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DEVELOPMENT OF DISCOLOURATION DURING CONVENTIONAL DRYING OF OAK TIMBER

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ABSTRACT

This research aimed to examine the development of inhomogeneous colour changes in oak timber during conventional drying and its relation to moisture content distribution across the wood thickness. To explore this phenomenon, control boards (quarter-sawn and flat-sawn, 38 mm thick) were cut from two oak logs, one of the sessile oak (*Quercus petraea*) and one of the pedunculate oak (*Quercus robur*). The control boards were dried in a conventional kiln according to the common drying schedule, and at specific time intervals, samples were taken to determine the moisture content profile. During each cutting of the samples, the appearance of discolouration was controlled. The results of the study revealed that there is a connection between the moisture content distribution within the boards and the appearance of discolouration. Furthermore, it was found that sessile oak timber dries more slowly and with less intense discolourations than pedunculate oak timber. It is confirmed that quarter-sawn boards dry slower compared to flat-sawn boards, and this applies to both wood species.

Keywords: conventional drying, oak timber, discolouration, moisture content profile

1. INTRODUCTION

The highly aesthetic texture of oak wood positions it among the most visually captivating and certainly the most high-priced hardwood species in Europe. There are three main types of oak trees in Serbian forests: the pedunculate oak (*Quercus robur*), the sessile oak (*Quercus petraea*), and the Turkey oak (*Quercus cerris*). The pedunculate oak and the sessile oak are used for more technical purposes. From the felled log to high-quality oak wood products, a series of processing steps must be undertaken, among which drying stands as one of the most critical. Drying involves removing a substantial amount of water from the wood while maintaining high quality and the wood's natural colour, a challenge particularly pronounced in oak wood. It is known that oak wood undergoes a slight darkening during and after the drying process, frequently accompanied by sections that remain lighter than the surrounding wood. This phenomenon diminishes the visual quality of oak timber and leads to financial losses in the industry. These wood surfaces, characterised by a lighter hue than the surrounding wood after drying, are commonly known as "white clouds" and often manifest as discolourations in the form of irregular alternating brown and white strips (Milić, 2020). In researching this problem, one direction focused on optimising the drying schedule to avoid the occurrence of discolourations, while another direction delved into the impact of wood extractives on discolouration development. Beyond the physiological processes that take place in living or freshly cut wood, it has been determined that these colour changes are caused by chemical reactions of extractive substances (tannins) and cell wall components (Koch and Skarvelis, 2007). Conditions favourable for the development of these discolourations involve high wood moisture content (above 30%), drying temperatures exceeding 30°C, and air humidity around (or above) 70% (Fortuin et al., 1998). of extractive substances in these regions. This prevents the chemical reactions that lead to darkening.

The objective of this study was to examine the relation between drying rate, moisture content (MC) gradient across the thickness of quarter-sawn and flat-sawn boards of pedunculate oak and sessile oak, and the internal discolouration during conventional drying processes.

2. MATERIAL AND METHODS

For this study, one log of sessile oak (*Quercus peatrae* L.) and one log of pedunculate oak (*Quercus robur* L.) were selected, each with an average diameter of approx. 40 cm and a length of about 3.0 m. From each log, two quarter-sawn and two flat-sawn trimmed control boards were sawn, with a nominal thickness of 38 mm and a width of 100-120 mm. These boards were marked, and samples were taken from each end to determine the initial MC gradient and density (Fig. 1). MC gradient samples were sliced into 7 lammelae, and the MC of each lammela was determined by the oven-dry method. Density was determined on samples with dimensions of 38x38x20 mm. The end grain of the control boards was protected with adhesive, and they were placed in a conventional kiln with a capacity of 200 m^3, along with other oak boards of the same thickness. The drying schedule started with an initial temperature of 33°C and concluded at 62°C, while an initial EMC was 17.5%, eventually reaching a final value of 4%. Drying was controlled based on 4 (out of 10) of the wettest electrical probes, positioned at a depth of 1/3 of the board's thickness. Drying continued until the moisture content reached 8%. During the drying process, the control boards were periodically removed from the kiln. From one end, a 20 mm sample was cut to determine the MC profile. The discarded 100 mm sections (Fig. 1) were used to assess the occurrence of internal discolourations. The end grain was readhered, and the boards were returned to the kiln. A total of 9 samplings were conducted at specific time intervals: 0 hours (initial), 48 hours, 96 hours, 240 hours, 384 hours, 576 hours, 1008 hours, 1416 hours (end of the active drying phase), and 1440 hours (end of the conditioning phase). The entire drying process lasted 1440 hours (60 days).

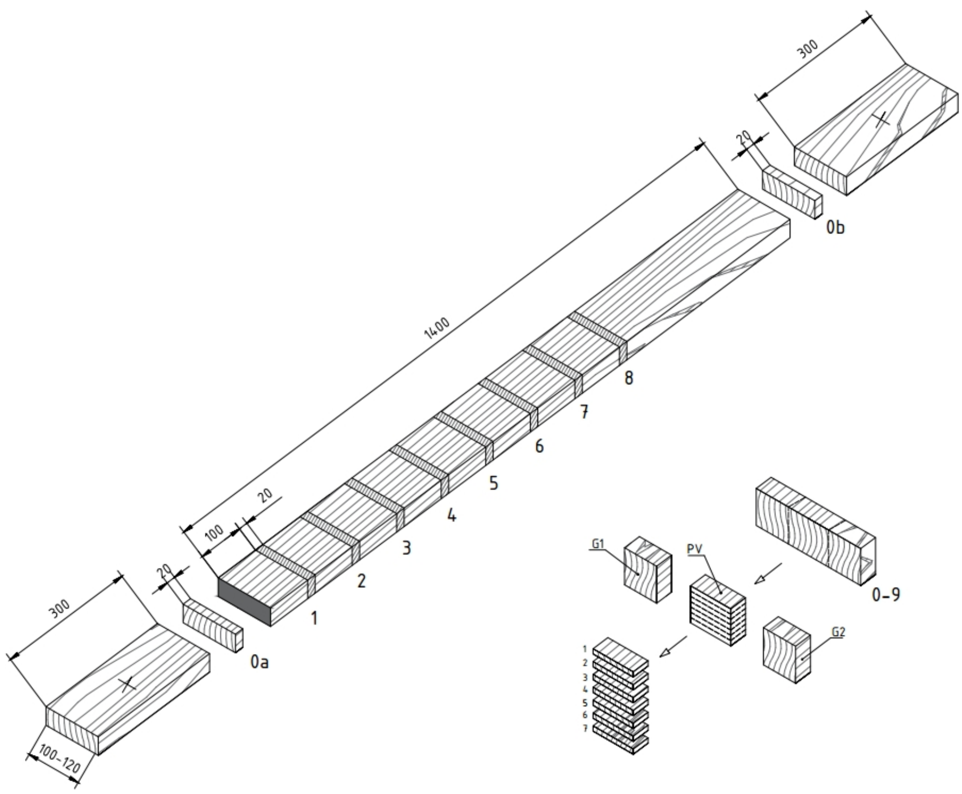

Figure 1: *Test samples for determination of MC profiles (7 lammelae) during drying*

3. RESULTS

The average oven-dry density of sessile oak wood was 675 kg/m³ (variations ranging from 630 to 732 kg/m³), which is in agreement with the literature data (Šoškić et al. 2005, Deaconu et al. 2023). The pedunculate oak wood exhibited 40 kg/m³ lower oven-dry density–635 kg/m³ (with variations between 620 and 647 kg/m³), slightly higher compared to values reported in the literature (Vavrčík and Gryc, 2012). The initial MC of the sessile oak and pedunculate oak boards was 60.8% and 61.7%, respectively.

Fig. 2 illustrates the MC profiles across the thickness of sessile oak control boards during the drying process. As expected, the outer layers lost free water fast during the initial days of drying, causing an MC gradient that later prompted the movement of water from the central layers towards the surface. The highest MC difference across the thickness of 20.3% occurred after 48 hours of drying for quarter-sawn boards, while flat-sawn boards exhibited the highest difference of 22.6% after 96 hours of drying. From then on, the MC difference between central and outer layers gradually decreased, ultimately reaching minimal values (2.3-3.3%) at the end of drying.

The difference in drying rates between quarter-sawn and flat-sawn boards became noticeable after 10 days of drying. After 42 days of drying, quarter-sawn boards reached an average MC of 15.6%, while flat-sawn boards reached an average MC of 10.1%, indicating significantly faster drying of flat-sawn compared to quarter-sawn boards. Consequently, this difference led to overdrying of flat-sawn boards (6.4% and 6.5%).

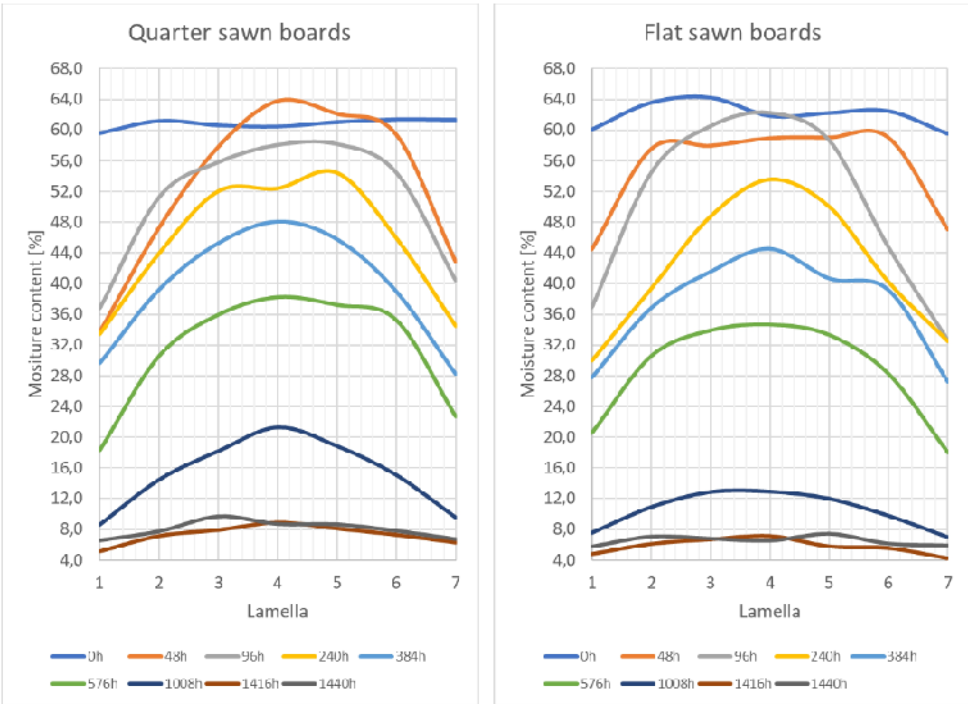

Figure 2: *MC profiles across the thickness of sessile oak boards during drying*

In terms of MC difference across the thickness during drying, a similar pattern was observed in pedunculate oak boards (Fig. 3). The highest MC difference was observed in quarter-sawn and flat-sawn boards after 240 hours (24.7%) and 48 hours of drying (25.1%), respectively. As drying progressed, the MC differences diminished, ultimately reaching minimal values of 0.8-1.4% at the end of the drying process. Again, a significantly higher drying rate was found in flat-sawn compared to quarter-sawn boards. This disparity in drying rates became evident already after 96 hours of drying. After 42 days of drying, quarter-sawn and flat-sawn boards achieved average MCs of 12.0% and 9.9%, respectively.

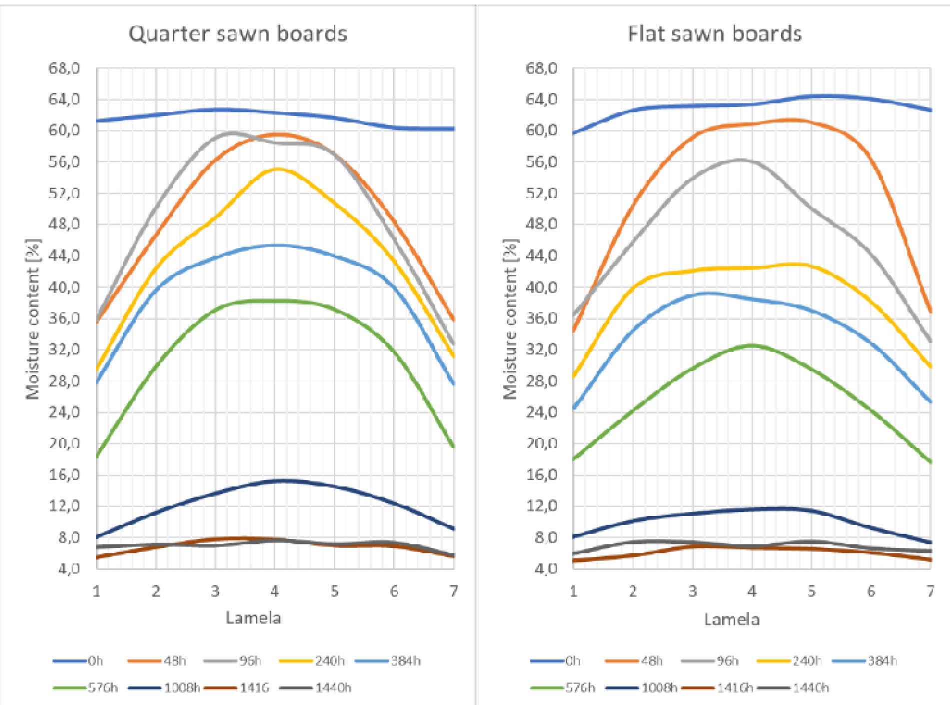

Figure 3: *MC profiles across the thickness of pedunculate oak boards during drying*

Figures 4 and 5 depict MC differences and photographs of board cross-sections taken at specific time intervals for both wood species. In the case of sessile oak, the emergence of cross-sectional discolourations in the form of a darker outer layer and a lighter inner layer is barely noticeable, only becoming apparent after 576 hours of drying (Fig. 4). These discolourations disappear entirely with further drying.

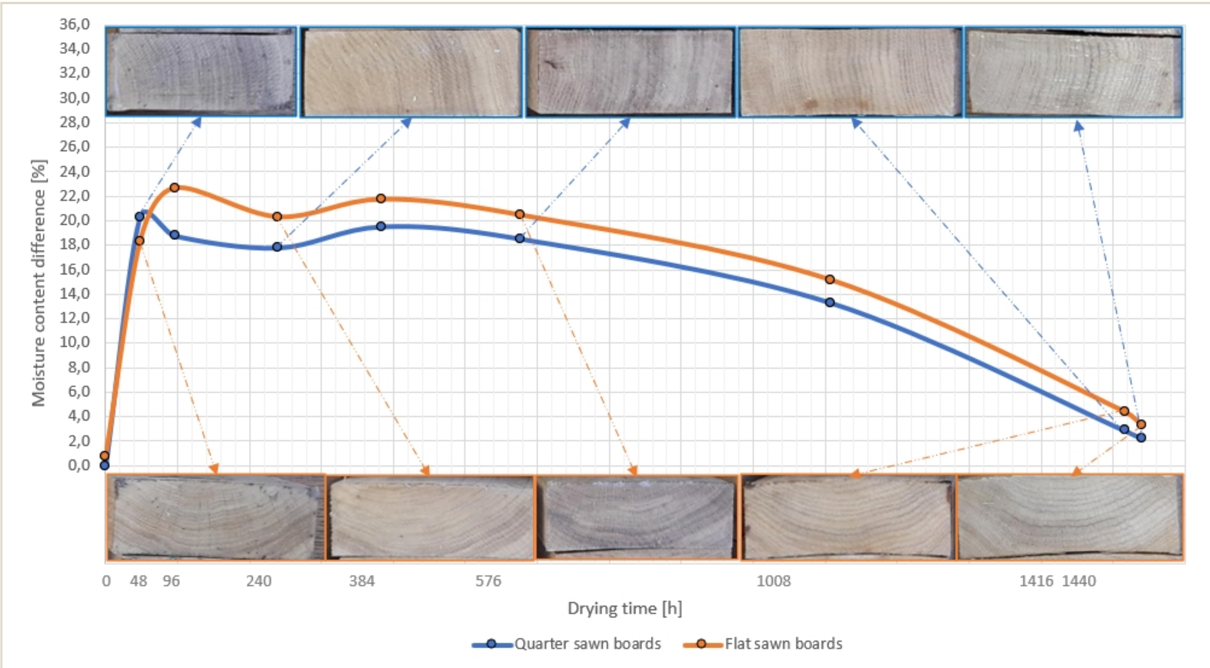

Figure 4: *MC differences and discolouration progression for quarter-sawn and flat-sawn sessile oak boards*

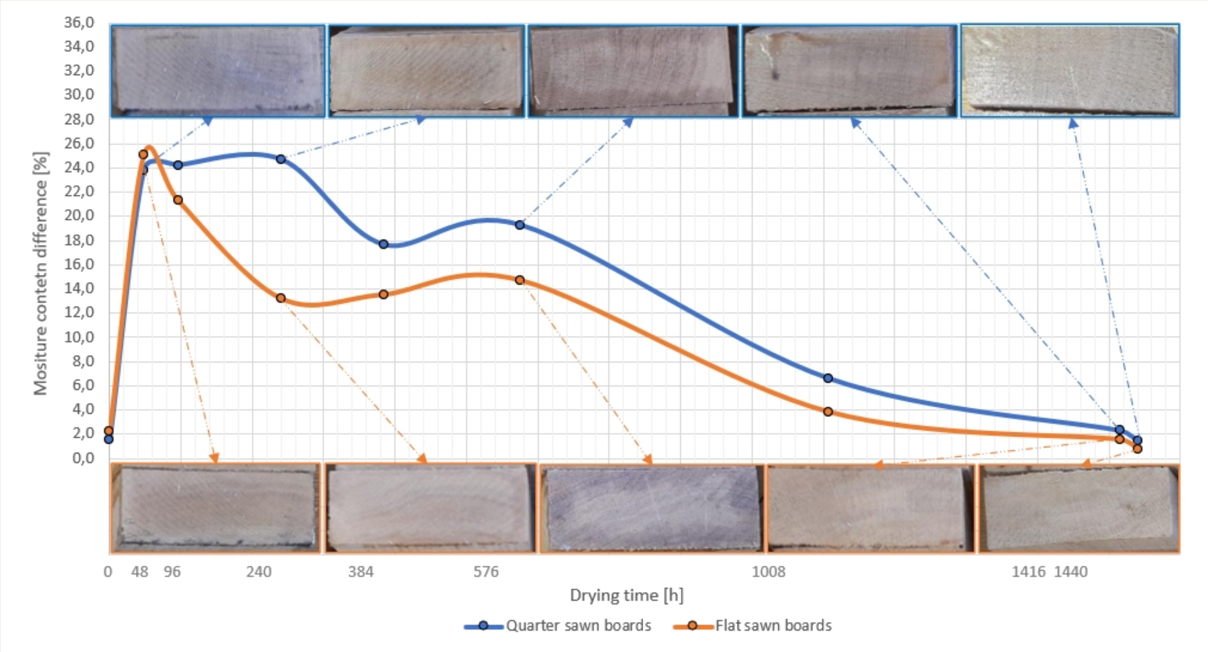

***Figure 5:** MC differences and discolouration progression for quarter-sawn and flat-sawn pedunculate oak boards*

In the case of pedunculate oak boards, the occurrence of discolouration on the cross-section can be observed after 240 hours of drying (Fig. 5). These discolourations progressively intensify, with the darker outer layer extending towards the central portions and the inner, lighter layer diminishing. At the end of the drying process, subtle irregularities remain visible on the board cross-sections.

The more pronounced discolourations in pedunculate oak compared to sessile oak are likely the result of a combined effect of multiple factors. One of these factors is the somewhat differing drying behaviour: e.g., a higher maximum MC difference (i.e., a higher moisture gradient) was observed in pedunculate oak, but this difference decreases significantly faster than in sessile oak during drying. After 42 days of drying, this difference for quarter-sawn and flat-sawn pedunculate oak boards was 7% and 4%, respectively, whereas for sessile oak, these values were as high as 13.5% and 15.5%. Nevertheless, the primary cause of the more pronounced discolourations in pedunculate oak could be the greater density variation within the boards of this species. Areas of higher density within the board retain water for a longer period than areas of lower density, behaving similarly to inner compared to outer layers of the board. This longer presence of free water leads to the accumulation of tannins, which further prevent the darkening of the wood (Felhofer et al. 2021, Hansmann et al. 2020). The irregular forms of discolouration in Fig. 5 also indicate potential density variation.

4. CONCLUSIONS

In this study, an investigation was carried out to explore the behaviour of pedunculate oak and sessile oak wood during the drying process, with a specific focus on moisture content (MC) gradients and the development of internal discolourations. The results shed light on the complex interactions between wood species, drying parameters, and discolouration formation. The following conclusions can be drawn:

1. The drying behaviour of sessile oak and pedunculate oak timber differs: pedunculate oak boards dry faster, with a somewhat higher MC gradient at the beginning of drying, but much lower in the later stages compared to sessile oak boards.

2. Both oak species demonstrated faster drying in flat-sawn boards compared to quarter-sawn boards, although the influence of grain orientation on discolourations remained unclear.

3. Pedunculate oak displayed more pronounced and persistent discolourations. While factors such as moisture content gradients and drying rates clearly influence discolouration, the density variation within pedunculate oak boards could be a significant contributing element to the observed differences in discolouration intensity.

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