

SHRINKAGE AND SWELLING OF SPECIMENS WITH DECREASING DIMENSIONS

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ABSTRACT

As the water content changes, the wood cells shrink or swell. These are some of the processes characterizing the variability of wood. They greatly complicate processing and limit the application of wood materials. These properties depend on many factors, one of which is the scale (dimensions) of the wooden samples. Many observations show that the shrinkage and swelling processes proceed differently when the wooden samples is a few millimeters or a few centimeters. There is an even greater difference in the behavior of earlywood and latewood when they are examined separately.

The article study the processes of shrinkage and swelling during repeated wetting and drying. Samples with a constantly decreasing cross-section were investigated.

Key words: wood, shrinkage, swelling, Douglas fir.

INTRODUCTION

Wood variability is characterized by a change in size, volume, shape and properties due to changes in the water content of the wood. This can happen quickly if we immerse the wood in water or significantly slower if we leave it in air with different atmospheric humidity. Dimensional change of test specimens is measured directly. The processes are reciprocal and are called shrinkage and swelling. One of the factors influencing these processes is scale (Enchev 1984; Bluskova 2009).

It turns out that wood reacts differently when the test bodies are several centimeters in size (macroscopic level) or only a few millimeters (mesoscopic level). If we continue to reduce the dimensions of the investigated surface – for example to micrometers – we will get the next level of influence (microscopic). The anisotropy at this level is thought to be influenced by the wood rays. Anisotropy is also influenced by the difference between the microfibril structure and the chemical composition of the radial and tangential cell walls (Barbetta et al. 2018).

The swelling-to- shrinkage ratio (Sw/Shr) also changes with changing specimen sizes (Lee and Jeong 2018). It is believed that it can fully explain the differences in external and internal shrinkage and swelling of the cell. The mechanism of swelling and desiccation of the individual cell – how much of its wall changes its size outwards and how much inwards – is not yet understood. It is possible that it is the ratio (Sw/Shr) that allows the clarification of this question at the macroscopic level (Nakano 2018).

The variation of shrinkage or swelling at different hierarchical levels (tissue, cell, and cell wall) indicates that the hygroscopic middle lamella plays a role in tissue-level deformation.

Higher microfibril angles and cell wall voids in pressurewood correlate with a lower drying/swelling ratio (Zhan et al. 2021).

Due to the inability of the large specimens to become fully wetted (even when vacuum-treated for weeks), the swelling of the specimens was significantly lower than that of the smaller specimens when the equilibrium water content was reached across the entire cross-section of the specimen. As a result of the formation of a moisture profile in the cross-section of the wood during drying, internal stresses arise. They are very large and when they exceed the strength properties of the wood, cracks appear across the fibers (Niemz 2006).

At harvest, the wood has a water content above the fibre saturation point limit of the cell walls. For its performance as a material, it is necessary to reach an optimal water content for its purpose. Reducing the drying time is a major concern in the drying process and can be achieved by increasing the ambient air temperature or by reducing the thickness of the material. The thickness of the dried test specimens is a significant factor in the wood drying process, and unlike increasing the temperature, decreasing the thickness also favorably affects the quality of the dried material (Klement and Hurakova 2016).

It was found that as the width of the annual rings decreases, the tangential and radial shrinkage increases (Wang et al. 2008). The structure of the ring itself, i.e. alternation of early and late wood also has an effect (Murata and Masuda 2006). The structure of the annual rings also determines the uneven drying and swelling in the radial and tangential directions.

These changes can be detected by measuring the roughness of the wood. The large increase in the roughness of the conditional radial and tangential planes is due to the greater swelling of the tissue zones dominated by fibers compared to the zones dominated by axial parenchyma, ray parenchyma and vessels. For thinner rehydrated samples, the surface roughness is lower than for thicker samples (Dunisch 2013).

Wood can be considered as a complex system that exhibits one or other characteristics precisely at the different hierarchical levels of the scale. It is possible that this complex system has the ability to regulate hygroscopic deformations by fine-tuning its hierarchical structures (Zhan et al. 2021).

The purpose of this paper is to study the influence of scale on the characteristics of the shrinkage and swelling processes, both as maximum values and as a relationship between them – the anisotropy and the Sw/Shr ratio. In addition, here the wood goes through different wetting and drying cycles, which will probably also contribute to differences in the values of the investigated processes.

METHODS AND MATERIALS

The study tree was harvested near the base of the university, at an altitude of 520 meters (Bulgaria, Barzia land, Berkovitsa municipality), subdivision 48 m. The forest is of the type closed-canopy-stand, its forest management class being Spruce B. It is a coniferous stand with forest management class „special“(according to Natura-2000, protected zones and habitats for birds).

The soil is brown forest saturated, clay sand, rocky, loose, non-erosive, medium rich on gneiss. The habitat type is C-2 (M-II-1) (30) I-st site quality. The present species composition is with 6 douglas firs, 4 hornbeams and individual beeches as well as aspens and sycamore maples.

The DBH of the third stem had a diameter of 28 cm (east – west 11-10 cm diameter respectively – north-south 19-12 cm). The tree was at the age of 53.

Douglas fir wood (*Pseudotsuga menziesii* Franco) was chosen to study the processes of shrinkage and swelling of wood. However, the selection and preparation of test specimens is not up to standard. The specimens bodies are selected so that the main characteristic that is indicative is the structure of the annual rings. The determination of the water content was carried out according to БДС ISO 13061-1:2019. The determination of shrinkage, swelling became according to the standard. The determination of wood density was made according to the stereometric method according to БДС ISO 13061-2:2019.

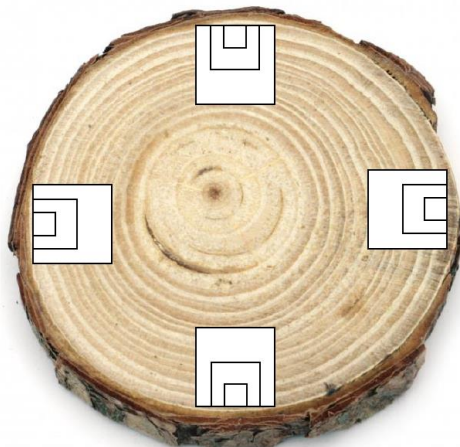


Figure 1: Placement and dimensions of test bodies (from 50×05×50 mm to 5×5×50 mm).

Four samples of 20 specimens with dimensions of 50×50×50 mm (radial×tangential×longitudinal of the fibers) were selected. Individual samples are oriented according to the directions of the world (Figure 1). When wet, each sample is placed in a separate bag with an attached weight. The bags have perforated walls for complete wetting of the wood.

A desiccator was used for soaking. It is equipped with a “Venturi tube” and works as a vacuum pump with -1 atm. The mode in which the desiccator works is 60 minutes under vacuum, then 15 minutes under normal pressure. It takes about two weeks to reach the maximum soaked state. About 10 days are needed for the complete drying of the test bodies to an absolutely dry state.

The wood was dried gradually at a temperature of about 60°C so that cracks do not occur in the test bodies. After that, it is heated only to about 80°C so that chemical transformations do not occur in it. To ensure compliance with the standard for the constant mass of the wood, the heating reaches 100°C, but only for 4 hours. This is how the first desorption is achieved.

After that, the mass and dimensions of the test bodies were determined in an absolutely dry state. The test bodies thus measured are placed in the desiccator, also being soaked to a constant mass (but this time maximum). This is how the first sorption is achieved. Mass and dimensions are determined again, in a maximally inflated state. From them, the density (initial, absolutely dry and maximum density) is calculated.

The water content (equilibrium and maximum humidity) was also calculated. The first swelling is also calculated. Anisotropy and swelling/shrinkage ratio (S_w/S_{hr}) were determined. These dryings are repeated three more times, the wood being soaked two more times. Between each cycle, an equal amount of wood from the radial and tangential directions was split from the specimens.

As a corrective, the values of the density of the wood (respectively in an absolutely dry state and the maximum density) were obtained. The accuracy of dimension measurement is 0.01 mm, and for mass – 0.01 g. The different samples are defined depending on:

- the type of wood (location relative to the directions of the world);
- type of treatment („wetting – drying” cycle).

RESULTS AND DISCUSSION

DOUGLAS FIR WOOD DENSITY VALUES

The average value for the standard density of Douglas fir in our country is 550 kg.m^{-3} (Bardarov 2021). Due to the nature of the present work, the standard density was not determined, but that in an absolutely dry state and that at maximum humidity. The published average value for the density in an absolutely dry state is 470 kg.m^{-3} (Blaskova 2009, Wagenführ 1996).

The work also determined the values of the density in the raw state – 733 kg.m^{-3} (at moisture in the raw state, average (heartwood / sapwood) $w_{\text{raw}}=71\%$). The resulting density in an absolutely dry state is on average 532 kg.m^{-3} , and the maximum density is 907 kg.m^{-3} (at a maximum humidity of $w_{\text{max}}=91\%$).

In the study of wood density, a slight and gradual decrease in values was observed in each individual cycle (Fig. 2). This is normal with so many drying and wetting cycles due to the solubility of the extractives in the wood. Another explanation can be found in the constantly decreasing cross-section and hence the greater role of early wood.

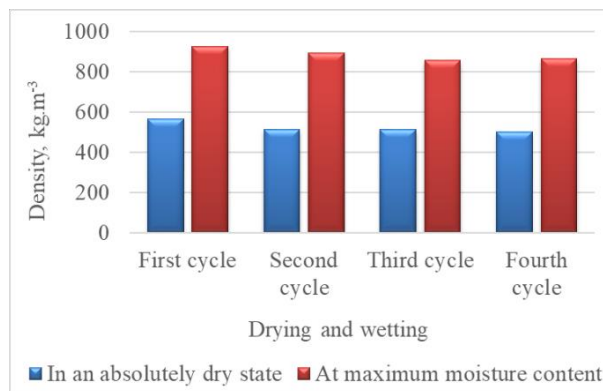


Figure 2: Douglas fir wood Density.

Due to the presence of compressed wood, the obtained density in an absolutely dry state is significantly higher than that reported in the literature, while the maximum density is within the specified limits. There is no definite dependence in the distribution of wood density in geographical directions, and the obtained values are different than expected.

SHRINKAGE AND SWELLING OF THE WOOD

The average values of shrinkage and swelling in the radial direction were 4.5% and 5.0%, respectively (Figure 3). They are close to the stated values for Douglas fir in Europe – 4.0-4.8% (Blaskova 2009, Wagenführ 1996). It can be seen from the figure that with each subsequent cycle of wetting and drying, the values gradually decrease. Each cycle corresponds to the reduction of the dimensions of the test samples.

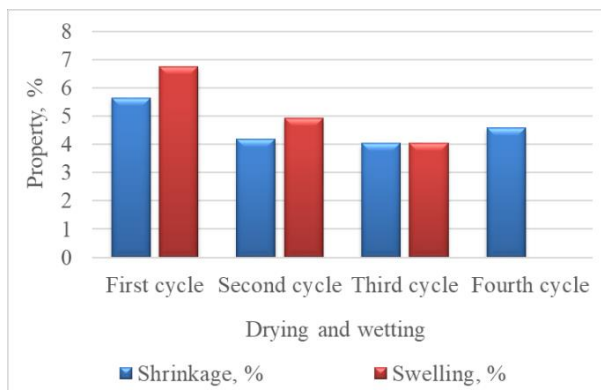


Figure 3: Shrinkage and swelling in a radial direction depending on the treatment cycle.

This may be an indication of the relationship between density (which also decreased gradually) and the studied properties. The reduction in swelling with each subsequent cycle means that the extractive substances in the wood also affect the swelling process. The reduction in swelling with each subsequent cycle means that as the extractive substances are released, the wood becomes increasingly hydrophobic. It is possible that these cycles may have changed the crystalline structure of cellulose.

The average values of shrinkage and swelling in the tangential direction were 6.4% and 6.6%, respectively (Figure 4). They are lower than the stated values for Douglas fir in Europe – 7.0-7.7% (Blaskova 2009, Wagenführ 1996). Unlike swelling and shrinkage in the radial direction, here there is a fluctuating change in values. At first we see a decrease, but subsequently the values increase again.

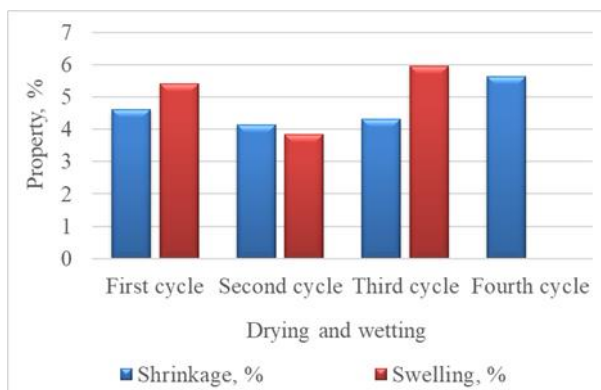


Figure 4: Shrinkage and swelling in a tangential direction depending on the treatment cycle.

Similar to the shrinkage and swelling in the tangential direction, the volumetric shrinkage is distributed in the same way with decreasing dimensions of the test specimens (Fig. 5). Since the role of swelling and shrinkage in the tangential direction in determining the stripped one is twice as great, the obtained values of these properties are similar. However, no trend was observed in the distribution of values with decreasing cross-section of the specimens.

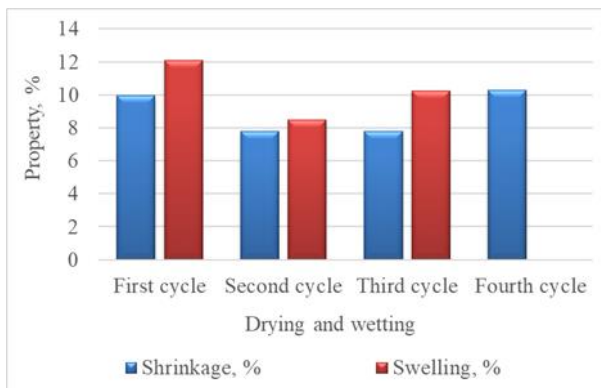


Figure 5: Voluminous shrinkage and swelling depending on the treatment cycle.

A slight increase is observed in the anisotropy values (β_t/β_r and α_t/α_r) (Fig. 6). This shows that the anisotropy of shrinkage and swelling is expressed more and more strongly as the cross-section of the specimens decreases.

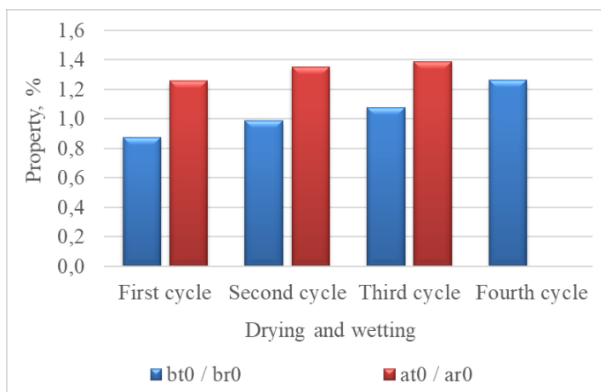


Figure 6: Anisotropy of shrinkage and swelling depending on the treatment cycle.

The role of the wood rays or the differences between the radial and tangential wall structure is more pronounced at a small cross-section.

CONCLUSIONS

- The values obtained for the maximum water content were only used as a correction, but they also did not show any trend, both after treatment cycles and geographically.

- Average values of shrinkage and swelling in the radial direction are close to the values indicated for Douglas fir in Europe and with each subsequent wetting and drying cycle the values gradually decrease
- The average values of shrinkage and swelling in the tangential direction are lower than the indicated values for Douglas fir in Europe and with each subsequent wetting and drying cycle the values of these processes also decrease.
- In volumetric shrinkage and swelling, the distribution of values according to treatment cycles and geographical directions follows the trends of those in radial and tangential directions. The likely explanation is that solar heating plays a role in this distribution.
- Anisotropy values (β_v/β_r and α_t/α_r) showed a slight increase after each treatment cycle. This shows that the anisotropy is expressed more and more strongly with a decrease in the cross-section of the test bodies.
- There is no definite trend in the values of the „swelling – shrinkage” ratio.

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