# FACTORS INFLUENCING OF SHRINKAGE PROCESSES IN WOOD – AN OVERVIEW

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**Abstract**

Shrinkage is the process of reducing wood size when its moisture content falls below the saturation point (FSP) of the cell walls. Depending on the state of the cell walls, which retain moisture and change their size, serious changes in the size and volume of the elements of its internal structure are observed. These changes are due to the fact that wood is made up of polymers that contain hydroxyl groups. Although this process is identical for every wood species, the mechanisms and the values of the main parameters that describe it are different. Differences are observed in the individual tree species and in the different types of wood as well as in the different location in the stem, etc. But they are most significant in the different directions of the internal spatial structure of the stem – radial, tangential and longitudinal. This process depends on various factors, and for some of them, their significance has been emphatically established by numerous observations, while for others it has yet to be determined to what extent and how they affect the wood shrinkage. The article examines studies on shrinkage of different wood species and at different levels of wood construction.

**Keywords:** wood, shrinkage, macroscopic structure, microscopic structure, chemical composition, anisotropy.

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## Macroscopic structure

As a physical body, wood is composed of cell walls, cell cavities and intercellular spaces. For different types of cells these characteristics are different. They differ even within an annual ring [3, 7]. Wood is a natural polymer made up of cellulose, hemicelluloses and lignin. They contain hydroxyl groups which attract water [14]. The amount and structure of these chemical compounds are not the same in different parts of the cell wall and in the intercellular space.

It is accepted that two types of water content are observed in the cells of freshly cut wood: free water (w>30%), which is found in the cell cavities, and bound water (w=0–30%), which is found in the cell walls [3, 7]. In addition, dry wood is highly hygroscopic and has the ability to absorb moisture from the environment and the wet wood releases moisture. During these processes the dimension and mass of the workpieces change and hence their properties.

Wood dries variously in various directions of the tree. The change in dimensions is the smallest in the longitudinal direction – on average 0.4% (0.1–0.6%), much larger in the radial direction – 4.3% (2.3–6.8%) and even greater in the tangential direction – 8.2% (6.0–11.8%). As a result volume shrinkage varies around 12.9% (8.5–18.8%) [17].

In addition to the determination of the absolute values of shrinkage for practical purposes a coefficient of shrinkage is also calculated. It shows by what percentage the size of the wood will decrease in the respective direction if the water content decreases by 1%. These physical parameters have been studied in detail and used to compare the wood of different tree species [18].

Study on shrinkage processes has been going on for a long time and the reasons for these processes are very diverse. Some authors try to explain the magnitude and anisotropy of shrinkage with the structure of annual rings. It was determined that as the width of annual rings decreases, tangential and radial shrinkage increases [19]. The structure of the ring itself, i.e. alternation of early and late wood also effect it [11].

The type of wood (juvenile, mature or peripheral) also has a significant influence on shrinkage processes. Large differences were observed in the values of juvenile, mature and peripheral wood [19]. The authors found that the longitudinal shrinkage ranged from 0.02% to 2.34%, with maximum values near the core and decreasing towards the bark. Furthermore with tree aging and the transition from juvenile to mature wood, the bulk density of Scots pine wood increases and wood shrinkage decreases [16].

Regardless of whether it is mature or peripheral wood, the difference between heartwood and sapwood also affects shrinkage values. Total and partial transverse shrinkage were significantly greater in the sapwood than in the pith [9].

## The position of the wood in the stem

Tangential shrinkage and the anisotropic ratio between radial and tangential size variations increase from the tip to the base of the stems [5].

Radial position and height significantly affect all physical properties of wood. Wood density and dryness within the tree varied at each height level decreasing along the stem from the base upwards. At the same height, wood density and radial shrinkage increase from the core outwards [10]. Longitudinal shrinkage also showed a decreasing trend with stem height [16].

**Wood processing**

Shrinkage as a process is affected by the internal stresses. These stresses are significantly influenced by the type of wood drying. There is a great difference in shrinkage values between atmospheric and kiln dried wood samples. Shrinkage values of kiln dried wood are almost twice as large [5].

To determine the stresses during drying the test pieces located in different positions from the core to the bark were examined. It was investigated how these stresses would change under two different shrinkage regimes. It was found that in both drying modes, the wood samples (in the form of washers) were initially subjected to tangential tensile stress and as the moisture content decreased, the tensile stress turned into compressive stress [8].

During shrinkage in addition to the size and shape, the wood also changes its surface roughness. The large increase in roughness in radial and tangential planes is due to the greater swelling of tissue areas dominated by fibers compared to areas dominated by axial or radial parenchyma or vessels [6].

**Microscopic structure**

The wood of the main construction groups is very different in its structure [1]. The structure of softwoods is very different from that of ring-porous species, which in turn are different from diffuseporous and exotic ones. The microstructure, i.e. the arrangement of the individual cells determines both the magnitude and the anisotropy of shrinkage. Wood rays also play a role in reducing shrinkage in the radial direction [3, 7].

The cell behaviour at the microscopic level is also strongly influenced by their arrangement and in particular by the alternation of early and late wood [11, 15]. Representative patterns reveal that in earlywood tracheids show anisotropic shrinkage, but in the latewood tracheids they show nearly isotropic shrinkage. Anisotropy in this process depends significantly on the mechanical interaction between early and late wood [15].

The magnitude of the shrinkage values in early and late wood may be different but also interchangeable. In studies conducted on radiant pine (Pinus radiata) some specimens showed stronger shrinkage in the early wood while others in the late wood. In the former micro cracks also appear in the early wood [21].

**Submicroscopic (nano-) structure**

In similar studies conducted in Japan, a unique dynamic of the swelling process was observed.

Wood cells were found to swell both outward and inward toward the cell cavity with no fundamental difference between coniferous, broadleaf, and exotic tree species [12]. Similar behaviour was observed for different wetting dynamics. The swelling of the wood during its rapid and slow wetting was investigated. In one process, the wood cells swell inwards while in the other they do not [11].

In studies conducted on the dynamics of the shrinkage the ultrastructure of the wood is assumed to be the main factor influencing the shrinkage of eucalyptus wood, in particular the angle of the microfibrils, the thickness of the cell wall and the walliness of the fibers. Observations have shown that the proportion of ray parenchyma has a major influence on residual collapse [20].

**Chemical composition**

It is known that the content of the extractives affects both the moisture content of the wood at the saturation point of the cell walls [3, 7]. Since the shrinkage processes are related to the amount of bound water in the wood it is reasonable to expect that extractives will also affect the magnitude of the shrinkage.

Their removal with hot water, alcohol and organic solvents cause greater shrinkage [4]. In similar studies, a clear linear relationship between lignin content and wood shrinkage has been established. As the lignin content increased from 14 to 26%, the tangential shrinkage decreased from 12 to 4% [22].

According to many authors swelling is the most strongly influenced by hemicelluloses. They contain the largest number of active sorption sites in their macromolecules. Thus they make the largest contribution to wood dimensions in the hygroscopic range. Furthermore, it is suggested that the ultrastructural organization of hemicelluloses reveals different features in radial and tangential cell walls [14].

**Influence of the scale of the test samples**

Major factor affecting shrinkage processes is the scale. The choice of the dimensions of the test bodies is important. It has been observed that the relationship between shrinkage or swelling and change in humidity is affected by the dimensions of the specimens used to measure them. Large specimens do not give reliable results due to the lack of uniformity in the moisture distribution.

Thus internal stresses are produced which affect the dimensional change and this may be the reason why in certain cases shrinkage and swelling is observed after the saturation point of the cell walls. For this reason, the measurement of shrinkage and swelling should be performed with small test pieces to make the results comparable [3, 7].

## Relationship between shrinkage, swelling and other properties of wood

It is believed that at higher density the swelling and shrinkage processes are of higher values because of the higher amount of wood matter. It can retain a greater amount of water in the cell walls [3, 7]. As for the shrinkage, however, there is no definite data on such a dependence. In the study of the shrinkage, it was found that increasing the conditional density from 300 to 450 kg.m$^{-3}$ the coefficient of anisotropy slightly decreases [5]. However, the authors believe that the conditional density is insufficient to provide an accurate prediction of the shrinkage process as well as its anisotropy.

As one of the undesirable processes of shrinkage is considered to be the collapse of the wood. This is the shrinkage at moisture content above the saturation point of the cell walls. It has been the subject of various studies. It was found that as wood density increased, collapse decreased in both tangential and radial directions [20]. It is possible that the relationship between collapse and diffusion coefficient is a combination of two different mechanisms.

Firstly, the extractive content may affect the distribution of wood swelling in different parts of the trunk. Secondly, the collapse may create additional stresses during shrinkage [2]. Although it depends on the physiology of the tree, the moisture content in the raw state is inversely proportional to the bulk density [13].

In order to better clarify the influence of the tree species on the process of shrinkage, a statistical analysis of 160 broad-leaved tree species was carried out. The data about them were taken from Rudi Wagenfuhr's Holzatlas. The advantage of that was that all tree species were tested under the same conditions. Both the chemical composition and the anatomical characteristics of each examined species were determined.

The physico-mechanical properties were determined and in particular those related to water. The same study conditions allowed to make a correlational analysis. Its purpose was to determine the degree of dependence of the chemical composition and anatomical elements on shrinkage indicators. We wanted to confirm or deny the statements that had been made before. The main emphasis was on shrinkage anisotropy.

When examining the chemical composition of the specified species, not many dependencies were found. As the amount of lignin increased, the amount of pentosans decreased ($R=-0.46$). No relationship was found between pentosans and the amount of cellulose. No correlation was found between the density and the chemical composition of the wood. Dependencies were established between shrinkage on the one hand and density and porosity on the other hand.

The values were close but with the opposite sign. No correlation was found between the anisotropy coefficient and the wood density. There is a straight line relationship between shrinkage in the radial and tangential directions. It was also confirmed in earlier studies [5].

Examining the anatomical structure, a relationship was established among the density of the wood, the wall thickness and the dimensions of the fibers, and here the relationships were close in value, but with the opposite sign. No correlation was found between shrinkage values and anatomical parameters. No correlation was found between the anisotropy coefficient and those indicators.

## Conclusions

Shrinkage processes have long been studied because of their practical importance. The studied articles revealed that the exploration of the process had started long before 50 years ago. Many of them could be grouped according to the levels of the desiccation scale. There is no consensus why different wood species have such different values, given that the shrinkage mechanism is identical for each wood.

It has not been clearified yet what causes the anisotropy, collapse, etc. The dynamics of the process and the magnitude of its values at different moisture contents have been established. New methodologies have been developed to study the influence of scale on shrinkage processes. In recent years, attention has been focused on the influence of submicroscopic structure on shrinkage anisotropy. Although all these studies are very theoretical they have significant practical implications for the woodworking and furniture industries.

### References


1. Bardarov, N. *A guide to the identification of tree species by the anatomical features of wood*. Publishing house at LTU, Sofia. 2014.
2. Blakemore, P., Langrish, T. Effect of collapse on fitted diffusion coefficients for Victorian ash eucalypts. *Wood Sci Technol*. 42. 2008. 535–549.
3. Bluskova, G. *Wood science*. Textbook. University of Forestry Publishing House. Sofia. 2009.
4. Choong, E., Achmadi, S. Effect of extractives on moisture sorption and shrinkage in tropical woods. *Wood and Fiber Science*. 23(2). 1989. 185–196.
5. Dumail, I., Castera, P. Transverse shrinkage in maritime pine juvenile wood. *Wood Science and Technology*. 31. 1997. 251–264.
6. Dunisch, O. Relationship between the anatomical structure and the swelling of conditioned wood surfaces. *IAWA Journal*. 34 (2). 2013. 197–208.
7. Enchev, E. *Wood science*. Textbook. Publishing house of Zemizdat. Sofia. 1984.

8. Fu, Z., Zhao, J., Huan, S., Sun, X., Cai Y. The variation of tangential rheological properties caused by shrinkage anisotropy and moisture content gradient in white birch disks. *Holzforschung*. 69(5). 2015. 573–579.
9. Hai, P., Jansson, G., Hannrup, B., Harwood, C., Thinh, H. Use of wood shrinkage characteristics in breeding of fast-grown Acacia auriculiformis A. Cunn. ex Benth in Vietnam. Ann. For. Sci. 66. 2009. 611.
10. Behzad, K., Kialashaki, A., Kord, B. The within-tree variation in wood density and shrinkage, and their relationship in Populus euramericana. *Turk J Agric For*. 34. 2010. 121–126.
11. Murata, K., Masuda, M. Microscopic observation of transverse swelling of latewood tracheid: effect of macroscopic/mesoscopic structure. *J Wood Sci*. 52. 2006. 283–289
12. Nakanoq T. Analysis of cell wall swelling on the basis of a cylindrical model. *Holzforschung*. 62. 2008. 352–356.
13. Ofori, J., Brentuo, B. Green moisture content, basic density, and shrinkage characteristics of the wood of Alstonia boonei, Antrocaryon micraster, Bombax buonopozense, Dialium aubrevillei and Sterculia rhinopetala. *Ghana J. Forestry*. 26. 2010. 41–49.
14. Olek, W., Kifetew, G., Bonarskitt, J., Marklund, E. *Effects of cell wall ultrastructure on the transverse anisotropy of wood shrinkage*. COST FP0802: „Micro Characterisation of Wood Material & Properties”. 2015.
15. Rafsanjani, A., Deromeb, D., Carmeliet, J. Poromechanical modeling of moisture induced swelling anisotropy in cellular tissues of softwoods. *RSC Adv*. 5. 2015. 3560–3566.
16. Riekkinen, M., Lukkarinen, A., Kama, J., Verkasalo, E. *Maturity effect on basic density, shrinkage, and shrinkage anisotropy of scots pine wood*. 2005.
17. Tsoumis, G. *Science and Technology of Wood. Structure, Properties, Utilization*. Van Nostrand Reinhold, New York. 1991.
18. Wagenführ, R. Scheiber, C. *Holzatlas*. VEB Berlin: Springer-Verlag. 1996.
19. Wang, E., Chen, T., Pang, S., Karalus, A. *Variation in anisotropic shrinkage of plantation- grown pinus radiata wood*. 2008.
20. Wu, Y.-Q., Hayashi, K., Liu, Y., Cai, Y., Sugimori, M. Relationships of anatomical characteristics versus shrinkage and collapse properties in plantationgrown eucalypt wood from China. *J Wood Sci*. 52. 2006. 187–194.
21. Pang, S., Orchard, R., Mc Conchie, D. Tangential shrinkage of pinus radiata earlywood and latewood, and its implication for within-ring internal checking. *New Zealand Journal of Forestry Science*. 29(3). 1999. 484–491.
22. Barcenas-Pazos, G., Velazquez-Morales, P., Davalos-Sotelo, R. Effect of Lignin Content on Shrinkage of Four Mexican Woods. *Holzforschung*. 54. 2000. 541–543. DOI https://doi.org/10.1515/HF.2000.091