Drying of Steaming Maple Timber in Drying Kilns, While Preserving the Color Acquired by the Wood Steaming Process

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Abstract. The paper presents a mode for drying steaming maple timber of thickness h = 38 mm from moisture W_1 = 50 % to W_2 = 10 %, while preserving the color of wood obtained by the steaming process. The drying process is divided into two parts. Evaporation of free water from wet wood at drying medium temperatures t_d = 35 - 40 °C and evaporation of water from wood below the hygroscopicity limit $W \leq 25$ % at drying medium temperatures t_d = 70 - 80 °C. Total color difference ΔE^* determined by the difference in values on the CIE $L^*a^*b^*$ color space coordinates dried by the proposed mode for steaming maple timber and the reference values ΔE^* = 1.03. According to the categorization of wood color changes in thermal processes by work (Cividini et al. (2007), this change belongs to the category of small color changes. A negative aspect of this drying mode is the approx. 25 % increase in timber drying time.

1. Introduction

The color of maple wood according to works [1-2] is white to light white-gray-yellow. In the CIE $L^*a^*b^*$ color space, the color of maple wood is described by the coordinates: L^* = 80.99; a^* = 5.20; b^* = 16.36 [3]. In the work: Wood color of central European wood species: CIELAB characterization and color intensification, authors: Meints - Teischinger - Stingl - Hansmann [4] for maple wood color give values: L^* = 87.9; a^* = 5.3; b^* = 22.3. Technological processes of thermal treatment of wet maple changing its color. The wood is darker and, depending on the steaming regime, acquires a pale pink-brown, red-brown to dark brown-red color [5-6]. The above statement is in accordance with the knowledge of the effect of heat on wet wood [6-13].

Wood drying is a hydrothermal process in which water is removed from the wood. Warm-air drying of timber is carried out in warm-air dryers out according to drying regimes ON 49 0651, GOST, or own drying regimes of individual companies: KATRES s.r.o., Hildebrand Holztechnik GmbH, Mühlböck Holztrocknungsanlagen GmbH, NARDI. Drying of maple wood is normally carried out at drying medium temperatures t = 60 – 80 °C. The realization of the drying process at these temperatures creates conditions not only for the removal of water from the wood, but also for the course of chemical reactions

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causing changes in the lignin-carbohydrate complex of the wood, manifested by a change in the color of the wood [14-18].

The aim of this work is to assess the proposed regime for drying of steaming maple timber thickness h = 38 mm from moisture content $W_1 \approx 50$ % to $W_2 = 10$ % in chamber drying kilns, in terms of wood color change and dried timber quality.

2. Technological parameters of the drying process

2.1. Thermal treatment maple timber - steaming

Maple timber has been steamed before drying - thermally modified by saturated water steam having a temperature of $t = 125 \pm 2.5$ °C for $\tau = 7.5$ h hours in order to obtain a brown-red color of the wood.

2.2. Mode for drying maple timber while preserving the original color of the wood

Drying of steaming maple wood was performed:

- in an air-conditioned room,
- in a hot air dryer timber.

2.2.1 Drying of steaming maple wood in an air-conditioned space.

From the steaming maple timber 20 samples with dimensions 38 x 70 x 500 mm were made, which were dried in an air-conditioned room at an air temperature of $t = 20$ °C and a relative humidity of $\varphi = 60$ %. The color of such dried steamed maple wood is marked - *Reference value.*

2.2.2 Mode of drying for steamed maple timber in a hot air dryer.

Heat-treated maple wood with steam thickness h = 38 mm were dried in a hot air oven chamber KC 1/50 manufactured by SUSAR Ltd. The conditions for drying of the steaming maple timber from moisture content of $W_1 \approx 50$ % to moisture content $W_2 = 10$ % shown in Table 1.

Table. 1 Maple timber drying mode.

Phase of drying	Timber thickness h = 38 mm		
	t_d [°C]	Δt [°C]	τ [h]
Initial heating	35	2	4
50 - 35	35	5	52
35 - 25	40	8	37
Conditioning	50	3	6
25 - 20	70	7	14
20 - 15	80	10	19
15 - 10	80	15	27
Treatment	80	6	7
Cooling	30	7	4

The drying process is divided into two parts. The drying process is divided into two parts. Drying during adiabatic evaporation of free water from wet wood is at temperatures t = 35 - 40 °C and relative air humidity φ = 70 - 60 %. At these temperatures, conditions for chemical reactions of lignin in the lignin-saccharide complex manifested by a change in the chromophore system causing a change in color of steamed maple wood are not created. At the end of said phase, conditioning is employed to partially eliminate the moisture

gradient formed in the lumber during the evaporation of water from the cell lumens. Conditioning is carried out by increasing the relative air humidity to φ = 84 % and the air temperature to t = 50 °C. Drying of maple wood below the limit of hygroscopicity of maple wood is carried out at humid air temperatures t = 70 - 80 °C.

2.3 Quality control of dried maple timber

After drying, the following were measured:

- color of steamed maple wood.
- the quality of the dried wood by determining: the deviation of the final moisture from the desired moisture w_0, the variation of the final moisture w_{k0} and the moisture content gradient Δw.

The color of the wood on the planed surface, after drying the maple timber, was measured with a Color Reader CR-10 colorimeter. The effect of the drying regime on the color change of maple wood was evaluated by:

- by determining the values at the coordinates L^*, a^*, b^* of the CIE color space L^* a^* b^* of dried steamed maple wood,
- by comparing the values at L^*, a^*, b^* of the dried timber by the warm-air drying regime with the reference values of the coordinates L^*, a^*, b^* of maple wood dried in an air-conditioned space,
- by determining the total color difference ΔE^* quantified by the relation:

$$\Delta E^* = \sqrt{\left(L_1^* - L^*\right)^2 + \left(a_1^* - a^*\right)^2 + \left(b_1^* - b^*\right)^2} \tag{1}$$

where: L^*, a^*, b^* values on the coordinates of the color space of maple wood dried in the air-conditioned space,
L^*_1, a^*_1, b^*_1 values on the color space coordinates of maple wood dried by the proposed warm-air drying mode in the KC 1/50 oven.

The deviation of the final moisture content from the required moisture is described by the equation:

$$w_0 = \frac{\sum_{i=1}^{n} w_{i\mathrm{k}}}{n} - w_{\mathrm{k}} \quad [\%], \tag{2}$$

where: n – number of control samples [-],
$w_{i\mathrm{k}}$ – final sample moisture [%],
w_{k} – required final wood moisture [%].

The variation in final moisture content is evaluated by the difference between the maximum and minimum moisture values of the samples according to the relation:

$$w_{\mathrm{k0}} = w_{\max} - w_{\min} \quad [\%], \tag{3}$$

where: $w_{\max}$ – maximum moisture content in drying samples [%],
$w_{\min}$ – minimum moisture content in drying samples [%].

The moisture gradient in the timber was determined from the difference in moisture of the middle layer and the diameter of the two surface layers:

$$\Delta w = w_{\mathrm{s}} - w_{\mathrm{pov}} \quad [\%], \tag{4}$$

where: w_{s} – center layer moisture content [%],

w_{pov} – moisture content of surface layers [%].

3. Result and discussion

The color of steamed maple wood dried in an air-conditioned room at an air temperature of t = 20 ° C and a relative humidity of φ = 60 % (reference value) is described by the coordinates:

L* = 69.6 ± 1.7; a* = 11.4 ± 1.3; b* = 18.9 ± 1.5.

The values of color coordinates: L*, a*, b* of dried maple timber of thickness h = 38 mm, according to the proposed drying regime, on a planned surface of 36 pieces of timber, are:

L* = 68.7 ± 1.6; a* = 11.5 ± 1.3; b* = 18.4 ± 1.4.

The differences between the color of dried maple wood in the oven and the color of maple wood dried in the air-conditioned space are shown in Table 2.

Table 2. Coordinate values: L*, a*, b* and total color difference ΔE*.

Parameter of the color space CIE L^* a^* b^*	L^* coordinate	a^* coordinate	b^* coordinate	ΔE^*
Wood dried in the chamber drying kilns	68.7	11.5	18.4	----
Reference value	69.6	11.4	18.9	----
Differences in ΔL^*, Δa^*, Δb^* and ΔE^*	- 0.9	0.1	- 0.5	1.03

The values on the color coordinates of the dried of the steaming maple timber in the chamber drying kilns compared to the reference values - of the steaming maple wood dried in the air-conditioned space differs slightly. The whiteness of maple wood decreased by ΔL^* = - 0.9, the value at the red coordinate increased by Δa^* = + 0.1 and the value at the yellow coordinate decreased by Δb^* = - 0.5. The value of the total color difference ΔE^* = 1.03, according to the categorization of wood color changes in the thermal processes reported by the authors (Cividini *et al.* 2007) [15] classifies the color change of maple wood into the category ΔE^* = 0.2 - 2, i.e. the category of small color changes.

The results of analyzes evaluating the quality of dried maple timber are shown in Table 3.

Table 3. Quality evaluation of dried timber.

Quality features		Measured value
Deviation of the final moisture content of the desired wood moisture content	w_0	0.8 ± 0.3 %
Fluctuation of final moisture of timber	w_{k0}	1.8 ± 0.2 %
Moisture gradient of timber	Δw	1.1 ± 0.3 %

On the basis of a comparison the measured quality values of the dried the steaming timber with the values of the high quality qualities [19], it follows that the dried maple timber of thickness h = 38 mm belongs to the quality class:

- II. quality class, deviation of final moisture from required moisture (w_0 = 0.6 – 1.5%)
- I. quality class, final moisture content variation ($w_{k0} \leq$ 2.0 %)
- I. quality class, moisture gradient ($\Delta w \leq$ 1.5 %).

The negative aspect of the presented steaming maple timber drying h = 38 mm is the approx. 25 % increase in the timber drying time compared to maple wood drying modes at temperatures t = 60 - 80 °C. It is caused by the realization of the drying process at lower temperatures.

4. Conclusion

The paper presents a mode for drying steaming maple timber for thicknesses h = 38 mm from moisture content $W_1 \approx 50$ % to final moisture content $W_2 = 10$ %, while preserving the original color of the wood acquired during the steaming process.

The color coordinates of the dried of the steaming maple wood in the CIE color space $L^*a^*b^*$ are: $L^* = 68.7 \pm 1.6$, $a^* = 11.5 \pm 1.3$, $b^* = 18.4 \pm 1.4$. The change in color of maple wood due to the drying process, expressed as the total color difference ΔE^* compared to the color of maple wood dried in an air-conditioned space, is $\Delta E^* = 1.03$. This color change, according to the categorization of wood color changes in the thermal processes reported by the authors (Cividini et al. (2007), classifies the color change of maple wood due to drying into the category $\Delta E^* = 0.2 – 2.0$, i.e. small color changes.

The negative aspect of the mentioned drying mode is the approx. 25 % increase in the drying time compared to the mapping wood drying modes at temperatures t = 60 - 80 °C.

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