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SOME MECHANICAL PROPERTIES OF DOUGLAS-FIR WOOD FROM BULGARIA

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ABSTRACT

The Douglas-fir is a perspective species for Europe, introduced in Bulgaria long ago. During this time many studies have been made on the growth and productivity of forests of this tree species. Mechanical properties are an important part in the design of timber structures and the calculation of processing regimes. The values given for the properties depend on the altitude and the location of the wood under study in the stem.

The subject of the research in this study is the Douglas fir wood and the determination of some mechanical properties of the wood, which has been done for the first time in our country. Standard methods and test bodies were used to establish the mechanical properties in this study.

Key words: Douglas fir, wood density, bending strength, compressive strength, hardness.

INTRODUCTION

Douglas-fir is native of the western coastal regions of North America. It is native only in the following states: California, Oregon and Washington. In Bulgaria, it has been found in a fossil state in the Pliocene sediments. In our country, it is widely distributed in gardens and parks as an ornamental tree. In Bulgaria, it was introduced for the first time to the parks near Sofia in 1891. The first forest plantation was created in Kazanlashko in 1906. In the spring of 1990, a forest plantation was created in Petrokhan. (Петкова 2022). Apart from it, it is found in 80 forest plantations in different parts of the country, along with larch and Weymouth pine. In order to study growth dynamics, spruce and Scots pine were planted in the forest plantation for comparison. These trees are already large in size (such as diameter) and options to use their wood are being discussed now. Knowing the properties would help in a more rational application of this wood. The study of the quality of the wood should be done in the forest, on

freshly harvested logs. The quality of standing trees in most countries is a problem halfway between wood harvesting and wood processing technology. Knowing the quality of timber produced in natural forests allows for their rational management. Quality control at various stages of the manufacturing process has always been important to the industry. For better processing of standing trees, several classification rules have been applied (Ajdinaj et al. 2021). After harvesting the wood, it is important to monitor the water content of the logs before cutting them. There is a correlation between the peaks of crack opening curves and the peaks of water content (Nziengui et al. 2017). The water content, especially its variation, also affects the operational characteristics of wooden structures. The authors found that there is also a strong relationship between the reduction in life of a timber structure subjected to constant loading and variations in water content.

Douglas fir is one of the most studied tree species. This is so not only because of the large stocks, but also because of the large sizes of the trees and stems. It is a fast-growing species with excellent wood properties. The density of Douglas fir wood in an air-dry state is on average –

ρ^{12}=550 kg.m^{-3} (ρ_0 =470 kg.m^{-3}, ρ_{raw}=670 kg.m^{-3}). The density of Douglas fir wood in our country in an air-dry state is on average 550 kg.m^{-3}, and of the wood from trees cut in the Boris garden in Sofia, according to P. Chernaev's studies, it is on average 520 kg.m^{-3}. The moisture of the freshly cut trees is on average w_{raw}= 60% (heartwood – 30-35% / sapwood – 70-110), and the moisture at the fibre saturation point of the cell walls wg.n.=28.0 %. It shrinks to a small size – α_v=12.0%. The wood of the Douglas fir is elastic, E_{ll}=12.3 N.mm^{-2} (σ_b=78.0 N.mm^{-2}), medium hard – longitudinal hardness of the fibers H_l=50.0 N.mm^{-2} (Enchev, E. 1984, Wagenfuhr 1996).

It is known that density is a complex quality parameter of any material. On the one hand, it is a consequence of the structure of the wood, on the other hand it affects all physical and mechanical properties. The distribution of earlywood and latewood zones within the annual ring also affects density. There is a big difference in density between earlywood and latewood zones. (Niemz et al. 2023). The wood of conifers and ring-porous species is characterized by a big difference in the structure of early and latewood. In the diffuse-porous and transitional species there is also a noticeable difference in some of the cell parameters, but it can be seen only under a microscope. The differences in the structure of the cells making up the early and latewood shows that the density of the latewood is about twice higher. In addition, the differences are also observed by the stem height and radius (Figure 1).

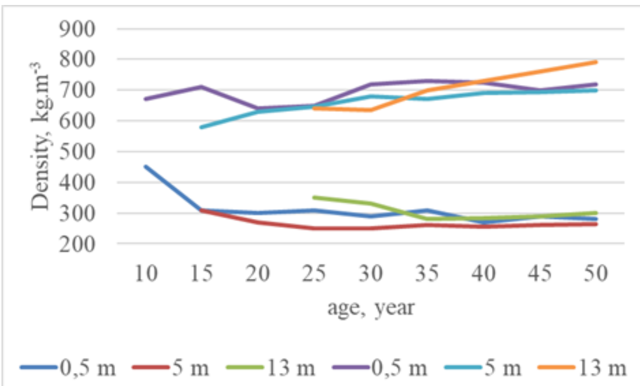

Figure 1: Changes in absolute dry density of early and latewood in a Douglas fir stem depending on the (a) age and (b) height, (Niemz et al. 2023).

Wood strength increases with increasing of latewood content. In softwoods there is a strong correlation between latewood content and the strength (Figure 2). The width of the annual ring is a less reliable indicator especially for softwoods (Figure 3). Environmental factors such as soil, exposure, and elevation are superimposed on its width, and it is a consequence of their habitat conditions (Niemz et al. 2023).

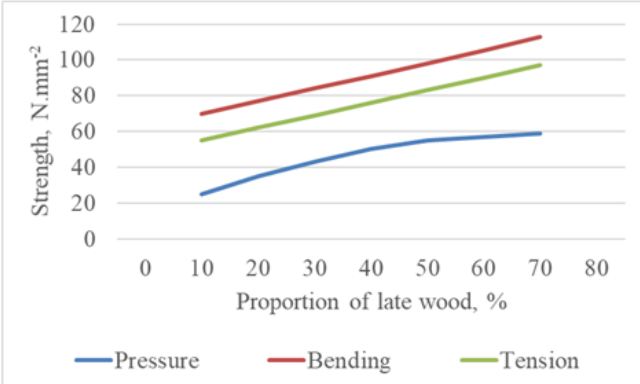

Figure 2: Effect of amount of latewood on various Douglas fir properties, (Niemz et al. 2023).

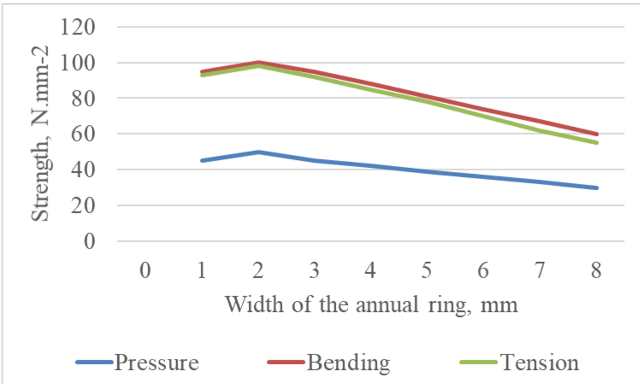

Figure 3: Effect of annual ring width on various Douglas fir properties, (Niemz et al. 2023).

One of the main problems when using the wood is the presence of growth-related defects. Due to them, it is difficult to extract large-sized timber. Even a minor defect such as slope of grain has a great impact on the wood properties. (Figure 4). This flaw affects tensile and bending strength more than compressive strength (Niemz et al. 2023). However, testing all three properties results in a failure pattern that is not permitted by the standard. This stratification fundamentally changes the way of testing and the values obtained.

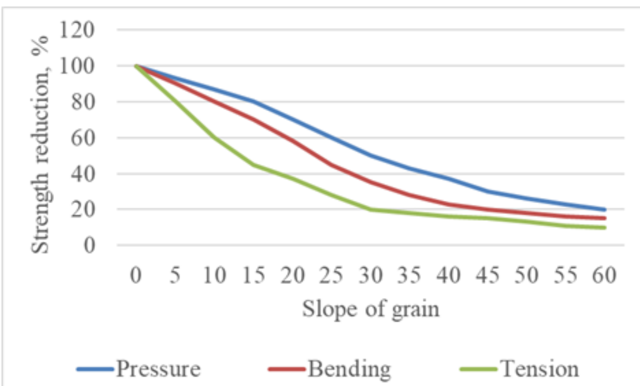

Figure 4: Effect of slope of grain on various properties of Douglas fir, (Niemz et al. 2023).

Other defects that are regularly present in the timber are knots. There has been a number of studies aimed at elucidating how they affect the mechanical properties of wood (Kollmann and Côté 1968). The authors studied parameters such as the influence of the largest diameter of the knot or the number of knots on the critical section of the structure.

METHODS AND MATERIALS

DESCRIPTION OF THE PLANTATION

This work examine the wood of the Douglas fir harvested from trees growing at different altitudes. The tree habitats were selected with a slight slope of the terrain. The slight slope of the terrain should allow the placement of the two diameters to be in the directions of the world, not related to the slope. Before felling the trees, the north direction was determined by a compass. Later, in the sawing workshop, the wood taken for the test pieces is oriented with respect to the directions of the world. Three 1- meter long sections were cut from each stem. The first one was from a height of 1.3 meters from the base. The second one was from the middle of the stem, and the third was from the base of the crown (BNS ISO 4471:1997). The length of the sections was adapted to the possibilities of transporting the wood.

One of the trees was harvested in the region of Prazhkovitsa at the altitude of 900 m (the land of Barzia, Berkovitsa municipality), subdivision 18–b. It is a seed plantation, forest management class Beech. It is a broadleaved, high-stemmed forest of „special" category. It has a northeastern exposure, on the upper part of the slope which is at 21 degrees. The soil is brown forest saturated, clay sand, rocky, loose, non-erosive, medium rich on gneiss. The type of habitat is C–2 (M-II-1) (30), 2nd site quality.

The present species composition is with ratio of 8 beeches, 1douglas fir, 1 spruce (the description of the plantation, which the trunks were taken from, belong to tax description included in present forest management plan State Forest Enterprise-Petrohan, Barzia). The diameter at breast height (DBH) was 33cm(east – west 18-14 cm diameter respectively – north-south 18-16cm). The tree was at the age of 49.

The other tree was harvested from a site 3km away from Barzia forest enterprise with altitude of 600m (Barzia land, Berkovitsa municipality), subdivision 56-6. 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 wth 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 28cm (east – west 12-13 cm diameter respectively – north-south 14-13cm). Tthe tree was at the age of 52.

DESCRIPTION OF THE WOOD

The studied wood was from boards harvested from the two mutually perpendicular diameters, aligned with the geographical directions. Test specimens for wood bending were obtained from them. The diameter of the test bodies was of 20×20×300 mm. They were oriented so that two of their sides were a radial section, and the other two were a tangential section.

Samples for the hardness of the wood were obtained and they were in accordance with the standard. The test bodies had the dimensions of 50×50×50 mm. The examined wood was from sections between the two mutually perpendicular diameters, aligned with the geographical directions. They were oriented so that two of their sides from a radial section, and the other two were from a tangential section. Since the test pieces were from the wood between the radial boards, the sections were firstly planed flat to achieve the desired orientation. From each section 10 specimens were harvested (totally 30 per stem). 10 test bodies were measured and three tests on hardness and three screw withdrawal tests were performed on them. The fact that these cubes have 6 sides (two opposite each other) was used. On some of them, the hardness was determined, and on the others – holes were drilled in which screws were driven. The screws were driven just before the test, as it is required by the standard. The wood for the specimens was conditioned to a water content of 8.9%. Determination of water content was carried out during the experiments (BNS ISO 13061-1:2019) Apart from the test pieces needed to determine the bending of the wood, there were also some made to determine the compressive strength along the grain in accordance with the specified standard (i.e. 20×20×30 mm).

RESULTS AND DISCUSSION

WOOD DENSITY

At the beginning of the measurements water content and density of the wood were determined. The obtained average value of the standard density (with water content of 12%) of the wood from the first stem was 518 kg.m^{-3}, and from the second – 522 kg.m^{-3}. It was almost the same for both stems indicating that altitude did not affect density. This value was close to the indicated average value for Europe, but completely overlaps the value indicated by Prof. Chernaev. Like the standard density, the density in the raw state was almost the same as that given in the literature – ρ_{raw}=670 kg.m^{-3}, but the density in the absolutely dry state was slightly higher – ρ_0=500 kg.m^{-3}. The water content in the raw state of the studied wood was less than that indicated in the literature – 49%. This can be explained by the time of the stems harvesting – October. The calculated water content was almost the same – 27% (Енчев 1984, Wagenfuhr 1996).

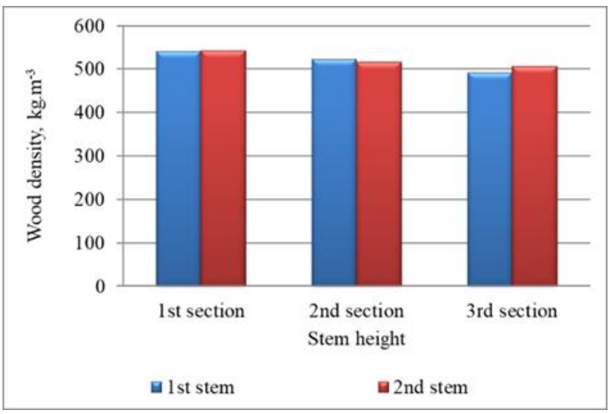

Figure 5: Douglas-fir wood density as a function of altitude and stem height.

Depending on the location of the wood in the stem, the density values had a visible trend. When the height of the stem increases, the density decreases. The decrease in the values were more noticeable in the first stem (ie, at the higher altitude).

BENDING STRENGTH

Douglas-fir wood is elastic, and the obtained average value was significantly higher than that reported in the literature – 100.4 N.mm^{-2}. In the first stem it is even higher – 111.0 N.mm^{-2}, while in the second, the average value was 89.8 N.mm^{-2} (Figure 6). The bending strength ranges from 80 to 127 N.mm^{-2}, while the value reported in the literature ranges from 68 to 89 N.mm^{-2} (Wagenfuhr R., 1996). In studies conducted in Bulgaria some time ago, the obtained value was 79 N.mm^{-2} (Bluskova, G. 2009).

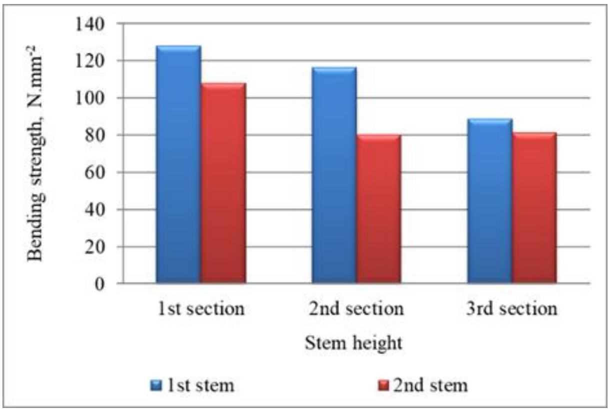

Figure 6: Bending strength of Douglas fir as a function of altitude and stem height.

Like density, the flexural strength values decrease with increasing stem height. In the first stem, this reduction is gradual, while in the second there is no difference between the values in the second and third sections.

COMPRESSIVE STRENGTH

The longitudinal compressive strength of the fibers was also higher than reported in the literature. On average for both stems it was 59.6 N.mm^{-2}. For the first stem the value was 61.5 N.mm^{-2}, while for the second it was 57.7 N.mm^{-2} (Figure 7). The strength varies from 58 to 63 N.mm^{-2}, while the value reported in the literature varies from 43 to 68 N.mm^{-2} (Wagenfuhr R., 1996).

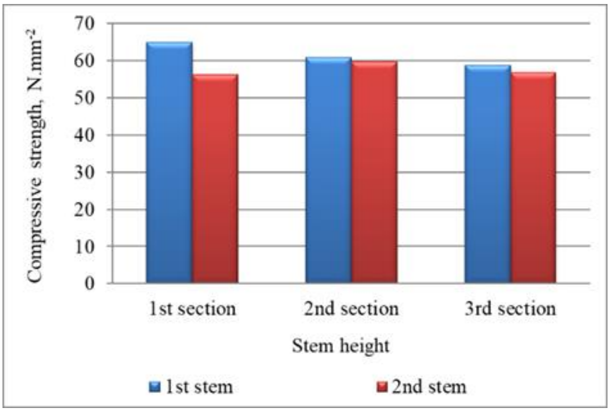

Figure 7: Compressive strength of Douglas fir as a function of altitude and stem height.

The obtained values for compressive strength along the height of the first stem decreased gradually, while for the second the picture was different. Wood values at the base of the stem were lower and then increased. With the third section they decreased again to the initial values.

WOOD HARDNESS

Douglas-fir wood is medium-hard with longitudinal fiber hardness Hl=50.0 N.mm^{-2} (Енчев 1984, Wagenfuhr 1996). The obtained values of the hardness were significantly lower (Figure 8). The obtained average value of longitudinal fiber stiffness was 37.9 N.mm^{-2}, while for transverse fibers it was 28.9 N.mm^{-2}. There is no dependence in the distribution of values in the radial and tangential directions. The average values obtained of the studied wood were 28.3 N.mm^{-2} radial and 29.4 N.mm^{-2} tangential to the fibers.

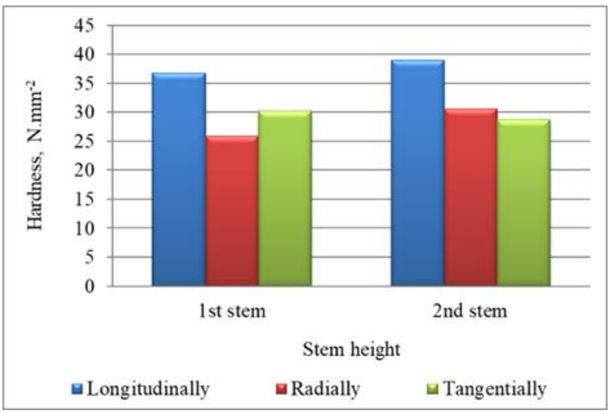

Figure 8: Hardness of Douglas fir as a function of altitude and stem height.

There is no definite dependence on the height of the stem. As it was expected, in the section at the base of the stem the longitudinal stiffness value of the fibers is the highest (40.3 N.mm^{-2}). In the second section, the value dropped to 36.2 N.mm^{-2}, and in the third section it rose again to 38.1 N.mm^{-2}. The trend of the values for the stiffness of the cross-fiber stiffness was similar. In the first section, the value was the highest (32.3 N.mm^{-2}). In the second, it decreased to 25.9 N.mm^{-2}, while in the third, it increased slightly again to 28.4 N.mm^{-2}. There was no dependence between the hardness values in the radial and tangential directions, with those in the tangential direction being slightly higher

There are no values reported in the literature with the respect to screw withdrawal resistance of Douglas-fir (screw retention). The average value obtained for the longitudinal screw retention of the fibers was 1763 N.mm^{-1} and transversely in 1808 N.mm^{-1} (Fig. 9). In the radial direction, the values were slightly lower, with an average value of 1706 N.mm-1. In the tangential direction, the value was 1910 N.mm^{-1}.

And here there was no definite dependence between the values of the screw retention on the height of the stem. The average value obtained for the longitudinal screw retention of the fibers in the first section was 1509 N.mm^{-1}. In the second section, the value rose to 1651 N.mm^{-1}, while in the third it dropped again to 1449 N.mm^{-1}. The screw retention values across the fibers were slightly higher but decreased gradually. In the first section the value was 1953 N.mm^{-1}, in the second section it was 1733 N.mm^{-1}, and in the third – 1568 N.mm^{-1}. There was no definite trend between the values in the radial and tangential directions.

CONCLUSIONS

After analysing the obtained results, the following more important conclusions can be made about the properties of Douglas fir in our country:

- The obtained value for wood density overlaps with that reported in the literature, being close for both stems, which disapproves the influence of altitude on this property;
- Wood density values decrease gradually along the height of the stem in both studied stems;
- The bending strength is higher than reported in the literature, as it is higher for the stem harvested at a higher altitude;
- Bending strength values decrease along the height of the stem, but there is no definite dependence;
- The longitudinal compressive strength of the fibers is higher than reported in the literature, as it is higher for the stem harvested at a higher altitude;
- o The values of the compressive strength decrease along the height of the stem, but here too there is no clear dependence;
- The obtained values for the hardness of the wood are significantly lower than those in the literature, as there is no dependence depending on the altitude and in the distribution of the values in the radial and tangential direction;
- There is no definite dependence in the hardness values on the height of the stem, both longitudinally and transversely of the fibers;
- The stem harvested at a higher altitude has slightly higher screw retention values compared to that harvested at a lower altitude;
- There is no definite dependence in the values of the screw retention on the height of the stem, both longitudinally and transversely of the fibers;
- In general, the wood has the same good properties as those reported in the literature, and for some of them the values are even higher.

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