Gradus Vol 6, No 3 (2019) 75-81
ISSN 2064-8014

THE EFFECT OF DIFFERENT MOISTURE CONTENTS ON SELECTED MECHANICAL PROPERTIES OF WOOD

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Keywords:
moisture content
tensile strength
bending strength
compression strength
Brinell hardness

Article history:
Received 24 June 2019
Revised 30 June 2019
Accepted 15 October 2019

Abstract
This study shows a broad comparison between some properties of six wood species. The examinations of the samples have been done both at a moisture content of 12% and over the fiber-saturation point. As it was expected, all mechanical properties decreased with increasing moisture content, but these decreases had highly different variation depending on wood species.

1 Introduction

The properties of wood are the result of several influencing factors. The structure of annual rings and the resulting inhomogeneity, the porosity, the moisture content (*MC*) and many other factors have great significance on its properties, and these can be never ignored. In this study, the *MC* of wood was selected as main factor, which highly affects most properties of wood (density, strength, elasticity, surface treatment, pliability, decay-resistance, electrical and thermal properties, anisotropic properties, shrinkage and swelling, etc.).

Water can be found in wood in three states: liquid water (free water) and water vapor in cell lumens, water bound in cell walls (bound water), and crystallized water linked to the chemical components of wood. The fiber-saturation point (*FSP*) is the *MC*, when all the intermicellar and interfibrillar cavities of the cell wall are saturated with water, but no free water is found in the cell lumen [4]. FSP is at about 30% *MC*, hangs on the wood species. Between the absolutely dry state and the *FSP*, both air and water can be found in the wood tissue. The mechanical properties of wood highly change, but over the *FSP* the mechanical properties of wood remain the same. Over *FSP*, free water is already present in the cell lumens and if the wood reaches its saturated state, no air remains in the lumens.

The aim of this study is to determine the differences of tensile strength, bending strength, compressive strength and Brinell hardness between 12% *MC* and *FSP*.

2 Materials and methods

During the described researches the mostly used Hungarian hardwood species had been selected: robinia (Robinia pseudocacia), sessile oak (Quercus petraea), beech (Fagus sylvatica) and poplar (Pupulus). The porosity of wood correlates well with its density:

- high density (>700 kg/m^3): robinia, beech
- medium density (550-700 kg/m^3): oak
- low density (<550 kg/m^3): poplar

Another important factor was that the selected species included both diffuse-porous (beech, poplar) and ring-porous wood species (oak, robinia). Only faultless samples with narrow annual rings had been tested, thus with homogeneous structure.

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Prior to the measurements, the samples had been prepared according to the standards, and the tests were conducted according to the standards as well. The samples were divided into two equal groups. The first group was put in a climate chamber at a temperature of 20 °C and a relative humidity of 65%, to have a *MC* of 12%. The other group was soaked into distillated water to have a *MC* over their *FSP*.

2.1 Tensile strength

Tensile strength refers to the resistance of wood to tension [3]. In wood industry, this is a more technological than constructional property, it plays greater role in the manufacture of plywood and particle boards. Wood is more resistant to tensile stress along its grains than perpendicular to its grains. The tensile strength was investigated along the grains, which is mostly affected by the microfibril angle in the S2 cell wall layer. The value of the tensile strength (σ_t) is given by the ratio of the highest load (F_{max}) and the area of the most highly loaded cross section (A) of the sample (Eq. 1):

$$\sigma_t = \frac{F_{max}}{A} \text{ (MPa)} \quad (1)$$

In addition to the maximum tensile force, the shape of the fracture after the test predicts the quality of wood as well, by showing the rigidity of the sample. The samples were designed as described in the standard ISO13061-06, with a size of 20 × 20 × 300 mm.

2.2 Bending strength

Both in the furniture industry and at the wood constructions, bending strength is an outstanding type of strengths, let us just think on roof-beams or on Thonet chair No. 14. In case of a three-point bending test for wood, the value of bending strength (σ_b) is calculated using the Navier-equation corrected by Tanaka [1] as follows (Eq. 2):

$$\sigma_b = \frac{F_{max}}{A} \text{ (MPa)} \quad (2)$$

The samples were produced as described in the standard ISO13061-03, with a size of 20 × 20 × 300 mm.

2.3 Compression strength

The resistance of wood to the load parallel or perpendicular to the grains is called compression strength. Since compression stresses often appear in wood structures as well as in many wood products, the significance of this mechanical property is not negligible. Compression strength (σ_c) is calculated using the following equation (Eq. 3):

$$\sigma_c = \frac{F_{max}}{A} \text{ (MPa)} \quad (3)$$

In our tests, compressive strength parallel to the grains was investigated as described in ISO13061-17.

2.4 Brinell-Mörath hardness

Hardness is the resistance of the material against the penetration of a tool. In 1900, Brinell expressed the hardness as the ratio of the load and the surface impressed by the 10 mm diameter ball. According to Mörath's amendment, very hard wood species are exposed to 1000 N, semi-hard wood species are exposed to 500 N and very softs are exposed to 100 N [5, 6], as it is shown in the standard MSZ6786/11-82. The Brinell-Mörath hardness (H_{BM}) is calculated by the next equation, using the depth of indentation (h), the diameter of the ball (D) and the diameter of the remaining impression of the ball (d) (Eq. 4):

$$H_{BM} = \frac{F}{D\pi h} = \frac{2F}{D\pi(D-\sqrt{D^2-d^2})} \text{ (MPa)} \quad (4)$$

3 Results and discussion

3.1 Tensile strength

The mean values obtained for tensile strength are shown in Figure 1 (dark green: air-dry, light green: over *FSP*). By comparison, air-dried minimum values (yellow) and averages (blue) are presented as separate columns, derived from the studies of Molnár [2] and Kovács [1].

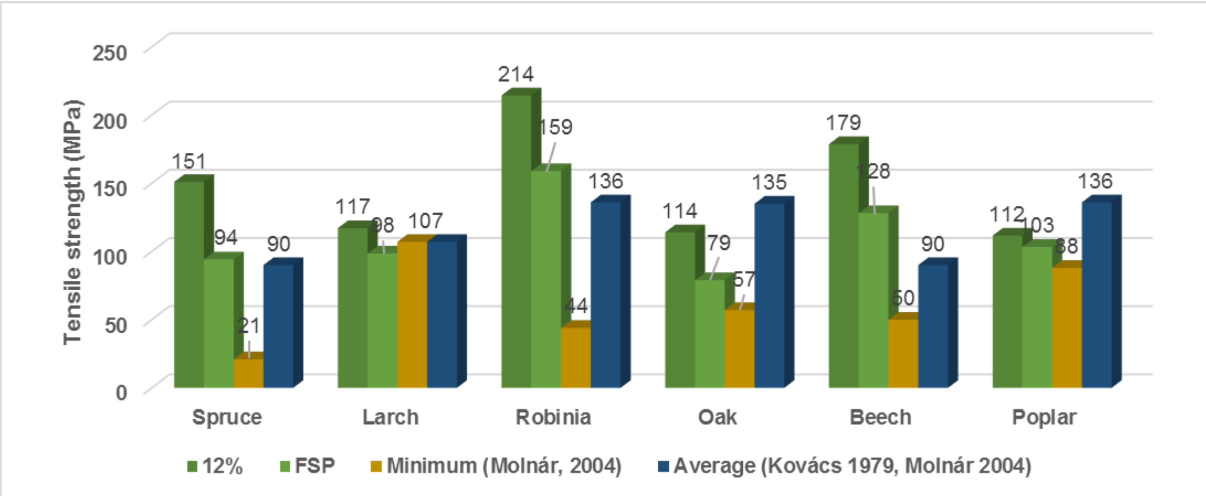

Figure 1. Changes of tensile strength depending on the moisture content of spruce, larch, robinia, oak, beech and poplar

As shown in Figure 1, the tensile strengths at 12% *MC* are well above the average values, except for oak and poplar. However, considering the maximum values given by Molnár [2], these protrusions cannot be considered as unique results. As example, the tensile strength can be as high as 245 MPa for spruce and 180 MPa for beech and oak. For robinia, Molnár [2] gives a maximum value of “only” 184 MPa, but this difference of 16% cannot be considered as a significant difference, as wood can have highly different mechanical-physical properties due to their diverse tissue structure even in one specie.

The loss of strength due to the increasing *MC* is 56.8 MPa (38%) for spruce, 18.6 MPa (16%) for larch, 55.5 MPa (26%) for robinia, 35.1 MPa (31%) for oak, 50.6 MPa (28%) for beech and 8.3 MPa (7%) for poplar. It should be noted that the relative standard deviation of the results over *FSP* was slightly higher (~ 31%) compared to the results of air-dry samples (~ 26%).

3.2 Bending strength

The results of the 3-point bending strength tests are shown in Figure 2. With increasing moisture content between 12% and *FSP*, bending strength decreases with 41.4 MPa (45%) for spruce, 51 MPa (52%) for larch, 56.1 MPa (39%) for robinia, 38.8 (36%) for oak, 62.8 MPa (55%) for beech and 42 MPa (49%) for poplar.

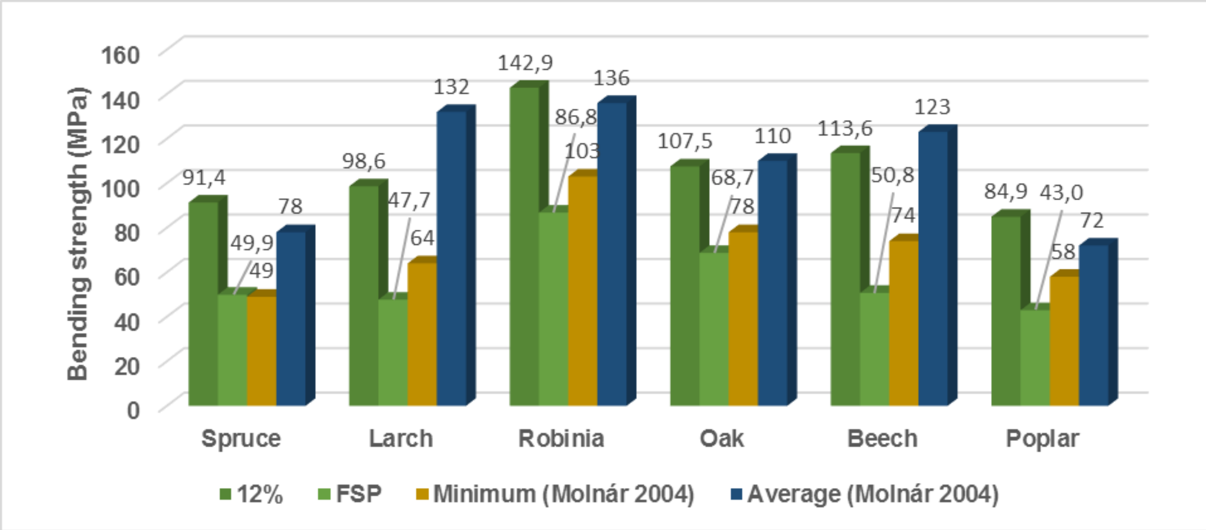

Figure 2. Changes in bending strength depending on the moisture content of spruce, larch, robinia, oak, beech and poplar

The results of spruce, robinia and poplar exceed the mean values, while larch is much lower compared to the results of Molnár [2]. The average results are much higher compared to the minimum-values in the literature. The reason in this case is mainly the high difference in the anatomy within each species.

3.3 Compression strength

The results of the compression tests and the comparative values of the literature can be seen in Figure 3.

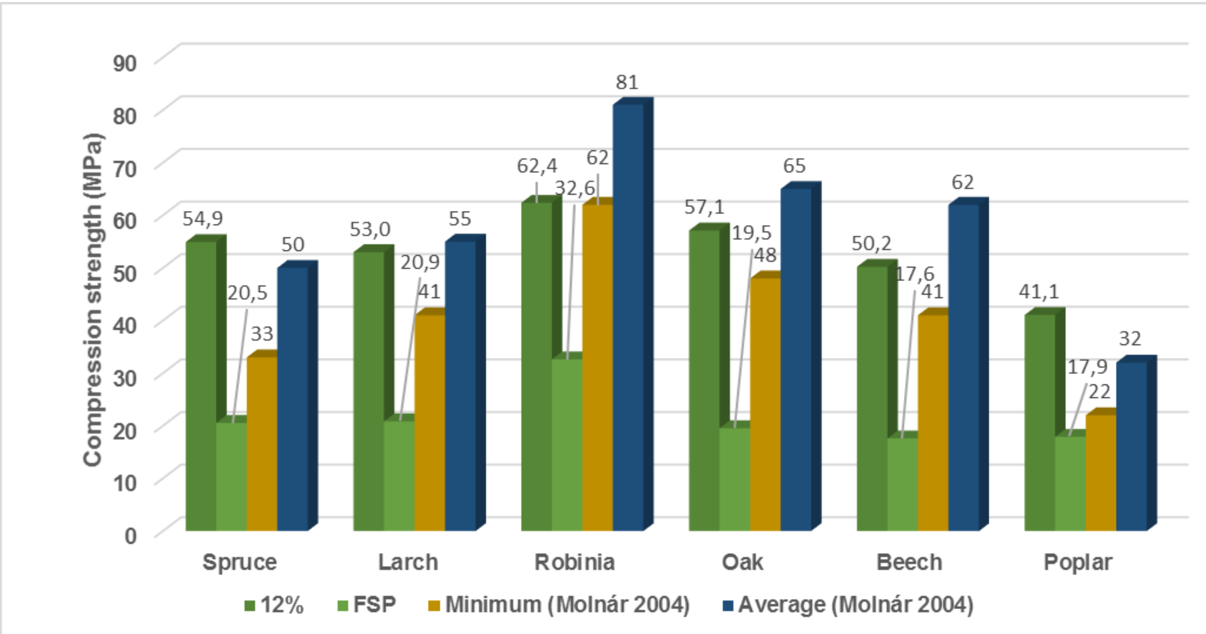

Figure 3. Changes in compression strength depending on the moisture content of spruce, larch, robinia, oak, beech and poplar

The compressive strength showed a significant reduction of averagely 60% with the change in *MC* between 12% and *FSP*. The compressive strength of spruce and poplar samples exceed the average values, while the remaining wood species remain below. The minimum values given by Molnár [2], has always been achieved.

3.4 Brinell-Mörath hardness

The hardness of the wood species was tested in all three anatomical directions which are shown in Figure 4-6.

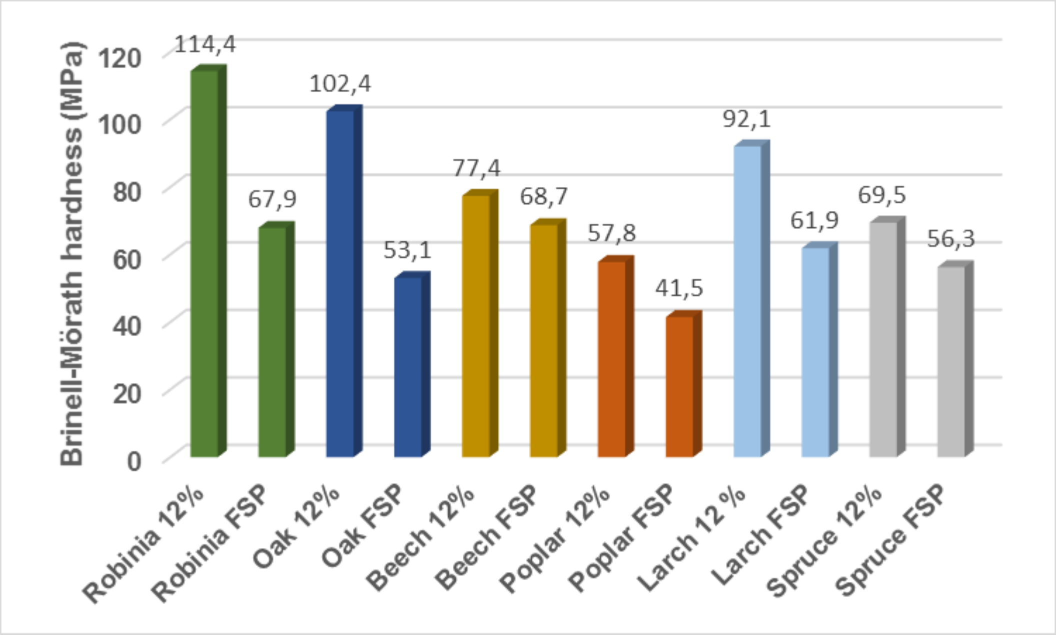

Figure 4. Changes of Brinell-Mörath hardness in longitudinal direction, depending on the moisture content of spruce, larch, robinia, oak, beech and poplar

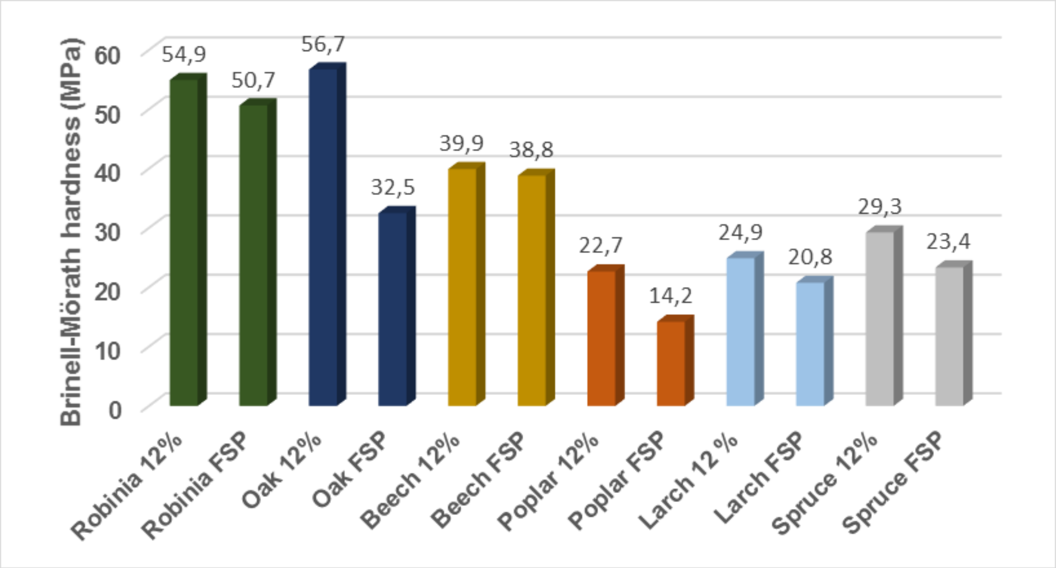

Figure 5. Changes of Brinell-Mörath hardness in tangential direction, depending on the moisture content of spruce, larch, robinia, oak, beech and poplar

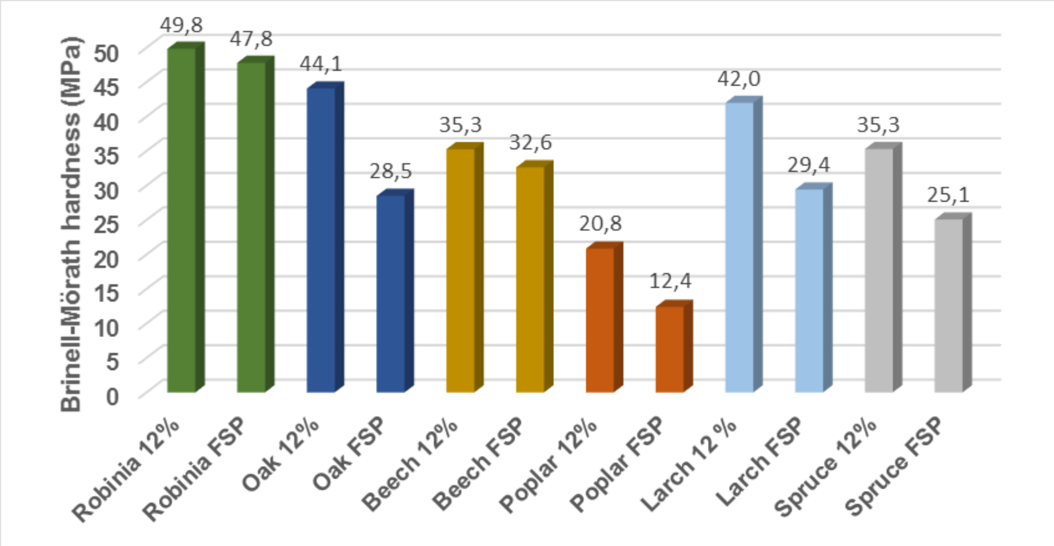

Figure 6. Changes of Brinell-Mörath hardness in radial direction, depending on the moisture content of spruce, larch, robinia, oak, beech and poplar

In order to be the high amount of data easier comparable, the degree of hardness reduction is presented in Table 1.

Table 1. Changes of Brinell-Mörath hardness in different anatomical directions between 12% moisture content and fiber saturation point of different wood species

Direction	*Robinia*	*Oak*	*Beech*	*Poplar*	*Larch*	*Spruce*
Longitudinal	41%	48%	11%	28%	33%	19%
Radial	4%	35%	7%	41%	30%	29%
Tangential	8%	43%	3%	37%	17%	20%

The reduction of hardness of the wood species in their three anatomical directions is quite different. The most significant change occurred in the fiber direction of the ring-porous species (robinia and oak). In the tangential and radial direction of robinia almost no change occurred as a result of the change in moisture content, but for oak this change was high, averagely 39%. For diffuse-porous species, the reduction of this property of beech is very low. However, poplar has a high hardness-decrease, moreover its radial decrease is higher than the decrease in its fiber direction. Both poplar and oak have huge cell lumens, which can absorb much more water compared to the other species. For softwoods, spruce shows a similar tendency to poplar in its hardness reduction resulted by the increase of *MC*. The change of this property of larch, the decrease in radial direction approaches the result in fiber direction, but the tangential hardness-change is significantly lower than the others.

Conclusions

As a conclusion, both tensile strength, bending strength, compressive strength and hardness of the air-dry samples closely correlate with the data from the literature. This confirms the correctness of the performed measurements which is necessary, to be the results comparable using other moisture content. The examined properties consequently decreased with increasing moisture content for all six wood species, but the ratio of changes was various, depending both on the measurement method and on the species. The selected species representing different groups of wood species, thus, these different groups have become better comparable.

Acknowledgment

This work was supported by the ÚNKP-18-3-I New National Excellence Program of the Ministry of Human Capacities.

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