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Contact drying of birch wood using different drying pressures

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Abstract

Research on the drying conditions of birch wood reveals that different drying methods can have a significant impact on its properties and overall quality. Birch, a wood species valued for its unique characteristics, including strength, flexibility, and aesthetic appeal, is highly suitable for a wide range of applications in industry. However, the drying process plays a critical role in determining the final quality, dimensional stability, and usability of the wood. As such, understanding the drying behaviour of birch wood is necessary for optimizing drying techniques, preserving its desirable properties, and ensuring its suitability for various products. One particularly interesting drying method is contact drying, which offers reduced drying times and lower heat consumption compared to traditional drying techniques. In this study, experimental samples were prepared from birch logs. The moisture content, moisture gradient, residual stresses, and density were measured, and drying was conducted under various pressures of 1.0 MPa, 1.4 MPa, and 1.8 MPa, with a drying temperature of 170°C. The results indicated that higher pressures led to an increased final moisture content, and substantial dimensional changes were observed during the drying process. Remarkably, the density of the wood increased by 13.03% to 19.55%, depending on the applied pressure. The study concluded that the optimal pressure for contact drying of birch wood is between 1.4 MPa and 1.8 MPa.

Keywords: contact drying, press drying of wood, birch wood, hardwood

Introduction

Wood drying is a crucial technological operation in the production process of high-quality wood products, where an improperly chosen or uncontrolled method can lead to a significant reduction in the material's utility value. Birch (*Betula* spp.) accounts for 6.6% of Europe's forests, with its share in Slovakia's total forest cover reaching just under 2% (State of Europe's Forests 2020). In the case of birch wood, which is characterized by its light colour, fine texture, and favourable strength-to-density ratio, the correct drying method is critical for preserving both its aesthetic and mechanical properties. In the wood processing industry, the most commonly used methods are conventional kiln drying and vacuum drying, which allow for better control of the drying process and reduce the risk of discoloration or cracking. Birch wood has the advantage of drying relatively quickly to the fibre saturation point (FSP), thus shortening the overall processing time and reducing energy costs.

However, it is sensitive to high initial moisture content, which can cause internal stresses and cracks due to uneven moisture movement. Despite this, it's good bending ability and high dimensional stability after proper drying make it an ideal material for the production of furniture, flooring, design elements, and musical instruments. Birch drying can be carried out in various ways, including conventional hot-air drying, high-temperature drying, or even by press (compression) drying. Based on the citated work Möttönen and Luostarinen (2004), Elustondo et al. 2023 shows, that high temperature drying (>100°C) is successfully used for American white birch (Betula papyrifera) (Erickson et al. 1984, Larson et al. 1986), but the preliminary results with sawn birch timber in Finland, especially concerning the wood colour, have been in consistent. Typically, high temperature drying of birch produces strongly red-coloured wood material because of the steaming used to transfer the heat to wood and prevent the casehardening of sawn timber. Steaming is typically used for the colour control with hardwoods, e.g., with beech and walnut (Burtin et al. 2000), giving a reddish colour for the dried wood, but it is not a usable method with sawn birch timber due to the uneven and glaring colour of the end product. Is also shown in citated work Elustondo et al. 2023 an application of high temperature drying is the press drying method, where the sawn timber is, in modern applications, compressed between perforated aluminium plates during the drying process at high temperature to keep the timber straight. The heartwood of some species of wood tends to darken and develop checks and honeycomb during press drying. For many applications, these defects may not adversely affect the lumber. In fact, the darker colour is often more appealing than the original colour (Larson 1986). In this paper of authors Burtin et al. 2000, the term press drying also known as contact drying is defined as the application of heat to both faces of a board through heated platens, thereby enabling the removal of moisture from the wood. Due to the compression applied during drying, the sawn timber remains straight and exhibits increased density, particularly in the surface layers of the boards. This results in improved surface hardness, enhanced strength, and material savings of 15-20%. With high-temperature drying, sawn birch timber can be dried within a single day (Burtin et al. 2000). Hittemeier et al. (1968) in their article evaluated the effect of press drying on wood. Certain properties of the press-dried specimens were examined and compared with the corresponding properties of specimens dried in traditional hot-air kilns according to standard drying schedules, as well as with the properties of specimens subjected to press steaming. In general, the strength values of the press-dried specimens, which exhibited no significant cracking or structural damage, were similar or very close to those of the specimens dried in conventional kiln dryers. This applied to all wood species except for rosewood, white oak, and post oak. The conclusion was that short exposure to elevated temperatures did not negatively affect the strength of the press dried material.

Aim and scope of work

The aim of this experiment is to evaluate the effects of different specific pressures (1.0 MPa, 1.4 MPa, and 1.8 MPa) applied by heating platens on the drying process of birch wood at a drying temperature of 170°C. The outcomes of this experiment will provide insights into the impact of pressing conditions and drying methods on the physical properties of birch wood, helping to optimize drying techniques for improved material quality.

Materials and Methods

For the experimental work, birch logs with a diameter of 35 cm and a length of 4 meters were harvested from the forest area of the Forest Enterprise of the Technical University in Zvolen. Samples with dimensions of 24×80×1000 mm were cut from tangentially sawn timber, 30 pieces in total. In the centre of each test sample, smaller specimens were cut to determine the initial moisture content using the weight method, moisture gradient, residual stresses, and density. The samples were also cut to determine initial moisture content, moisture gradient and density as well. Initial MC and final MC of wood were determined using the gravimetric method according to STN EN 49 0103. The moisture content was calculated using Eq. 1.

$$MC = \frac{m_w - m_0}{m_0} \cdot 100 (\%) \tag{1}$$

where: m_w is the weight of the wet sample (g) and m_0 is the weight of the absolute dry sample (g)

Oven-dried density was measured before and after contact drying. The measurement was performed under laboratory conditions. The density (ρ_0) of wood at 0% moisture content was measured according to STN EN 49 0108. The oven-dried density was calculated using Eq. 2.

$$\rho_0 = \frac{m_0}{V_0} \; (\mathrm{kg.m^{-3}}) \tag{2}$$

where: m_0 is the weight of oven-dried moisture samples (kg) and V_0 is the volume of oven-dried moisture samples (m^{-3}).

The measurement of moisture gradients was carried out separately for each wood species before the drying process as well as after the process itself (Eq. 3).

$$\Delta_w = w_s - \frac{\sum w_p}{2} \ [\%] \tag{3}$$

where: Δw - moisture gradient, w_s - moisture content centre, w_p - moisture content surface

Based on the validation experiments, the specific pressure of the heating platens was determined as p_1 = 1.0 MPa, p_2 = 1.4 MPa, p_3 = 1.8 MPa, and the drying temperature was set at 170°C. Perforated aluminium plates were used in the experiment, which allowed for intensive evaporation of moisture from all surfaces, including those in contact with the plates. The drying process was both uninterrupted. During the uninterrupted drying process, the temperature of the wood was measured at three locations of the cross-section and in two positions. In the interrupted drying process, every 10 minutes, the moisture was determined using drying samples, along with the moisture gradient, casehardening, and wood density (in five layers of the cross-sectional slice). The results were evaluated at a moisture content of 8%. The experimental results are shown in graphs 1 to 6, which display data up to the final moisture content of 0%.

Results and Discussion

The initial moisture content of the samples was 60±0.5%. The contact drying time at all plate pressures was 60 minutes, and after 40 minutes of drying, the moisture content of the samples was 5.5% at a plate pressure of 1.0 MPa, 4.2% at a specific plate pressure of 1.4 MPa, and 2.8% at a plate pressure of 1.8 MPa. The drying curves are shown in Fig. 1. Contact drying of wood is one of the very intensive drying processes and the drying curves are almost linear.

The intensifying factors here are the temperature and pressure of the heating plates on the dried material. As the pressure increases, the drying time decreases in the ratio 1:0.99:0.96. The drying time for the mentioned material dried by convection method was approximately 64 hours Compared to the convective drying method, contact drying is interesting in terms of drying time, which is shorter by a factor of ~120 times and therefore the heat consumption.

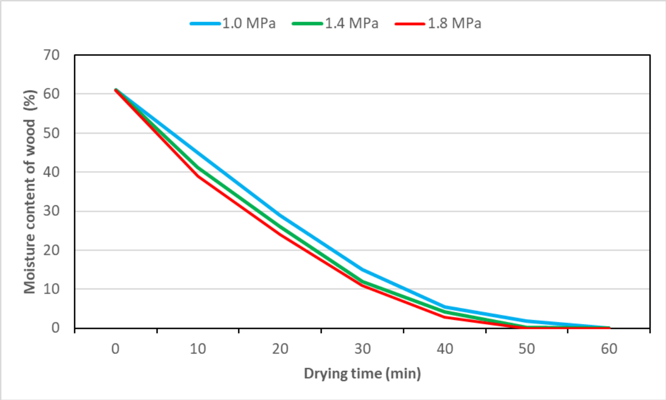

Fig. 1. Drying curves of contact drying with different specific pressures

The physical nature of the acceleration of the drying process with increased pressure of the heating plates on the dried material is explained by the reduction of its thickness, the increase of its density and thus the overall increase of the thermal conductivity of the wood (Trebula and Dekrét 1998). Measurements of moisture gradients were taken not only every 10 minutes at the beginning of drying, but also more frequently in the early stages of the process (after 5.5 and 7 minutes). The reason for this was to capture the maximum moisture gradients, which occur most rapidly in the first minutes of contact with the plate. The values of the moisture gradients in the contact drying process are shown in Fig. 2.

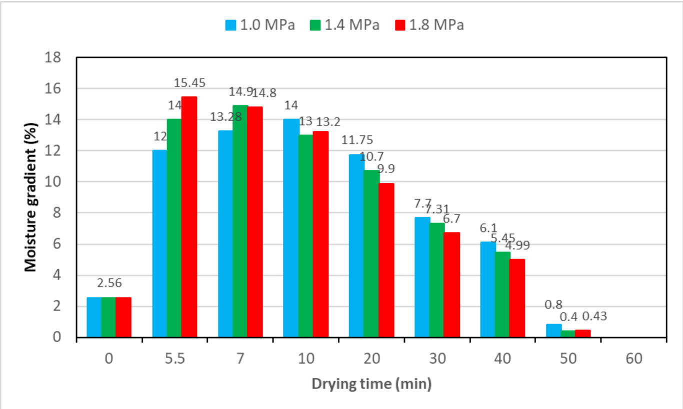

Fig. 2. Values of moisture gradients

At the start of the drying process, the moisture gradients increased noticeably and the effect of the pressure of the plates can be seen. The large initial values are due to the high evaporation of moisture from the surface of the samples in contact with the plates. As the plate pressure increased, the values of the moisture gradients also increased. The maximum values were measured within 7 minutes from the start of drying. This corresponds to the first section of the temperature progression in the samples (Fig. 6). After that, the values decreased and in this section the plate pressure had the opposite effect. Almost zero values were after 50 minutes of drying.

The average initial density of the samples in the absolutely dry state was 633.8 kg·m^{-3}. After contact drying, the total density increased (Fig. 3) as a function of pressure by 14.3%, 15.0% and 21.0%, respectively. The increase in wood density affects the thermal conductivity and thus the drying time (Trebula and Dekrét 1998), the strength properties and the hardness of the surface layers. In the drying process, the cross-section of the vessels undergoes plastic deformation so that the original circular cross-section of the vessels changes to an elliptical cross-section. In conventional drying, the deformation is much smaller. As also shown by Burtin et al. (2000) this results in improved surface hardness, enhanced strength, and material savings of 15-20%. With high-temperature drying, sawn birch timber can be dried within a single day.

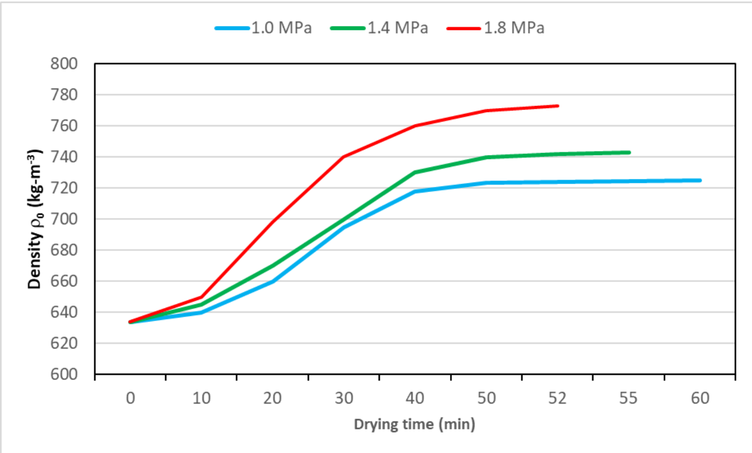

Fig. 3. Changes densities during time of drying

The dimensional change of the dried samples during contact drying is shown in Figures 4 and 5. In the drying process, the dried material is under constant pressure, so that, in addition to drying, compaction also occurs. As the pressure of the plates on the dried material increases, the thickness (drying and compaction) decreases in the range of 3.75 to 4.2 mm on average (Fig. 4). The present observations are consistent with the author Blomberg et al. (2006) that, density after contact drying ranged from 700 to 800 kg·m^{-3} for beech wood specifically. As also shown by Jung et al. (1993) noticed that contact drying can affect the density of dried samples. The dimensional change in width was in the range of 1.25 to 0.8 mm (Fig. 5). The effect of plate pressure on the change in specimen dimensions (thickness, width) was insignificant.

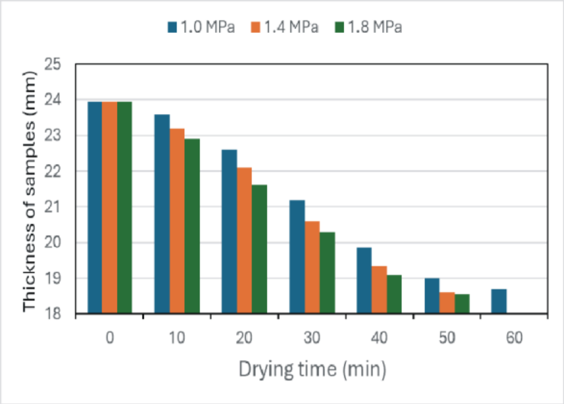

Fig. 4. Thickness change during drying time

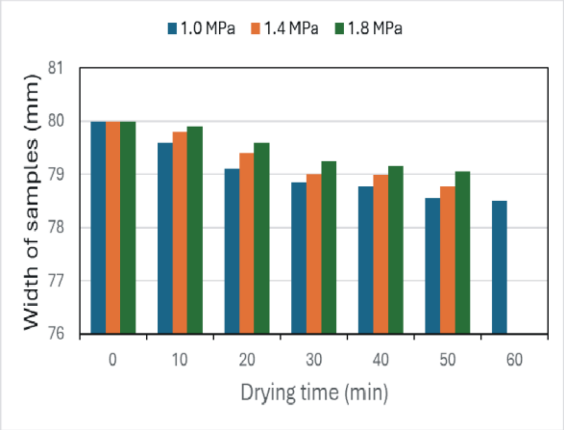

Fig. 5. Width changes during time

The temperature evolution in the wood up to complete drying at pressure *p* = 1.0 MPa is shown in Fig. 6. The distribution and evolution of temperatures at pressures of 1.4 and 1.8 MPa are similar and the effect of pressure of the plates did not affect the temperature distribution in the dried samples.

The curves marked 1.4 and 3.6 are the temperature distributions in the surface layers of the wood and in two different positions. Curves 2 and 5 are the temperatures measured during drying in the middle layers.

The drying process in terms of temperature curves can be divided into three sections. The temperature rises rapidly and reaches a value of approximately 100°C in the first section, over the entire cross-section. This section ended when the temperature stabilised and began to follow a constant course.

The second section is characterised by a constant temperature over the entire cross-section of the samples. The differences between the temperature at the centre on the surfaces of the samples are minimal. This was the shortest section, ending with the removal of free water from the inner layers of the wood.

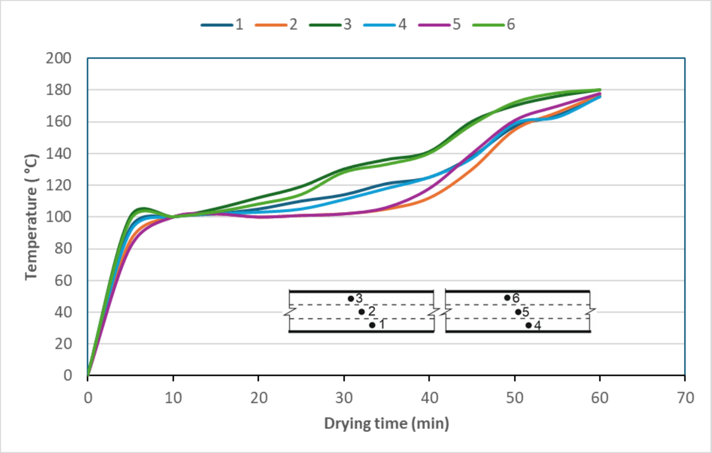

Fig. 6. Course of the temperatures in wood (p = 1.0 MPa)

In the third section, the temperature of the samples increases, with the surface layers heating more rapidly. The evaporation of bound water in the inner layers of the wood also begins. At the end of the drying process, the temperature difference across the cross-section of the wood becomes equal ($t_s = t_d$) and the moisture gradient decreases.

A summary table 1 of basic statistical characteristics was created to verify the variability of width, thickness, and density measurements. When the density changed, an average of 703 kg·m^{-3} was recorded with relatively low variability. The change in thickness indicates very small differences between samples. At the same time, the evaluated use of different pressure levels showed a greater range, but their variability did not have a significant effect on the measured dimensional changes. Overall, the table confirms that the differences found between measurements are statistically insignificant.

Table 1. Basic statistical characteristics of changes density, thickness and width

Variable	N - number of measurements	Average value	Minimum value	Maximum value	Standard deviation
Change of density (kg.m^{-3})	24	703.0	633.8	773.0	46.1
Pressure (MPa)	24	93.6	1.0	103.0	28.5
Change of thickness (mm)	19	21.2	18.6	23.9	2.0
Pressure (MPa)	19	101.9	101.0	103.0	0.8
Change of width (mm)	24	79.2	78.5	80.0	0.5
Pressure (MPa)	24	1.4	1.0	1.8	0.3

Conclusions

The aim of the work was to determine the effect of the pressure of the heating plates on the change of the average wood moisture content (drying curves), moisture gradients, change of dimensions and wood density in the process of contact drying. Birch specimens with a thickness of 24 mm and a tangential course of annual circles were used. Drying was carried out at a temperature of the heating plates of 170°C and specific pressures of 1.0 MPa, 1.4 MPa and 1.8 MPa. The following conclusions can be drawn from the measured data:

- Contact drying is a very intensive drying method and the drying curves were linear in character (moisture loss was directly proportional to time).
- The effect of pressure applied on drying time was significant and with increasing pressure the drying time became shorter.
- The values of the moisture gradients increased significantly in the first drying period.
- The effect of the pressure of the plates was similar to that of the drying time. Higher values of moisture gradients correspond to higher plate pressures. The maximum values of the moisture gradients were already measured after 5.5 minutes from the start of drying. During the second drying period, the moisture gradients decreased, and the effect of the plate pressure was reversed (higher values at lower pressure).
- The density of wood in the absolutely dry state increased between 14.3 and 21% depending on the pressure. The effect of pressure applied on the change in density was very significant and a positive effect on the mechanical properties of the wood can be assumed.
- The effect of the pressure of the plates on the change in the dimensions of the samples (thickness, width) was insignificant. The thickness of the samples decreased by 22.5% (5.39 mm) due to contact drying (drying and pressing). The change in the width of the samples was 1.8% (1.5 mm).
- The temperature history on the cross-section of the samples can be divided into three sections. The control of the drying process was made on the basis of the measured temperatures at the centre of the samples.

The results show a very positive effect of contact drying on the resulting drying time but also on the change in wood density. Contact drying is a specific drying method and research on the influence of drying conditions on the change of wood properties is important.

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