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DIMENSIONAL STABILITY OF BEECH BLANKS IN THE CONTACT DRYING PROCESS

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ABSTRACT

Timber drying is a crucial process for a wide range of applications, including machining, processing, and final use. It enhances dimensional stability and improves mechanical and physical properties, as well as biological properties such as resistance to mould and fungal growth. The drying process is influenced by various factors, with primary objectives typically focused on minimising costs, reducing drying time, and achieving acceptable drying quality. Achieving an optimal balance between these objectives requires compromises among the rapid drying techniques. Contact drying has gained attention as a potential solution for speeding up the process. The application of contact drying, utilising heated plates at a temperature of 160°C, is investigated in the study. Three specific pressure levels were examined: 1.0 MPa, 1.4 MPa and 1.8 MPa. The results indicated a substantial increase in sample density during contact drying, with pressure playing a significant role in this effect. Additionally, the variation in sample thickness was more pronounced in tangential samples. Across both radial and tangential orientations, samples subjected to the contact drying method exhibited greater dimensional stability compared to those dried by convection.

Keywords: contact drying; beech blanks; press drying; dimensional stability.

INTRODUCTION

The European beech (*Fagus sylvatica* L.) is a native species of European forests. It accounts for 11.9% of Europe's forest stock (State of Europe's Forests 2020), with a proportion of 35.4% in Slovakia (Green Report 2023). Beech wood is in demand on the market because of its excellent physical and mechanical properties, good workability, and aesthetic appearance Konopka *et al.* (2021), Sedliačiková and Moresová (2022), Dudiak *et al.* (2024). The fundamental technological operations in beech wood processing include drying. This is a demanding hydrothermal process that requires constant attention due to the changes in wood properties during drying, the length of the drying process, the quality of the dried material, as well as its energy and economic demands, as reported in several scientific studies by Blomberg (2006), Kumar (2021) and Dzurenda (2022). After modification (by steaming, thermowood or heat treatment), beech wood acquires higher stability, durability, and extended possibilities of use, including exterior (Tolvaj *et al.,* 2009, Barcík and Gašparík 2014, Dzurenda and Dudiak 2021, Suchta *et al.,* 2021, Vidholdová and Slabejová 2021). In addition to the most common warm-air drying of timber and blanks in drying kilns, which is time and energy consuming, other drying technologies such as high-temperature drying

Barański *et al.* (2017), Klement *et al.* (2019) and contact drying Schmitdt (1967), Schrepfer and Schweingruber (1998) Kúdela and Rešetka (2012), Klement *et al.* (2022) and have also received research attention. Press drying or contact drying of wood is a method of wood drying processing. The main objectives of pressing are to increase the wood's density, enhance its mechanical properties, and create a defined surface relief. The final properties of compressed wood are also strongly influenced by its dimensional stability following the pressing process (Kúdela and Rešetka 2012). Contact drying is implemented in a press where the heat from the heating plates is conducted from the upper and lower surfaces of the lumber inward towards the centre, in the direction of the plate thickness. Contact drying is a rapid method for removing moisture from wood. However, this quick-drying process and the high temperatures involved can cause changes in the wood, such as darkening its natural colour, and in particular species, severe cracking and honeycombing (Hittemeier *et al.,* 1968, Heebink and Compton 1966). Contact drying offers several benefits, including keeping the wood flat during drying, improving its dimensional stability, reducing inventory requirements, and efficiently utilizing heat energy (Tang *et al.,* 1994).

Significant research efforts by Hittemeier *et al.* (1968) focused on finding new products and processes to utilise this material better. One promising product is press-dried panelling, as described in a report by the U.S. Forest Products Laboratory. This process, known as contact drying, involves applying heat to both sides of a board using heated platens to remove moisture. The drying process typically occurs at temperatures ranging from 120 to 230 °C, with a platen pressure between 1.7 MPa and 2 MPa. While contact drying provides good contact with the board, it can result in thickness shrinkage and some defects, such as discolouration, cracks, and honeycombing. However, these colour changes may negatively affect the product for many uses, and the darker colour can even be more desirable than the original wood. The author also states in his work that boards of 1.5 cm thickness were dried to a final moisture content of 6% for about 25-75 minutes, while samples of 2.5 cm were dried for about 100-200 minutes, depending on the type of wood species (oak, ash, elm, beech etc.). from the point of view the density of pressed wood is primarily influenced by the degree of compression and the wood species (Blomberg *et al.,* 2006). According to the authors Blomberg *et al.* (2006), for seven different wood species, including beech, pressed under constant pressure, the average density values ranged from 750 to 1100 kg·m^{-3}, depending on the species; however, for beech wood, the values ranged from 700 to 800 kg·m^{-3}. Comparable observations are in concordance with those of Zhou *et al.* (2018) and Simpson (1983), who researched density by contact drying. Samples were oven-dried temperatures at 115, 135, 160, 185, and 205°C, respectively. The thickness of the sample was dimensions of 50 mm (longitudinal) by 50 mm (tangential). Drying was underway, with the material placed between two plates and a pressure of 3.5 MPa applied in the radial direction. Contact drying created a curve of density: high density at the two surface regions that gradually decreased toward the core region. During contact drying, wood becomes plastic and can undergo large deformation under the combined effects of moisture, high temperature, and mechanical compression. As the drying process progressed, heat and water evaporation gradually moved inward, resulting in the densification of the core layer. Consequently, surface regions in the timber were compressed more than core regions, creating a density profile. Surface regions had a density ranging from 600 to 850 kg· m^{-3}, and the core regions had a density of only between 400 and 450 kg· m^{-3} for maple wood (Simpson, 1983). Based on the cited work of Unsal and Candan (2008), the density and dimensional stability of lumber can be enhanced through the combined effects of thermal energy and compression treatment. As a result, studying the hot-press drying process of selected trees (pine, fir, poplar) holds significant theoretical value for promoting its efficient and high-value utilisation. During hot-press drying, heat and mass transfer are critical factors influencing the drying behaviour of wood. The heat from the heating platens is conducted from both the upper and lower surfaces of the lumber inward toward the centre, following the direction of the board's thickness.

The authors demonstrate that these conclusions were experimentally measured to investigate the effect of heating platens' temperature on the moisture state in poplar lumber with a moisture content (MC) above the fibre saturation point (FSP) during press drying. The maximum temperature and pressure were observed at the centre layer of poplar lumber during hot-press drying. As the temperature increased from 120 to 140 °C, the maximum temperature values rose from 111.2 to 127.3 °C, whereas those of pressure increased from 219.4 to 276.9 kPa. However, a delay occurred between the maximum values of pressure and temperature.

The aim of this article is to examine the effect of contact drying on the density and dimensional stability of wood. Specifically, beech wood, using temperatures of 160°C and under varying specific pressure levels of 1.0, 1.4 and 1.8 MPa.

MATERIALS AND METHODS

Beech wood (*Fagus sylvatica* L.) was used for experimental measurements. The samples were selected from two beech logs, each with a diameter of 40 cm and a length of 300 cm. The forest is located in the area known as Budča (475 m a.s.l.), which belongs to the University Forest Enterprise of the Technical University in Zvolen, Slovakia.

Radial and tangential samples were cut out from the log according to the cant sawing pattern. The dimensions of the drying samples were 120 × 800 × 30 mm (width × length × thickness).

The process of contact drying was conducted in a hydraulic single-storied press type CBJ 500-5 (TOS RAKOVNIK). The temperature of the heating plates was 160 °C. Three specific plate pressures of 1.0, 1.4 and 1.8 MPa were used. The group of samples was dried until the temperature measured at the centre of the sample reached the temperature of the pressing plate (t_p = 155 °C). The contact drying was completed at that time.

One filling always consisted of samples from one radial (R) and one tangential (T) log.

The drying mode of contact drying consisted of three phases (I - III.). Samples were dried at a constant temperature (II.) after a gradual rise in temperature (I.) to 160 °C. The cooling phase was (III.) after reaching the desired temperature in the centre of the samples. The final phase was conducted at 20 °C.

Convection hot air drying in the Memmert HCP laboratory dryer was used to compare the changes in the monitored properties of the sample groups. According to ON 490651, the standard drying mode was applied to the given wood species, taking into account its thickness and initial moisture content. The samples were also cut to determine their initial moisture content and density. The initial and final moisture content (MC) of the wood was determined using the gravimetric method, as specified in 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.

$$\rho_0 = \frac{m_0}{V_0} \text{ (kg·m}^{-3}\text{)} \tag{2}$$

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 thickness and width of the samples were measured before and after every contact drying with an accuracy of 0.01 mm. The samples were placed in an air-conditioning chamber at a temperature of 20 °C and a relative humidity of 60% after contact drying. Similarly, samples after convection drying were measured and conditioned. The dimensions of the samples were measured again after conditioning (Fig. 1).

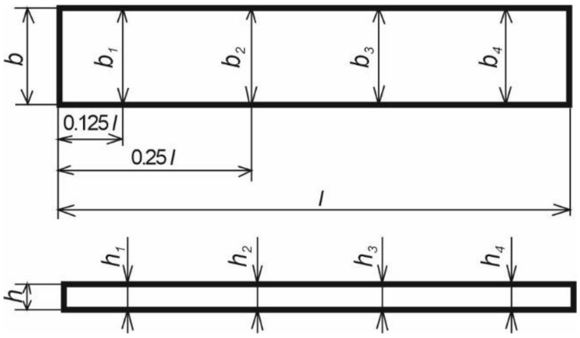

Fig. 1 Scheme of measuring the thickness and width of samples.

All samples were still conditioned to an equilibrium moisture content of ≈20% and then the thicknesses and widths of the samples were measured. From these values, the stabilizing effect of contact drying on the width using the anti-drying factor was evaluated:

$$F_b = \frac{b_{KV} - b_{KT}}{b_{KV}} \cdot 100 \qquad (\%) \tag{3}$$

Where: b_{KV} swelling of wood in width, dried by convection, transferred from one state of moisture balance to another (%), b_{KT} swelling of wood in width, determined by the contact method, transferred from one wood state of moisture balance to another (%).

Effect of contact drying on thickness:

$$F_h = \frac{h_{KV} - h_{KT}}{h_{KV}} \cdot 100 \qquad (\%) \tag{4}$$

Where: h_{KV} swelling of wood in thickness, dried by convection, transferred from one state of moisture balance to another (%), h_{KT} swelling of wood in thickness, dried by the contact, method transferred from one state of moisture balance to another (%).

RESULTS AND DISCUSSION

Table 1 presents the measured average values of the initial and final humidity for individual groups of samples, as well as the total contact drying time. The average density values of the samples in the dry state, both before and after drying, are presented, along with an increase in average density resulting from contact drying.

Tab. 1 Initial and final moisture of the samples, drying time, and density of the samples.

Type of samples	Pressure of plates (MPa)	MC (%)		Drying time (min)	Density ρ_0 ($kg \cdot m^{-3}$)		
		Initial	Final		Before drying	After drying	Change of density ($kg \cdot m^{-3}$)
Radial	1.0	77.48	3.95	80	675.61	770.92	+95.31
	1.4	80.27	6.08	80	684.16	785.15	+100.99
	1.8	69.5	5.52	90	675.62	786.47	+110.85
Tangential	1.0	71.87	5.78	100	669.93	722.07	+52.14
	1.4	54.14	5.37	110	663.08	752.35	+89.27
	1.8	55.54	4.87	90	666.95	774.85	+107.90

It can be seen from the measured data that the initial moisture content of the samples ranged from 54.14% to 80.27%, and the final moisture content ranged from 3.95% to 6.08%. Drying time was shorter for radial samples, while plate pressure had no effect on drying time, and the effect of sample type was also not significant. The drying time for contact drying is in the range of a few minutes, whereas conventional warm-air drying can take several hours or even days, which makes a significant difference in time requirements. For example, in the case of our sample beech wood, with a thickness of 30 mm and an initial moisture content of approximately 70%, the warm-air drying process would take approximately 169 hours. For a beech sample of the same thickness, the drying time for contact drying was approximately 110 minutes, so it is approximately 85 times shorter.

Our measurements confirmed that the density after contact drying ranged from approximately 722 to 786 $kg \cdot m^{-3}$. As a result of contact drying, the density of the samples increased by an average of 92 $kg \cdot m^{-3}$, while the effect of plate pressure on the density value was confirmed. A larger increase in density was discovered for radial samples (average value 102 kg·m-3). This difference was caused by the direction of the plate pressure. In the case of radial samples, the direction of the pressure was tangential, the densification, and thus the increase in density was greater. For tangential samples, the average value was 83 $kg \cdot m^{-3}$.

Blomberg *et al.* (2006) report that density after contact drying ranged from 700 to 800 $kg \cdot m^{-3}$ for beech wood specifically. As also shown by Jung *et al.* (1993), contact drying can affect the density of dried samples. According to Kúdela *et al.* (2018), the density distribution across the specimens in the pressing direction was not similar. The highest density values were observed in the surface layers (1–2 mm), gradually decreasing towards the centre. As the degree of compression increased, the density profiles across the specimen thickness (in the pressing direction) became more identical.

The change in the dimensions of the samples depending on the drying time are shown in Figures 2, 3 and 4.

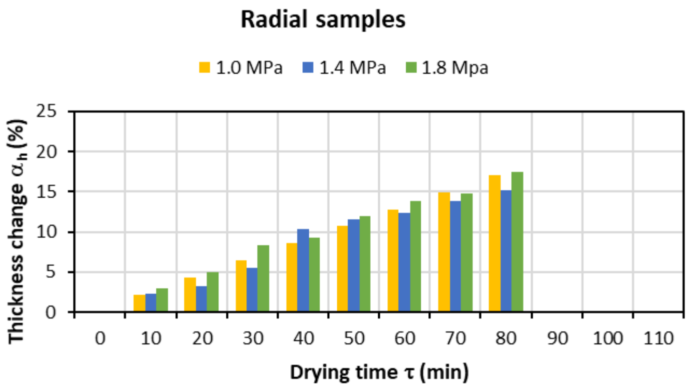

Fig. 2 Thickness change at different contact drying pressures – radial samples.

In the case of radial samples, the influence of plate pressure was almost insignificant, and the differences in the change in the thickness of the samples at individual pressures were less than 1.0% (Fig. 2). The differences in the change of the thickness of the samples were caused by the fact that the direction of the pressure is in the tangential direction for the radial samples and the radial direction for the tangential samples.

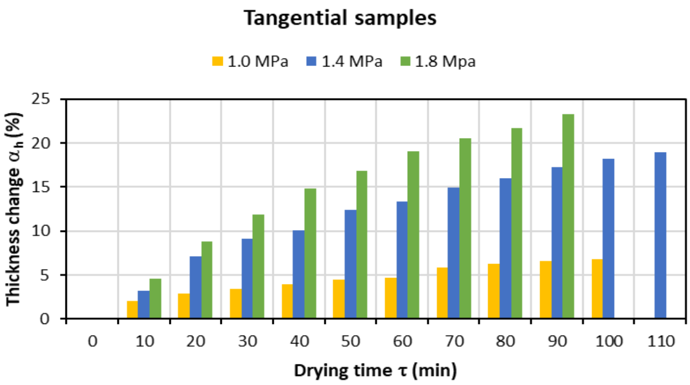

Fig. 3 Thickness change at different contact drying pressures – tangential samples.

The influence of plate pressure during contact drying was more remarkable for tangential samples, where a thickness change of 6.75% was measured at a pressure of 1.0 MPa and a 23.3% change in thickness at a pressure of 1.8 MPa (Fig. 3).

The values of the change in sample width are significantly smaller than the change in thickness (less than 3%). The effect of pressure on the change in width was confirmed for both radial and tangential samples (Fig. 4).

However, the effect of plate pressure is opposite to the change in thickness. As the pressure on the plates increased, the change in the width of the samples decreased. Greater values of the change in width were observed when evaluating the change in this dimension after conditioning the samples to a humidity of 12%. Based on the authors' work by Jung *et al.* (1993) and Hou *et al.* (2018), research was conducted on 24 mm thick samples using three species of coniferous wood (pitch pine, larch, and white pine), where the contact was dried under two-platen pressures of 0.17 and 0.34 MPa. The initial moisture content of the samples ranged from 30% to 89%.

Results confirmed that an increase in the higher pressure caused thickness shrinkage. Other studies conducted by Kúdela and Rešetka (2012) confirm that dimensional stability is closely related to both the pressing temperature and the pressing time. Their experiments confirmed a noticeable improvement in dimensional stability as the pressing temperature and time were increased. These pressing conditions also resulted in a notable reduction in both the moisture content and the sorption capacity of the pressed wood.

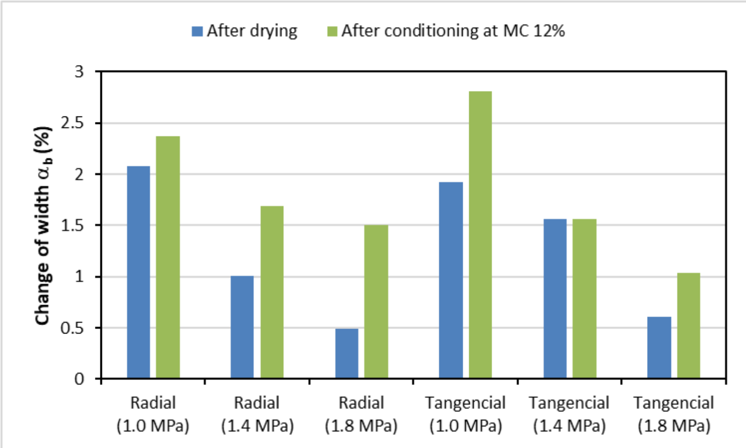

Fig. 4 Width change at different contact drying pressures and samples.

This means that the thick swelling of the samples during contact drying was greater by the indicated F_h values at all pressures compared to convection drying. The bigger difference was with the radial samples. Some authors have also estimated the mechanical properties during contact drying, as shown by the cited work by Klement *et al.* (2022). The results showed a very favourable effect of contact drying on the change in the observed mechanical properties of beech wood. Increasing the bending strength enhances the use of wood in elements subjected to increased loads. Increasing the hardness of the surface after contact drying will allow the use of such dried wood in places with high stress, such as floors.

Based on the measured changes in the dimensions of the sample group during contact and convection drying, the values of the anti-drying factor were calculated (Tables 2 and 3).

Tab. 2 Dimensional change during contact and convection drying and anti-drying factor: radial samples.

Measurements	Contact drying						Convection drying	
	Pressure 1.0 MPa		Pressure 1.4 MPa		Pressure 1.8 MPa			
	Thickness	Width	Thickness	Width	Thickness	Width	Thickness	Width
Before drying (mm)	30.19	110.39	31.10	111.37	30.19	110.66	30.91	110.45
After drying (mm)	25.03	108.10	26.45	110.25	24.83	110.12	28.24	107.61
After air conditioning MC=12% (mm)	25.82	107.77	26.65	109.49	25.09	109.00	27.37	105.59
After air conditioning MC=20% (mm)	28.09	109.56	29.32	111.59	27.74	111.21	28.42	109.42
The difference before and after drying (%)	17.09	2.07	14.95	1.01	17.75	0.49	8.64	2.57
Difference after air conditioning from 12% to 20% (%)	8.08	1.63	9.12	1.88	9.54	1.99	3.70	3.50
Factor F_h / F_b (%)	**-118.3784**	**53.4286**	**-146.4865**	**46.2857**	**-157.8378**	**43.1429**	-	-

Tab. 3 Dimensional change during contact and convection drying and anti-drying factor: tangential samples.

Measurements	Contact drying						Convection drying	
	Pressure 1.0 MPa		Pressure 1.4 MPa		Pressure 1.8 MPa			
	Thickness	Width	Thickness	Width	Thickness	Width	Thickness	Width
Before drying (mm)	30.3	110.68	30.41	110.65	29.97	110.51	30.61	110.55
After drying (mm)	26.96	108.55	25.03	108.92	23.47	109.84	29.38	106.25
After air conditioning MC=12% (mm)	27	107.57	24.95	108.92	23.19	109.36	28.59	105.03
After air conditioning MC=20% (mm)	28.77	108.78	26.63	110.30	24.88	110.95	29.69	110.09
The difference before and after drying (%)	11.02	1.92	17.69	1.56	21.69	0.61	4.02	3.89
Difference after air conditioning from 12% to 20% (%)	6.14	1.11	6.32	1.25	6.81	1.43	3.7	4.6
Factor F_h / F_b (%)	**-65.95**	**75.87**	**-70.81**	**72.83**	**-84.05**	**68.91**	-	-

The anti-drying factor F informs the stabilizing effect of contact drying compared to convection drying. The results of F_b mean that for both groups of samples and all pressures. The samples dried using the contact method are more dimensionally stable in terms of swelling than those dried using the convection method, particularly in terms of thickness swelling. The calculated F_h values were negative.

CONCLUSION

The objective of this study was to assess the impact of contact drying on the changes in thickness and width of wood samples, as well as their overall dimensional stability and changes in density, depending on the pressure applied during the drying process. Samples with a thickness of 30 mm, exhibiting both radial and tangential grain orientations, were used for the experiment. Drying was performed at a plate temperature of 160°C, with pressures set at 1.0 MPa, 1.4 MPa, and 1.8 MPa. The results were then compared with those of conventional hot air drying.

Based on the data collected, the following conclusions can be drawn:

- contact drying proved to be highly efficient, reaching low final moisture content in a short period. In comparison to warm-air drying, which takes approximately 169 hours for beech wood of the same thickness, contact drying shortened the drying time to less than 2 hours, approximately 85 times faster;
- radial samples dried faster than tangential samples, while the specific plate pressure had no significant effect on the drying time. During the contact drying process, the density of the samples increased considerably, with plate pressure playing a substantial role in this increase. For radial samples, the density increased by an average of 102 $kg \cdot m^{-3}$, while for tangential samples, it increased by 83 $kg \cdot m^{-3}$;
- the average thickness change for radial samples was 16.6%, with no notable effect from the plate pressure. However, plate pressure significantly influenced the thickness change for tangential samples, ranging from 7% to 23%;
- the width change in the samples during contact drying was nearly identical for both radial and tangential samples, with the highest values observed at the lowest plate pressures;

- in terms of dimensional stability during swelling, samples dried by contact drying showed greater stability compared to those dried by the convection method for both radial and tangential samples across all pressure levels;
- thickness swelling was greater for samples dried by contact drying compared to those dried by convection, with the most significant difference observed in the radial samples.

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