



Kinetics of drying beech wood contain red false heartwood

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Abstract

The article was focused on analysing the differences in the drying of beech wood (*Fagus sylvatica* L.) containing red false heartwood. The woodworking industry and, gradually, the construction sector in Slovakia have been increasingly oriented toward the greater utilization of beech wood as a primary raw material. The occurrence of false heartwood in beech significantly affected the quality of logs and sawn timber. It was necessary to determine the differences in drying between beech with red false heartwood and mature beech wood. The differences in drying kinetics during a two-stage convective drying process, moisture loss, moisture gradients, and density were analysed. From the measured values, differences in drying intensity between red false heartwood and mature beech wood were identified, which were caused by the altered structure of red false heartwood and changes in permeability to liquids and vapours. The moisture loss was higher in red false heartwood samples (0.187-0.189%/h) at moisture levels above the fiber saturation point (> 30%) compared to mature wood samples (0.135-0.145%/h). Below the fiber saturation point (< 30%), the moisture loss was lower (0.148-0.177%/h) in red false heartwood samples, while in mature wood samples, it either remained unchanged or increased (0.171-0.145%/h). Red false heartwood lost moisture faster and had lower final moisture content at the end of drying.

Keywords: mature wood, red false heartwood, air drying, kinetics of drying, beech wood

Introduction

European beech (*Fagus sylvatica* L.) is the most widespread tree species in Slovakia and has a high representation across Europe (Straže, Žveplan 2022). This species exhibits numerous defects, such as red false heartwood, reaction wood, and others (Furst et al. 2006; Čunderlík et al. 2017). Generally, the formation of red false heartwood is associated

with a reduction in moisture content and the vitality of parenchyma cells (Kúdela, Čunderlík 2012; Barański et al. 2017). The occurrence of red false heartwood in beech significantly affects the quality of logs and sawn timber (Kudra et al. 2003; Delinsky 2005; Trenčiansky, Hansmann 2007; McDonald et al. 2010). Besides physical differences between beech wood with and without red false heartwood (Dzurenda, Dudiak, Kučerová 2023), they were also exhibit distinct drying properties (Marinescu et al. 2010; Barański et al. 2017). The final material quality was evaluated by Shahverdi et al. (2010), and it was reported by the authors to be influenced by the type of red false heartwood as well as the drying mode used (Korkut, Budakci 2009; Barna 2011; Won et al. 2015). The behaviour of sapwood and red false heartwood during drying was compared by Bajraktari (2010), and it was found that red false heartwood is dependent on the presence of juvenile wood in the samples, which interactively modifies its properties and thus the final material quality. The moisture gradient before drying was higher in red false heartwood samples (Shahverdi et al. 2013) than in mature wood samples, as observed in studies by Klement and Vilkovská (2018, 2019), leading to shorter drying times for red false heartwood samples. Based on experimental work (Klement, Vilkovská 2015), it can be concluded that during high-temperature drying, red false heartwood samples dried more slowly than sapwood samples. Increasing the drying temperature had a more pronounced negative effect on the final quality of heartwood-zone samples compared to sapwood-zone samples. The aim of this research was to determine the differences in drying kinetics between red false heartwood and mature beech wood during convective drying.

Materials and Methods

The research on drying kinetics of beech wood containing red false heartwood was conducted on materials containing and not containing red false heartwood. For the samples containing red false heartwood, a 2-meter long log with a diameter of 46 cm was selected, displaying mosaic-type red false heartwood (Fig. 1b). For the samples without red false heartwood, a 2-meter long log with a diameter of 39 cm was chosen (Fig. 1a). All logs originated from the University Forest Enterprise of the Technical University in Zvolen, localized in the cadastral area of the village Kráľová with coordinates 48°29'51.868''N, 19°9'58.718''E.

The logs were cross-cut into sawn timber using a horizontal bandsaw. From the produced sawn timber, smaller dimension boards were selected to ensure they originated from symmetrically identical positions in both logs (Fig. 2).



Fig. 1. Beech log sections: a) without red false heartwood, b) containing red false heartwood

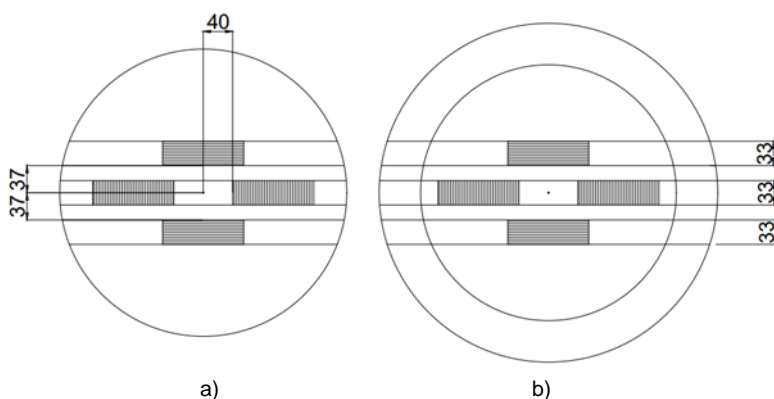


Fig. 2. Cutting diagram and sample selection from log sections according to the position of the pith: a) without red false heartwood, b) containing red false heartwood

From each board, the following were produced: 2 drying samples (A), a moisture sample (B), a moisture gradient sample (C), and a density sample (D) (Fig. 3).

The drying chamber load consisted of 6 symmetrical samples (A) arranged according to their position in logs with RFH (red false heartwood) and without RFH:

- 4 weighing samples:
 - 2 radial - 1 with RFH, 1 without RFH,
 - 2 tangential - 1 with RFH, 1 without RFH,
- 2 samples for continuous moisture gradient monitoring:
 - radial - 1 with RFH, 1 without RFH.

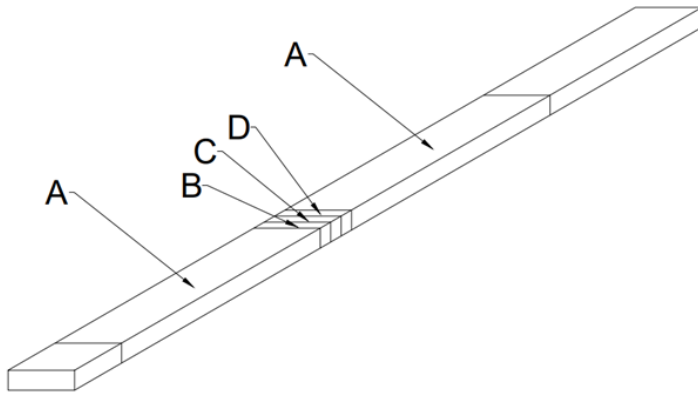


Fig. 3. Sample dimensions and positioning within the board; A: drying sample: 33×110×400 mm, B: moisture content sample: 33×20×110 mm, C: moisture gradient sample: 33×15×110 mm, D: wood density sample (after trimming): 20×20×30 mm

Moisture content

The prepared specimens were weighed on a scale with an accuracy of 0.01 g before drying (m_w). Subsequently, they were dried to absolute dry condition (m_0) at a temperature of $103\pm 2^\circ\text{C}$. The initial wood moisture content was determined according to standard STN EN 13183-1.

Moisture gradient

The moisture gradient was determined before and after drying for all dried specimens. During the drying process, moisture gradients were regularly measured every 4 days by first cutting a 20 mm section from the edge of the sample, followed by cutting a moisture gradient sample. The dimensions of the moisture gradient samples were 15×33×110 mm. These samples were then cut into three equal slices: 2 surface slices and 1 centre slice (Fig. 4).

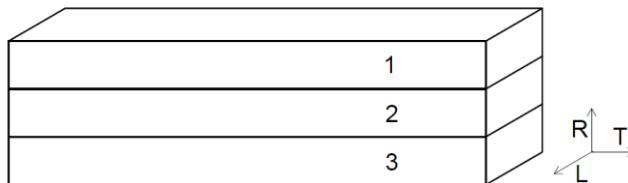


Fig. 4. Moisture gradient sample: 1, 3: surface slices (for measuring outer moisture content); 2: centre slice (for core moisture determination); L - longitudinal, R - radial and T - tangential direction

The moisture content of the slices was determined gravimetrically before and after drying to absolute dry condition. The moisture gradient was evaluated as the difference between

the moisture content of the surface slices and the centre slice of the wood sample. The moisture gradient was calculated using the formula:

$$\Delta w = w_c - \frac{\sum w_s}{2} \quad (\%) \quad (1)$$

where: Δw - moisture gradient (%), w_c - moisture content of the centre slice, w_s - moisture content of the surface slices.

Wood density

For density measurement, specimens were prepared in accordance with standard STN EN 323. The samples measured 20×20×30 mm. Each specimen was dimensionally measured using a calliper with an accuracy of 0.01 mm and weighed on a scale with a precision of 0.01 g. Subsequently, the samples were dried to absolute dry state. After drying, their dimensions and weight were remeasured.

Drying process

The actual drying process was conducted in a Memmert HCP 108 laboratory chamber dryer. A two-stage drying mode was used (Table 1). The parameter adjustments were determined based on the current moisture content of the drying samples during the process.

Table 1. Parameters of the two-stage drying regime

Drying stage	Wood moisture content w	Air humidity φ (%)	Drying temperature t (°C)	Psychrometric difference Δt (°C)
1st stage	$w > \text{FSP}$	90	60	2
2nd stage	$w < \text{FSP}$	52	60	3

After weighing, the drying specimens were placed in the drying chamber with sufficient spacing between individual pieces to ensure uniform air circulation. Throughout the entire drying process, the moisture content of the samples was monitored at regular 24-hour intervals. The samples were dried to a final moisture content approx. of 10%.

Results and Discussion

Moisture content

The wood moisture content was determined before and after drying for all test specimens. During the drying process, the moisture content of the drying samples was monitored to establish the drying curve. The initial hypothesis suggested that the red false heartwood zone would exhibit lower initial moisture content compared to the mature wood zone (Kúdela, Čunderlík 2012). Contrary to expectations, the red false heartwood zone showed higher moisture content than the mature wood by an average of 9% (Table 2).

On the based the completion of drying, the moisture difference between zones equilibrated to an average of just 0.5%.

Table 2. Wood moisture content

Sample		Pre-drying moisture gradient (%)	Average	Post-drying moisture gradient (%)	Average
Mature wood	Tang.	59.67	59.49	9.51	9.73
	Rad.	61.01		9.99	
	Rad.	57.80		9.68	
Red false heartwood	Tang.	65.92	68.69	9.64	10.18
	Rad.	69.05		10.17	
	Rad.	71.09		10.73	

Moisture gradients

The moisture gradient was determined before and after drying for all dried specimens to assess moisture distribution across the sample cross-sections. The moisture gradient had been considered a critical parameter for evaluating drying quality. Before drying, the moisture gradient was higher in red false heartwood samples (Table 3), while mature wood samples showed lower gradients. This finding supported the initial hypothesis about the pre-drying moisture gradient distribution in the samples (Shahverdi et al. 2013; Klement, Vilkovská 2016, 2019). During the drying process, the moisture gradient was monitored using two dedicated samples (Fig. 5). Throughout nearly the entire drying process, the moisture gradient remained more uniform in mature wood samples. After drying, the difference in moisture gradients between all samples became minimal. The drying process successfully achieved the desired effect of reducing and equalizing moisture content throughout the material's thickness.

Table 3. Moisture gradient

Sample		Pre-drying moisture gradient (%)	Average	Post-drying moisture gradient (%)	Average
Mature wood	Tang.	2.10	1.89	1.13	1.35
	Rad.	1.57		1.59	
	Rad.	2.00		1.34	
Red false heartwood	Tang.	4.07	3.46	0.94	1.34
	Rad.	4.64		1.48	
	Rad.	1.67		1.59	

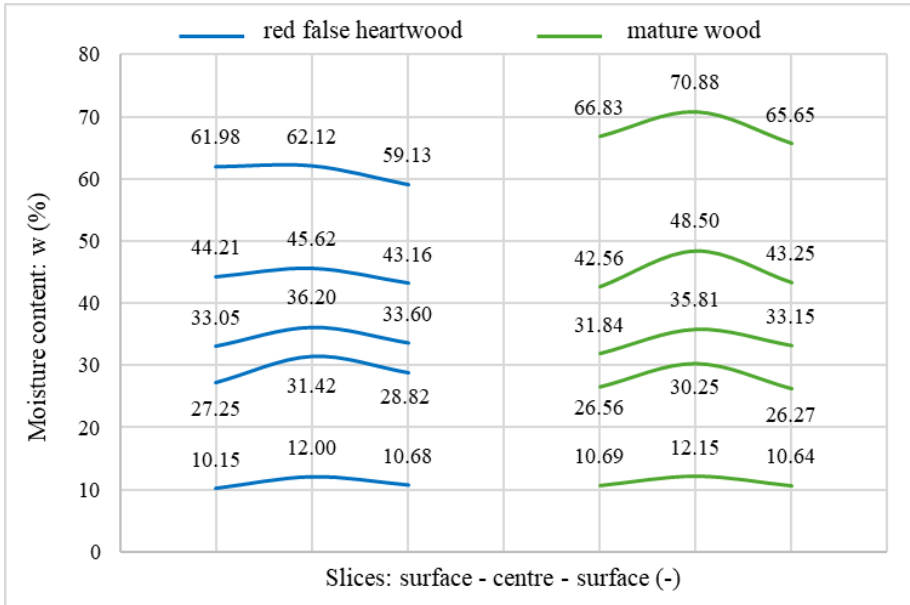


Fig. 5. Moisture gradient of radial samples

Wood density

The wood density was measured in the absolute dry state. As shown in Table 4, samples of mature wood had higher density than red false heartwood samples, with an average difference of 68.4 kg/m³. Electron microscopy (Tescan VEGA) examination revealed the presence of hyphae (Fig. 6) in the red false heartwood. This finding provides an explanation for both the reduced weight and higher moisture content observed in red false heartwood compared to mature beech wood. During sample selection, logs that were free from other defects were specifically chosen. Visual inspection confirmed that the red false heartwood appeared healthy, which would normally suggest similar density between samples. However, significant density differences were revealed by our measurements despite this visual similarity. The presence of hyphae in the red false heartwood to be responsible for these measurable property differences between the two wood types. This demonstrates that microscopic examination is essential for fully understanding variations in wood density and moisture characteristics.

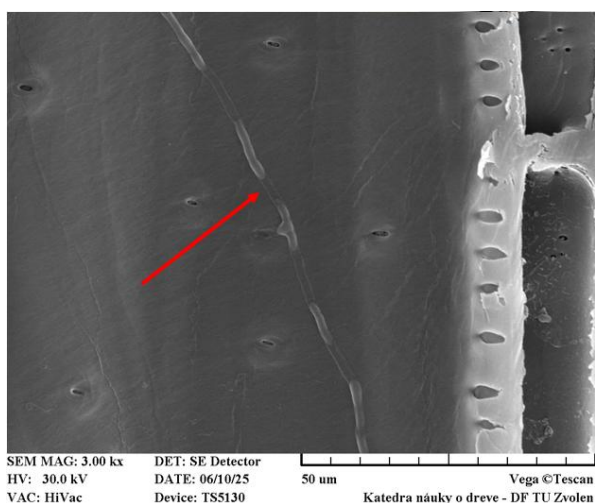


Fig. 6. Hyphae in beech red false heartwood vessels (SEM Tescan Vega, Department of Wood Science)

Table 4. Wood density

Sample		Density (kg/m ³)	Min./Max. (kg/m ³)	Average (kg/m ³)	St. dev.
Mature wood	Tang.	681.4	655.1 / 710.3	679	20.3
	Tang.	710.3			
	Rad.	669.3			
	Rad.	655.1			
Red false heartwood	Tang.	597.1	597.1 / 625.8	610,6	11.1
	Tang.	615.9			
	Rad.	603.7			
	Rad.	625.8			

Drying curve

The drying curve is used to illustrate the material's drying process, with moisture loss being shown over time. Analysis of the drying curves revealed how moisture content changed in each sample throughout the drying period. A significant moisture reduction was observed during the second drying stage, which began 8 days after the start of drying. For radial samples (Fig. 7), moisture content decreased gradually until reaching equilibrium between samples. The tangential samples (Fig. 8) showed different behaviour - red false heartwood lost free water more rapidly, with noticeable moisture reduction just 3 days into drying. While the moisture loss patterns of red false heartwood subsequently matched those of mature wood, a consistent 2% difference remained until the final stages, when it narrowed to 1%. These results demonstrate that red false heartwood dried faster than mature wood, consistently reaching lower moisture levels during the same drying time. The faster initial drying of red false heartwood's tangential samples suggests structural differences affecting water movement, while the eventual convergence indicates similar

bound water removal rates in later stages. The findings highlight how sample orientation (radial vs. tangential) and wood type (red false heartwood vs. mature wood) both significantly influence drying kinetics.

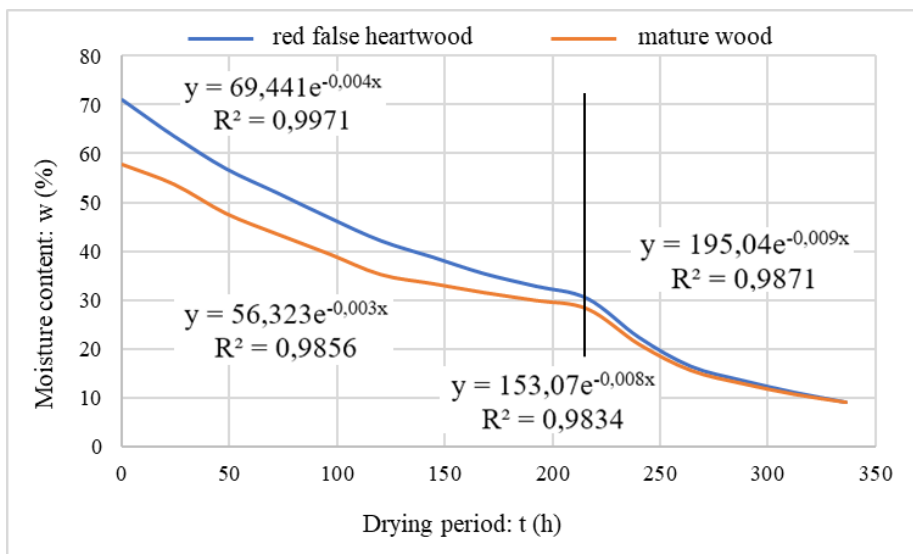


Fig. 7. Drying curve of radial samples

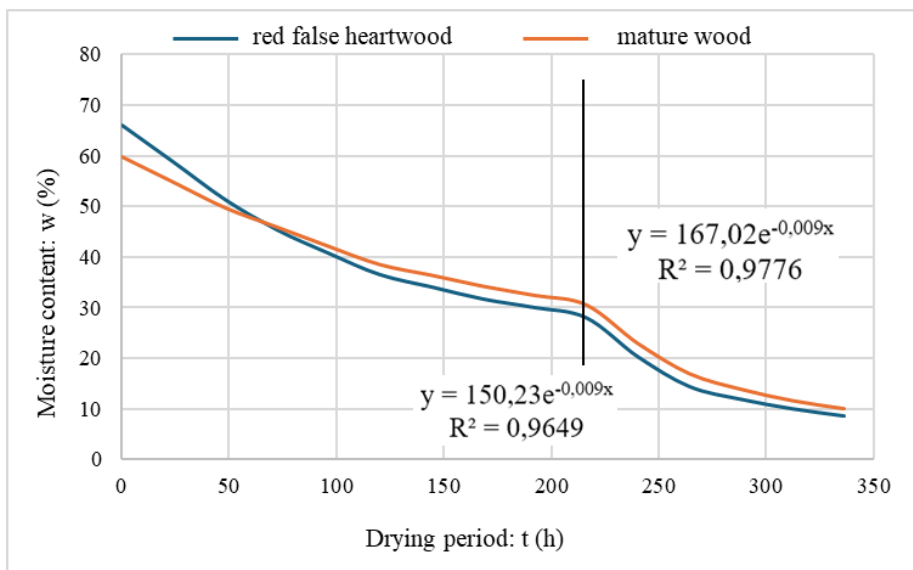


Fig. 8. Drying curve of tangential samples

To analyse the drying rate over time, the moisture loss of the drying samples was calculated (Table 5). The drying rate analysis was divided into two zones: the free water zone (above FSP) and the bound water zone (below FSP). The zone above FSP was

characterized by sample moisture content of $w \geq 30\%$, while the zone below FSP had moisture content of $w < 30\%$. In red false heartwood samples, a decrease in moisture loss rate was observed when moisture content fell below 30%. This reduction was caused by tylosis formation in the red false heartwood vessels.

Table 5. Moisture loss rate of drying samples over time

Sample		Moisture loss rate (%/h)	
		$w \geq \text{FSP} (\geq 30\%)$	$w < \text{FSP} (< 30\%)$
Mature wood	Tang.	0.135	0.171
	Rad.	0.145	0.145
Red false heartwood	Tang.	0.187	0.148
	Rad.	0.189	0.177

Conclusions

Several important conclusions were reached through comprehensive measurements and analysis:

- The initial moisture content averaged 68.69% in red false heartwood samples compared to 59.49% in mature wood samples - a 9% difference that contradicted our expectation of lower moisture levels in red false heartwood. Following the drying process, the moisture contents equalized between both wood types.
- The moisture gradient before drying was significantly higher in red false heartwood samples (3.46%) compared to mature wood samples (1.89%). However, after drying, both sample types achieved similar moisture gradient levels (approximately 1.35%).
- The wood density of mature wood samples averaged 679 kg/m³, which was 68.4 kg/m³ higher than that of red false heartwood samples (610.6 kg/m³). Electron microscopy analysis of the red false heartwood samples revealed the presence of hyphae.
- The drying kinetics of red false heartwood and mature wood samples showed similar patterns. However, tangential samples of red false heartwood exhibited 1% lower final moisture content compared to tangential samples of mature wood after drying completion. Based on these results, no significant difference was observed in the drying kinetics between beech red false heartwood and mature beech wood.
- The moisture loss rate was higher in red false heartwood samples (0.187-0.189%/h) when moisture content was above the fiber saturation point (FSP). Below FSP, the moisture loss rate decreased to 0.148-0.177%/h in red false heartwood. This reduction occurs due to altered permeability caused by tyloses formation in the vessels of red false heartwood.

The results were most likely influenced by the presence of hyphae in the beech red false heartwood, despite our careful material selection process that excluded other wood defects such as knots, reaction wood, decay, fiber distortion, juvenile wood, etc. For future measurements, it will be necessary to pay greater attention to material selection, even if this means working with smaller zones of red false heartwood.

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