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Dimensional variation of three softwood due to hygroscopic behavior

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HIGHLIGHTS

- Hygroscopic behavior of three softwood species was monitored.
- Equilibrium moisture content was quantified.
- Coefficients of linear shrinkage and expansion, were determined.
- The obtained values allowed to identify differences between the hygroscopic behavior of the softwood species studied.

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ABSTRACT

With the aim of monitor the hygroscopic behavior of three softwood species in situations of changes in its moisture content, an experimental program based on dimensional measurements, hygrometer readings and weightings procedure, was carried out. Maritime Pine (*Pinus pinaster*), Spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*) specimens were evaluated and compared. For each wood species, half of specimens were previously dried while the other half was previously saturated. Three main variables studied during the period of specimen's adjustment to an external environment of 20 °C and 57.5% relative humidity (RH) were: mass, dimensional and moisture content variations. Based on the obtained experimental results, the equilibrium moisture content, as well as coefficients of linear shrinkage and expansion, were determined. Experimental results confirmed that besides RH and temperature, the equilibrium moisture content of wood depends on its moisture history. Moreover, using the obtained values it was possible to identify differences between the hygroscopic behavior of the softwood species studied.

1. Introduction

Wood is a natural and renewable resource, with significant applications in material production, building construction and civil engineering. In use, wood is jointly subjected to mechanical and moisture loads and inappropriate loading of wood can result in mechanical damage and biodegradation.

The amount of moisture, or water, in wood depends on the surrounding climate. After harvesting and in the absence of direct contact with liquid water, the moisture content of wood is controlled by temperature (T) and relative humidity (RH). Wood is constantly gaining and losing moisture from or to the surrounding air until an equilibrium point is reached, called equilibrium moisture content (EMC).

Owing to the cellular structure of wood, water can be held in two ways: (1) free water in the cell cavities, and (2) chemically bounded water in the cell walls. In the drying process of wood after harvest, the removal of free-water occurs first, with no change either in dimension or in physical and mechanical properties of wood. At the state where no free-water is present in the cell cavity and the cell wall is fully saturated with bounded water, the cell is said to be at the fiber-saturation point (FSP). For practical purposes, this level of moisture content is generally considered around 25–30%, but it may be significantly different among wood species [1]. The variation of moisture content below the FSP is accompanied by changes on both physical (dimensional variation) and mechanical properties [2]. During desorption the specimen undergoes shrinkage, whilst during absorption the specimen swells. Macroscopically, this process can be quantified by the volumetric or linear shrinkage coefficient: radial (k_r), tangential (k_t) and longitudinal (k_l). Moreover, the shrinkage process is direction dependent: $k_t \gg k_r \gg k_l$. This anisotropy is the origin for relevant distortions on the shape of wood pieces.

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Furthermore, changes in the moisture content below the FSP also result in variations in the mechanical properties of wood. In practice, a linear relationship between elastic modulus of wood and moisture content can be assumed within a range of 8–20% [3].

Standard methods specify methodologies for measuring shrinkage and swelling [4–8]. These methods use oriented small wood specimens. For measuring volumetric changes generated by moisture content variations below the FSP the immersion method is proposed. On the other hand, radial and tangential shrinkage are determined by measuring changes on dimensions with accuracy not less than 0.02 mm.

Aside recommended standards used for present research, it is important to mention that new image-based measurement methods, such as digital image correlation (DIC) have been developed [9,10]. This recent contact free technique was already used in some published researches for determination of shrinkage coefficients [11,12].

Important research efforts have been made on the use of high temperature in the drying process with the purpose to reduce wood hygroscopicity [13,14]. There are studies regarding prediction models for wood moisture content and density [15], and studies that explore variations of moisture content at different temperatures and relative humidity, in order to understand wood hygroscopic behavior and enable comparisons between different species and also within the same species [16–18].

To understand shrinkage and swelling anisotropic phenomena of wood it is mandatory to determine the equilibrium condition of wood species in different environments. This knowledge is important to predict the performance of wood elements during their life-time. Moreover, data from the equilibrium condition of wood and the magnitude of the shrinkage and swelling coefficients allows taking into account design measures to predict and avoid cracks and induced stresses. The development of cracks reduces the market value of the wood elements and can decrease significantly its performance from a structural point of view, in particular, if located near the joints.

This study is focused on understanding and comparing the relation between dimensional variation and moisture content of three softwoods largely applied in the European construction sector, namely Maritime Pine (*Pinus pinaster*), Spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*).

2. Experimental program

2.1. Specimens and test configuration

Two experimental campaigns were performed in order to monitor shrinkage and swelling behavior of the three softwoods selected. One tested 220 specimens: eighty of Maritime Pine, eighty of Spruce and sixty of Scots Pine. The other one tested a total of sixty wood specimens: twenty specimens of each species.

Specimens have dimensions of $50(R) \times 50(T) \times 10(L)\,mm^3$, in which R, T and L stands for radial, tangential and longitudinal orthotropic directions.

Both experimental campaigns aimed to understand the shrinkage and swelling behavior, under controlled conditions, of Maritime Pine, Spruce and Scots Pine. To analyze the shrinkage behavior specimens were saturated, while to analyze the swelling behavior specimens were oven dried. For both experimental campaigns, before start test program, half of specimens of each species were dried (D) while the other half was saturated (S). Drying process was made using an oven at 103 °C ± 2 °C until obtaining constant mass. Saturation was obtained after submersion of specimens in a water tank, during a period of 2 weeks, ensuring that the specimens had constant mass [5]. Mass was considered constant when the difference between two successive weight measurements, spaced by 2 h, was less than 0.5% [19].

After imposing these two different starting conditions, all specimens were placed in a climatic chamber (FITOCLIMA 28000 EDTU from ARALAB) with constant environmental conditions of 20 °C and 57.5% (RH) until reach stabilization of specimens.

The stabilization process was considered complete when dimensional variation of specimens was less than 0.5% in a period of 12 h. Although the three softwoods studied had different speeds of stabilization, all specimens remained inside the climatic chamber until the three softwoods were considered stable. Dimensional and weight variations were collected during the stabilization processes, respecting pre-defined periods of time, until the equilibrium moisture content was attained.

The measurement system for dimensions was constituted by a metal base that supported a standard-dial gauge (with a precision of 1 μm), in order to ensure the accuracy of measurements. Four metal bases were made; three of them were used to measure continuously one single specimen, one of each wood species, while the other one was used for measuring all remaining specimens. The readings obtained by the three fixed metal bases served to confirm the accuracy of the measurement collected by the fourth, non-fixed, steel base. Fig. 1 shows the setup adopted for the dimensional measurements during the swelling/shrinkage process of the specimens inside the climate chamber. The weights were obtained by a lab balance with an error lower than 5 mg.

In the case of experimental campaign with larger sample, in addiction to weight collection, moisture content readings were also made using a hygrometer (CSA ELECTRONIC – DELTA-8N). The goal was to evaluate the accuracy of the hygrometer readings in comparison with the oven dry method suggested by [19]. However it is important to consider the fact that hygrometer readings are only reliable for moisture contents between 8% and 24% [20], providing large errors in the case of higher moisture content values. In this way, the comparison between these two measuring techniques was limited to moisture content values bellow the FSP.

2.2. Test development

Besides the difference of sampling, two experimental campaigns have two important differences related with test development: the period of stabilization (1) and spacing between readings (2). Campaign with larger sample has a larger stabilization period (96 h) with spacing of 12 h between dimension readings and 24 h for weight and moisture content readings. Smaller campaign submitted dried and saturated specimens to stabilization periods of 29 and 78 h, respectively. Spacing of readings were not equidistant: the first three readings were taken in periods of 2 h, the following three readings in periods of 3 h, then one period of 4 h, two periods of 10 h and to finish a period of 42 h.

The option to perform a campaign with smaller reading intervals during a smaller stabilization period is based on the fact that dimensional and moisture content variations are substantially larger during the first 36 h of test in case of saturated specimens and during the first 12 h in case of dried specimens. Further, smaller periods allowed a better observation of dimensional variation in first hours of stabilization period and allowed determining more accurately the relation between moisture content and linear shrinkage/swelling, in radial and tangential directions.

In addition to these differences, experimental campaign with smaller sample evaluated the consequences of a full humidity cycle on the swelling capacity of wood through the comparison between only dried [OD] specimens and specimens dried after a saturation process [SD]. For that, after the stabilization process of the saturated specimens, the same specimens were dried and submitted to another stabilization process, as suggested in [4,5].

3. Results and discussion

3.1. Larger experimental campaign

Fig. 2 presents graphically the evolution of average values of linear shrinkage (β) and swelling (α) of saturated and dried specimens in radial and tangential directions (β_r, α_r, β_t and α_t, respectively). Linear shrinkage and swelling values were calculated based on formulas (1) and (2) suggested in [4,5].

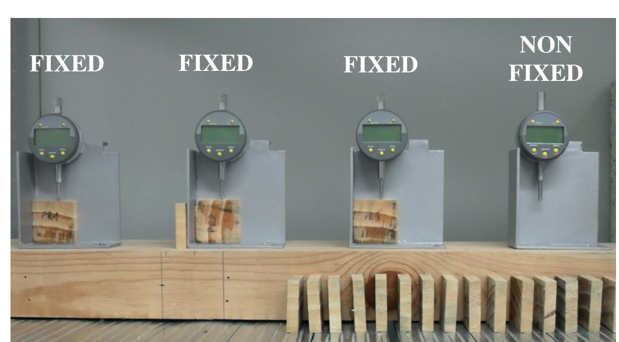

Fig. 1. Measurement tests: (a) specimen geometry; and (b) fixed and non-fixed measurement systems.