

# Modeling hygrothermal recovery of wood in relation with locked-in strains during tree life

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## Introduction

Heating of green wood involves a complex set of deformation processes, including reversible thermal strain, reversible shrinkage due to decrease of moisture content, and irreversible viscoelastic recovery of growth stress activated by temperature called hygrothermal recovery (HTR) by Yokota (1962). This leads to an irreversible tangential swelling and a radial shrinkage above 70°C (glassy transition of lignins) due to the release of locked-in strains (Kubler 1959, Gril 1993, Salmen 1990). Locked-in strains are first generated in the maturation process and then by the loading history applied to the wood before tree felling. An attempt to model HTR behavior is proposed, based on the hypothesis that rheological conditions during maturation are equivalent to those of hygrothermal treatment.

## Experimental data

RHT experiments were realized by Bardet (2012), in order to measure HTR on a Japanese softwood in directions (R, T, L) and to study the influence of distance from pith (specimen from outer zone, middle zone and inner zone) and of the thermal process.

Specimens were cut from a Japanese Cypress (*Chamaecyparis obtusa*) recently felled, with dimensions 20mm in the observed direction and perpendicular section 4x4 mm<sup>2</sup>. They were kept in water at 3°C before testing. The testing device was a Thermo Mechanical Analyser (TMA) equipped with compression attachment, so that the specimen were submitted to a slight compression stress (equivalent to 5 g) and immersed in water, the system controlling the temperature both during heating and cooling. Variations of dimensions were recorded with an accuracy of 0.01 μm. The specimens were submitted to a thermal process as follows: heating at 3°C/min from room temperature to 85°C, constant temperature during 240 mn cooling at 3°C to 25°C. This process was repeated one or 2 times. A typical curve for a tangential test is given in figure 1.

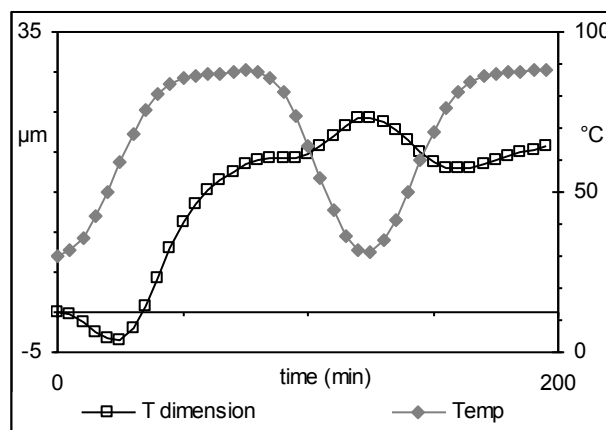


Fig. 1 : Typical hygrothermal recovery curve for tangential test, outer zone (variations of dimensions and temperature against time)

The first heating leads to a large increase of dimension (around 20  $\mu\text{m}$ ) related mainly to hygrothermal recovery of growth strains. The first cooling causes a slight additional increase of dimension explained by an increase of fibre saturation point leading to a swelling (reversible phenomenon). This is made evident by the second heating causing a slight decrease of dimension corresponding to the reverse reversible phenomenon.

A method to separate hygrothermal recovery and reversible deformation is applied by subtracting a curve from one to another. This method can be applied to tangential, radial and longitudinal tests from outer, middle and inner zone.

## Modeling

Locked-in strains are first generated in the maturation process and then by the loading history applied to the wood before tree felling. Wood maturation corresponds to biochemical processes happening after the deposition of secondary layers, such as lignin polymerisation, completion of cellulose crystallisation or cross-linking in the amorphous regions of the cell-wall material. This phenomenon induces maturation strains, which can be simulated by presuming that rheological conditions during maturation are equivalent to those of hygrothermal treatment (Gril and Thibaut 1994). Loading history applied to the wood depends on the action of subsequently formed wood layers, new cells are submitted to longitudinal tension and previous cells to compression. Finally, wood in the tree is pre-strained: near the bark wood is under tension in the longitudinal direction, under compression in the tangential direction and almost stress-free in the radial direction, near the pith wood is under compression in the longitudinal direction and under tension in both tangential and radial direction.

Loading history is simulated using a parabolic model (Bardet 2002) submitted to a succession of steps with different temperature, humidity and mechanical conditions. The first step, maturation, is modeled by an imposed strain (1%), at 80°C for one week. Then tree life is modeled by an imposed stress at 25°C for several years. This leads to spectrum of locked-in strains. These locked-in strains due to maturation and stress history are partially released by cutting specimens from the tree (elastic recovery). Remaining locked-in strains are released by heating the wood in water or steam, this viscoelastic recovery is thermally activated and is related to the experimental HTR.

## References

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