3 : Evolution of the different contributions to the total strain measured on the sample placed in the fork device.

The evolution of the stress (Fig. 4) shows a slight relaxation with the cyclic moisture variations. In the hypothesis of a tensile strength of 7 MPa for beech in the radial direction (Ehrhart et al. 2018), the maximum stress applied to the wood sample was less than 40 % of this value, which could suggest that the viscoelasticity had a linear behavior during the test (Mukudai 1983).

Conclusion and perspectives

Using an original apparatus, the viscoelastic and mechanosorptive contribution to the total creep of a wood sample under stress has been successfully isolated. Originally in green state, the wood sample discovered for the first time the hygroscopic domain and moisture contents never seen before; this situation produced slight stress relaxations for each cyclic moisture variation and a more important strain when new moisture contents were encountered. This test should be performed for different hardwood species, load amplitudes and orientations in order to have representative values of the hygroactivated strain that could be compared with a rheological model. The separation of the viscoelastic and mechanosorptive contribution in the memory strain could benefit to the model improvement but requires further investigations as they act together during the test and are both hygroactivated. The work goes further in this direction to adapt a computational model coupled with an optimization code, with the aim of generating drying schedules adapted to intermittent energies.

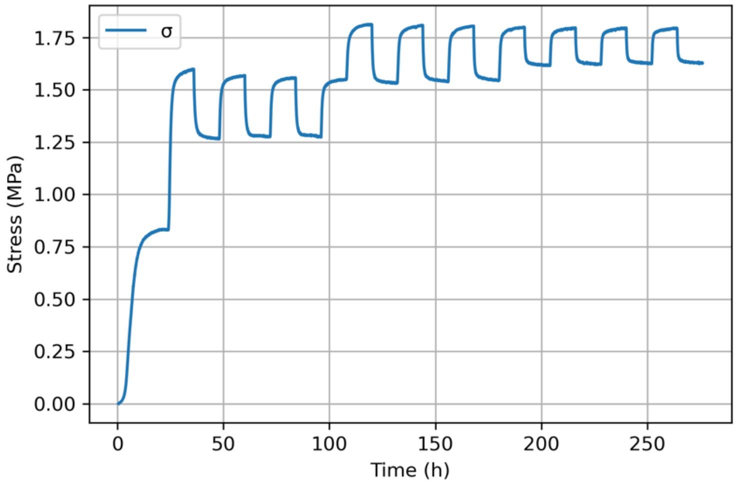

Fig. 4 : Evolution of the stress in the sample placed in the “fork” device.

Acknowledgements

ADEME is a partner of the project and co-finances with FCBA a scholarship for a thesis whose subject is to take advantage of fluctuating energy for the wood drying process by using an intelligent control system.

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