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Determination of Optimum Lumber Drying Schedule of Tree of Heaven Grown in Türkiye

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: The invasive tree species threaten the domestic species of a region. However, they can be evaluated for wood industry when they were cut to decrease the population. This study studied a fast-growing deciduous tree species, tree-of-heaven (*Ailanthus altissima*), to determine the optimum drying schedules of lumbers from Turkey-grown individuals.

Results: Optimum schedule was determined from different suggestions in literature and applied in a 1m^3 capacity laboratory type-drying kiln on 39 lumber pieces with dimensions of 65x65x2000 mm. The drying time and quality were evaluated according to standards and different methods (e.g. prong test) from literature. Although the fast-growing species had some risks with having more juvenile wood ratio and lower density, it could be dried 65 to 10% moisture content with in as short as 10 days with moderate-protective drying quality.

Conclusion: Relatively shorter drying time with high quality compared to similar species (e.g. ash) might contribute the economic sustainability of sawmills. Because the shorter drying cycles will save more energy for per volume and they may be more profitable with shorter sellable dried lumber cycles. On the other hand, although the species was fast-growing, medium density (574 kg/m^3) characteristics might show the potential for being a good alternative for the wood industry.

Keywords: *Ailanthus altissima*, drying evaluation, invasive.

HIGHLIGHTS

This work offers a detailed schedule for drying Tree-of-heaven lumbers.
Tree-of-heaven lumbers can be fast dried at low stress levels without or a few defects.
The invasive tree species can be evaluated in wood industry after all investigations.
Drying evaluations should include investigating existing checks occurred before drying.

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INTRODUCTION

Wood is a valuable material due to its advantages. However, its source forest is an essential part of the ecological cycle of nature. The usage of forest products, especially tree stems, critically affects the forests' sustainability. In some cases, domestic species and the current forest area of a region or country may not be enough to feed the wood industry. Then importing can be an alternative solution, but it will not be sustainable. Invasive and non-native tree species, which may threaten the forest areas, can be an alternative solution. Evaluating the species in the wood industry can be seen as an efficient way to eliminate those (Medved et al., 2019). If their invasive character can be controlled to protect natural domestics resources, fast-growing species will be an alternative resource. During the 2021 summer, wildfires affected a big area (app. 25,000 hectares) in the southeast of Turkey (Acar et al., 2022). After that, the Ministry of Agriculture and Forestry (2022) announced an action plan to recover the area. The plan included planting deciduous species, including tree-of-heaven, oak, ash, etc., at 30% ratio with red pine, the domestic coniferous species.

The mentioned tree-of-heaven (Ailanthus spp.) species is identified as a fast-growing deciduous species and an invasive tree species in terms of the silvicultural aspect (Motard et al., 2011; Petruzzellis et al., 2019). Although a fast-growing species, wood density can reach up to 650 kg/m^3 in European individuals (Gorišek et al., 2019; Szabolcs and Varga, 2021). Kúdela and Mamoňová (2006) found that the properties and anatomical structure of tree-of-heaven were similar to ash species. The physical and mechanical properties were similar to walnut (Panayotov et al., 2011) and ash wood (Molnár and Bariska, 2006; Brandner and Schickhofer, 2013). Therefore, there were many studies for evaluating tree-of-heaven in wood industries: plywood (Divya et al., 2022), thermal modification (Barboutis and Kamperidou, 2019; Németh et al., 2020), pellet (Kamperidou et al., 2018), paper (Baptista et al., 2014). Additionally, when the *A. altissima* tree characteristics are investigated, it can reach 3 m in height in its first year and individuals can reach 20–30 m in height and 0.6–0.8 m in diameter for the duration of their life (Hu, 1979). The trees produce broad crown with thick and sparsely situated branches (Panayotov et al., 2011). These characteristics may indicate an opportunity to use the species in the construction industry, which consume higher volumes related to other wood industries, as Brandner and Schickhofer (2013) indicated.

For many end-uses and secondary manufacturing processes, the lumber should be dried to avoid undesirable defects such as excessive shrinkage, warping, splitting and checking (Effah, 2014) to ensure high-quality wood products. Therefore determining the proper drying schedule is critical. There were some studies for drying *Ailanthus* wood. Hadi and Terazawa (1984) tried to determine proper drying schedule on the one-inch boards (2.7 cm thickness) by following the defects and comparing them to 100°C temperature tests. However, they did not indicate the subspecies, although the wood properties of *Ailanthus'* subspecies were different. Boone (1988) presented schedules that were gathered from the world literature from Asian and Oceanian woods. However, the schedule for *Ailanthus* was indicated as "*Ailanthus spp.* (white sirus)". This common name was used in the literature for *Ailanthus triphysa* (Peyre et al., 2006). While wood density of *A.triphysa* was found 230 kg/m^3 (Shanavas and Mohan Kumar, 2003), as indicated before, it was one-third of *A.altissima* from European individuals. Therefore, the drying schedule might be used with modification. Gorišek et al., (2019) studied drying characteristics with physical and mechanical properties of *Ailanthus altissima* wood within the scope of the "APPLAUSE - Alien PLAnt SpEcies" project (Project no. UIA02-228) in Slovenia.

MATERIAL AND METHODS

This study aimed to determine the optimum drying schedules of Turkey-grown tree of heaven (*Ailanthus altissima*) lumber. A 23-year old *Ailanthus altissima* tree grown in the Bahcekoy region (Istanbul, Türkiye) with a diameter variance of 280 - 320 mm was harvested.

Log Sawing

Logs were cut from the tree as shown in Figure 1. After the standing part from 1.3 m height from the soil, three logs with 2 m length were cut. The small end diameters of the three logs were 310 mm in average. However, 300 mm, which was the minimum diameter, was based on sawing optimization. The nominal lumber dimensions were specified 65 x 65 mm (+/- 5 mm) for further studies. The tangential shrinkage ratio was assumed to be 8.2%, considering the maximum tangential shrinkage ratio (Panayotov et al., 2011) and drying from the fiber saturation point (FSP) to 10% target moisture content (MC). Target MC was set at 10 %,which is Turkey's practical annual average equilibrium moisture content (Welling et al., 2010). A total of 39 lumber pieces (13 per log) were cut (Figure 1).

Dry Kiln

1m^3 lumber capacity conventional-type dry kiln (Hildebrand HD 74 MK, Germany) was used (Figure 2). It had a fully automatic control system managed by Helios LG20 (Logica, Italy) hardware and WoodWizard 2 (Logica, Italy) software.

Stickers with 40 mm thickness at 500 mm intervals were used for lumber stacking. The lumbers were placed with a gap of 25 mm between them as suggested by Kantay (1993) for homogenous drying (Figure 3). Air speeds through the lumbers were 2 m/s.

Determining Drying Schedule

The drying schedule was the one suggested in Boone (1988) for white sirus (*Ailanthus spp.*) from Asia and Oceania with the following modifications: a) for the equalization (decreasing moisture differences) step, the target MC was decreased by 3 %; b) for conditioning (stress relief treatment) step, target MC was increased by 4 %; c) relative humidity (RH) and equilibrium moisture content (EMC) values related to dry- and wet-bulb stress were taken from the table of Simpson (1973) (Table 1). Otherwise, the schedule was for 25.4 mm to 38 mm (4/4 to 6/4 inches). Therefore, the adjustment was applied for 65 mm thickness according to 'Tropix' project (Tropix, 2023), which suggested that the air RH should be increased 10% at each step for thickness was between 38 – 75 mm. Additionally, the schedule was thought to be more sensitive due to drying a medium-density (> 550-600 kg/m^3) and containing more juvenile wood ratio hardwood species. Because the EDG (1994) remarked that juvenile wood could cause longitudinal stress due to more shrinkage in this direction.

Therefore, additional temperature decrement by 5°C at each step considering the difficulty of raising the high relative humidity at high temperatures, the drying costs, and the need to be more protective for this species. Although the referenced and adjusted schedule had nine steps, the available drying software related to hardware had fewer (five) steps for schedules. It had only two steps for the drying phase, considering moisture content was above or under the fiber saturation point (30%). Therefore, the average values were considered for each step. Additionally, ash species from Wood Wizard software species library (Logica, Italy) were based on for heating (20°C to the temperature of the first step) and core heating (deeply heating wood) phases (Table 2).

Moisture Measurement

The MC of lumber was monitored with sensors in the kiln according to EN 13183-2 (2002). Two sensors were placed to 1/3 depth of couple lumber pieces to follow the average MC. Additionally two sensors were placed to 1/6 and 1/2 depth of a lumber for following the moisture gradient. After drying, the MC of all timbers were measured according to the same method with a portable moisture meter (Hydromette HT 65, GANN, Germany). The device did not have an adjustment for measuring *Ailanthus spp*. Therefore, it was adjusted for ash species according to Kúdela and Mamoňová (2006).

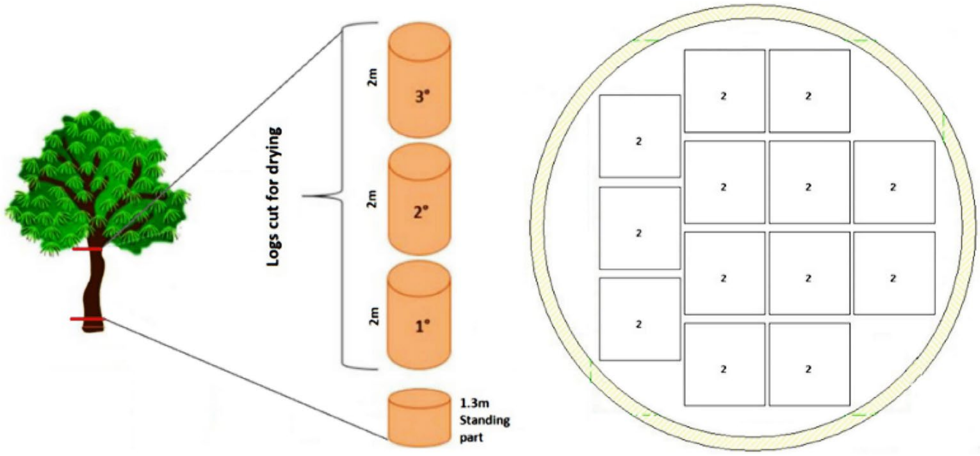


Figure 1: (Left) Log cutting, (Right) Lumber cutting diagram.

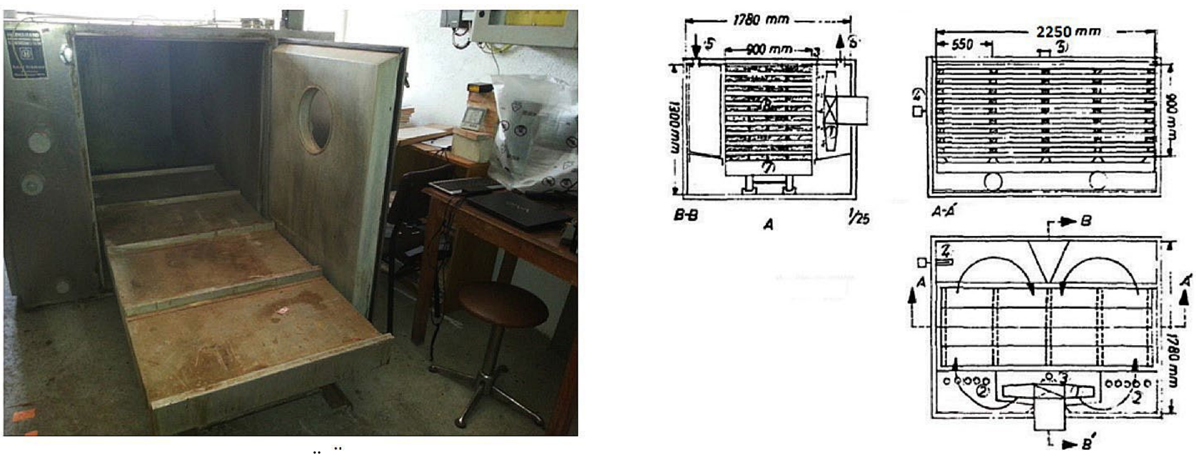


Figure 2: Drying Kiln (Drawing: Ünsal, 1994).

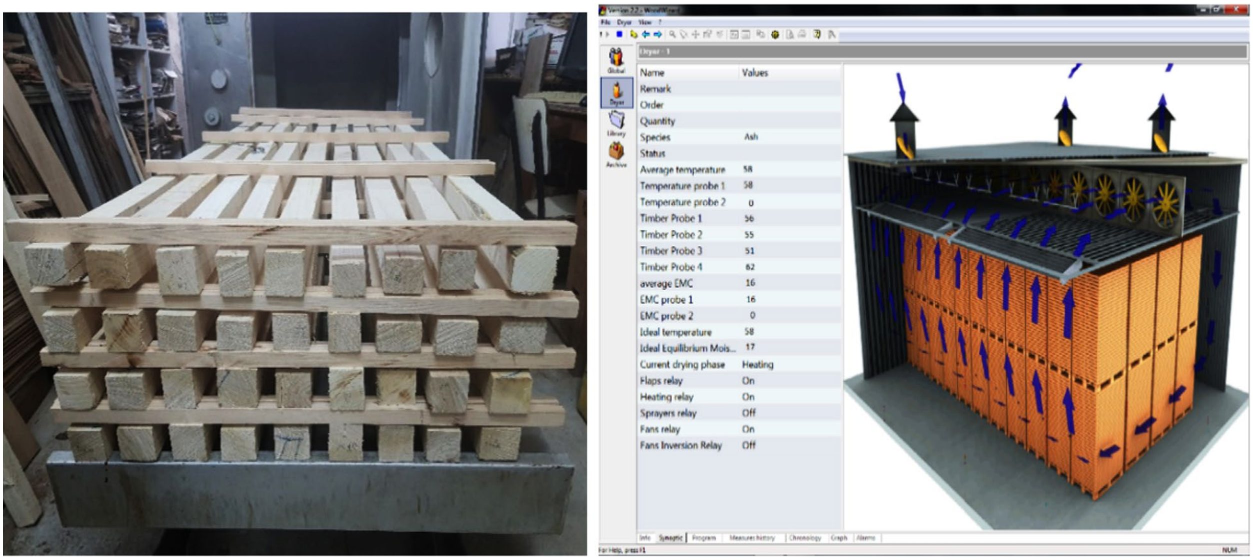


Figure 3: Stacking (Left) and a sample screen of drying automation software (Right).

Table 1: Drying schedule for 4/4, 5/4, 6/4 stock (for 25 to 38 mm) (Boone, 1988).

Step	Moisture content (MC, %)	Temperature (°C)		Relative humidity (%)	Equilibrium moisture content (%)	Drying gradient
		Dry-bulb	Wet-bulb			
1	Above 50	60.0	56.0	82	14.2	2,1
2	50 to 45	60.0	55.0	77	12.6	2,4
3	45 to 40	60.0	53.0	69	10.6	2,8
4	40 to 35	65.0	56.0	64	9.2	3,3
5	35 to 30	65.0	53.0	54	7.6	3,9
6	30 to 25	70.0	54.0	45	6.1	4,9
7	25 to 20	75.0	54.0	35	4.8	5,2
8	20 to 15	80.0	50.0	22	3.2	6,3
9	15 to final (10)	85.0	55.0	24	3.2	4,7
Equalizing		82.0	69.0	57*	6.8*	-
Conditioning		82.0	79.0	88*	10 (Target MC)	-

*The values were taken from table of Simpson's study (1973).

Table 2: Drying schedule for available drying software and hardware.

White Ash (for 75mm thickness from Helios library)			Applied Schedule (for Helios)
Heating	Degrees /Hour	8	8
	EMC	17	17
Core Heating Time		16	16
Initial MC to 30%	Drying Gradient	2.2	2.6
	Temperature (°C)	42	58
16% to Target MC	Drying Gradient	2,8	4,0
	Temperature (°C)	55	75
Conditioning	Time (hour)	16	16
	EMC (%)	10	10

**MC: Moisture content, EMC: Equilibrium moisture content.*

Drying Time Prediction

Drying time calculation from Vanicek company (formerly VT Trockentechnik, now Mühlböck, Austria (2023)) was based on for evaluation (Ünsal and Dündar, 2015). It had three steps for calculating the drying duration:

a) Moisture difference (MCd, %) was calculated from initial moisture (MCi, %) and target moisture (MCt, %).

$$MC_d = MC_i - MC_t \quad [1]$$

b) Drying time (Dt, hour) was calculated with hourly drying percentage (Dp, %) and coefficients (Cd, %) related to oven dry density (kg/m^3) (Table 3). If the density was not specified in the table, the coefficient was found with interpolation. The oven-dry density was determined according to EN 13183-1 (2003) standard.

$$Dt = MC_d / Dp \quad [2]$$

Table 3: Hourly drying percentage coefficients.

Oven Dry Density (kg/m^3)	Density Coefficient*
200 – 400	2.00 – 1.00
400 – 600	1.00 – 0.50
600 – 800	0.50 – 0.15
800 – 1000	0.15 – 0.05

For 25mm thickness.

c) If the lumber thickness was different from 25mm, the calculated drying time (Dtt, hour) was multiplied by coefficients for thickness (Ct) adjustment (Table 4).

Table 4: Coefficients for thickness adjustment.

Thickness (mm)	Thickness Coefficient
15	0.46
20	0.72
25	1.00
30	1.31
35	1.66
40	2.02
50	2.83
60	3.72
70	4.68
80	5.72
90	6.83
100	8.00
120	10.50
140	13.30

$$Dtt = Dt \times Ct \quad [3]$$

However, the calculation was proper for standard-sized boards such as thickness/width ratio was generally 1/2. Drying stresses that develop in wood during drying depend strongly on the board width (Perré and Maillet, 1989). Figure 4 shows the effect of board width on the overall drying process. As expected, the drying process is as fast as the small board width. In the range of 20 to 8% of the final moisture content, the total drying time varies by 2 to 3 between a square section and an infinite width (Perré and Turne, 1999).

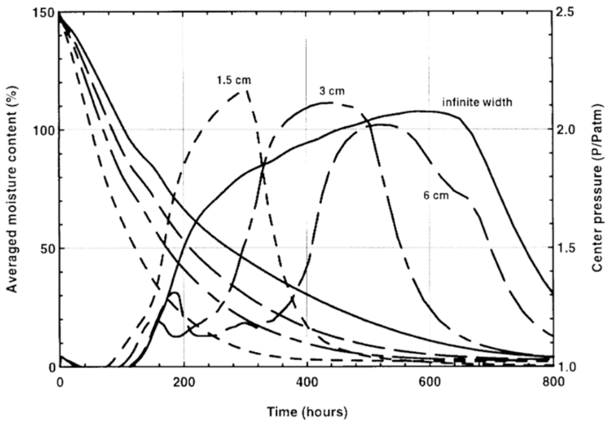


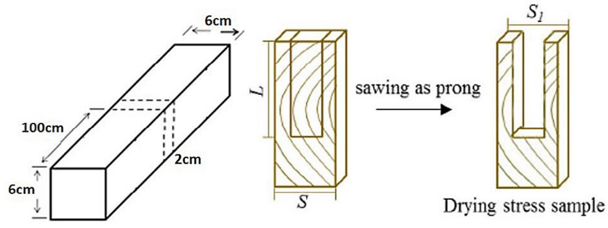
Figure 4: Overall drying curve and internal pressure for different widths (Perré and Turne, 1999).

Quality Control (After Drying)

European Drying Group (EDG, 1994), TRADA template and CEN standards were combined to evaluate the drying quality. The quality in EDG (1994) was specified with classes: S "standard", Q "quality dried" and E "exclusive" (from acceptable to the best, respectively). MC distribution was evaluated according to EN 14298 (2017) and EDG (1994) with basing on both individual pieces and average MC limits.

Evaluation of the Drying Stresses

The prong samples to evaluate the drying stress were cut from the middle of the dried specimens and sawn, as shown in Figure 5. Possible internal checks were investigated on the cut area.



*L: End length, S: Bottom length of prong, S_1: Top length of prong.

Figure 5: (Left) Sampling from lumber, (Right) Prong sample with stress (from Cai and Oliveira, 2011).

The standard prong test has been used for decades to determine the conditioning time needed for complete stress relief (Fuller, 2000). Therefore, prong samples were used for measuring the drying stresses. Measurements were applied in two stages, immediately after drying and 24 h after drying. As Fuller (2000) stated, there were many prong tests, which had different manuals, and many prong tests with different manuals suggesting different "standard" prong geometry and response, and there is little apparent agreement on the appropriate prong geometry and prong response. Therefore, three methods that have the same sample geometry were used.

a) EDG (1992) had a zonal evaluation using the TRADA pattern. When the sample was placed bottom-left corner of the pattern, the slope of the sample end was placed in a zone. The zones showed three levels of drying stresses: 1) Low, 2) Moderate, 3) Severe (Korkut and Guller, 2007) (Table 5, Figure 6). For an alternative measurement method, the prong was placed to cut the area and maximum deflection was recorded. A point according to prong length and deflection were placed into the pattern.

Table 5: Case hardening evaluation with prong sample and TRADA pattern (EDG, 1992).

	S (Standard)	Q (Quality)	E (Exclusive)
First measurement	Moderate (2)	Light (1)	Light (1)
After 24 hours	Severe (3)	Moderate (2)	Light (1)

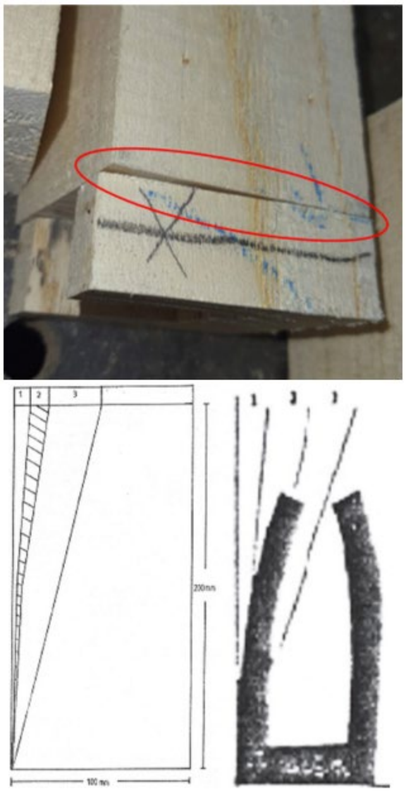


Figure 6: (Left) Trada pattern (EDG, 1992), (Middle) prong sample placed on the pattern and (Right) prong sample movement after 24 hours.

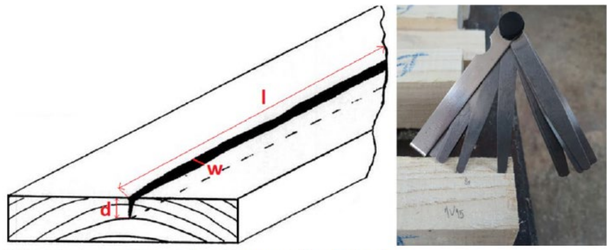
b) Cai and Oliveira (2011) measured the total displacement of each sample (S and S_1 difference in Figure 5). There was no classification, but they compared different drying operations with the values.

c) Zhan and Avramidis (2017) and Zhou et al. (2020) calculated the stress value was calculated [4]. Where; Y is the stress value and S, S1, and L are the characteristic dimensional variables (in mm) that are shown in Figure 5.

$$Y = \frac{S - S_1}{2L} \times 100 \qquad [4]$$

Fissure Development

The fissuring types such as surface, middle and internal (honeycombing), end checking and splitting, and dimensions for current (before drying) and occurred checks (after drying) were recorded. Internal checks were controlled on the cross-cut area after taking prong samples. Surface, end and internal checks dimensions were measured with a feeler gauge (precision: 0.05 mm) for width, caliper (precision: 0.01 mm) for depth and tape measure (precision: 1 mm) for length. All checks were evaluated according to EDG (1994). Otherwise, end checks were evaluated according to the table of Ciniglio (1998) that was mentioned in Maria et al. (2022) (Figure 7, Table 6, Table 7).



*Check dimensions, l: length, w: width, d: depth.

Figure 7: (Left) Surface check dimensions*, (Center) Check width measurement with a feeler gauge.

RESULTS AND DISCUSSION

Evaluation of the Schedule and Moisture Contents

Initial MC of all lumbers were higher than 60%. It exceeded limit of the moisture meter. However, readings of the drying software confirmed the values. The 1/3 depth were 67% and 64% while the other probes for measuring moisture gradient were 67 % and 88 %. The change of MC during drying and other experiment results were shown in Figure 8. The moisture content distribution for all lumbers was shown in Figure 9 and the results were shown in Table 8.

According to the results; change of MCs were in the 6.3 % range. It was evaluated S (standard) quality according to EDG. Although the results were not in the range according to EN standard, the mean was in. Therefore, first of all, MC - thickness and MC – heartwood ratio correlations were investigated, and there were no relations (R^2 = 0.1435 and R^2 = 0.1056, respectively). Then, it was thought that the reason for the wider distribution arose from improper conditioning. As seen in Table 9, although the target MC was adjusted to 10%, the software passed to the conditioning phase at 11 % MC. After the 16-hour conditioning, average timber MC was 12 %. Therefore additional conditioning phase (16 hours) was manually applied. The heating relay was closed to decrease the drying stresses. However, the suggested (and adjusted) schedule offered the same temperature for conditioning. As a result, the first conditioning period behaved as an equalizing, and the second period as a cooling phase.

Drying Time

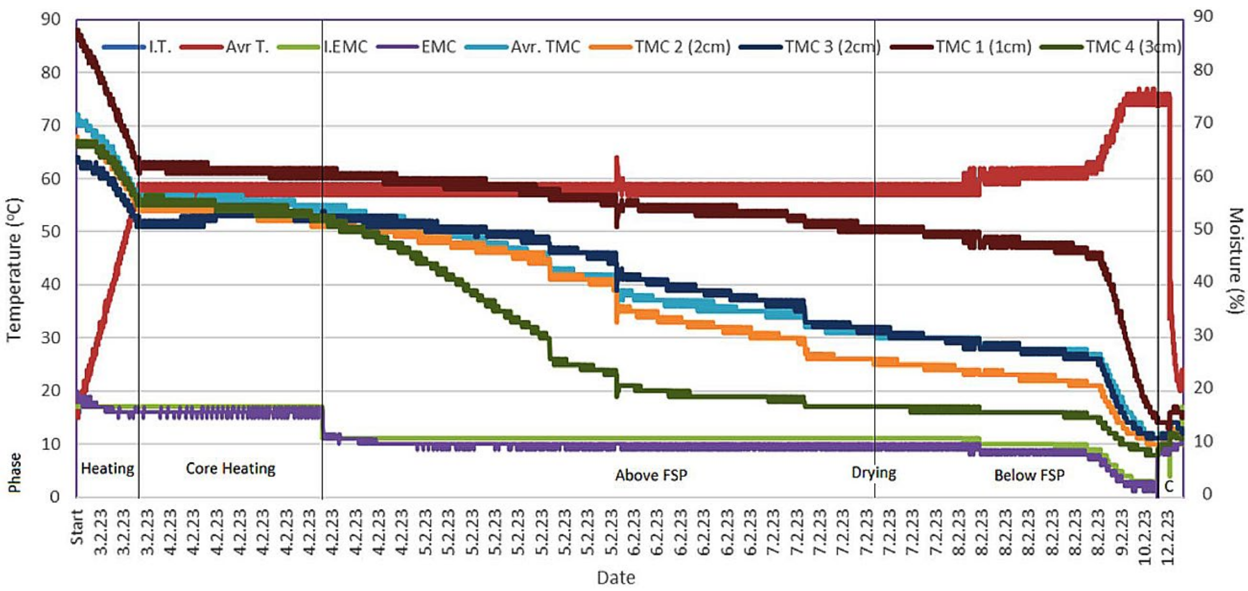
The drying was realized for 234 hours (9.75 days). According to the drying time prediction calculation by Vanicek (Ünsal and Dündar, 2015) (oven-dry density was measured 574 kg/m³), it was calculated at 465 hours. The predicted time was longer ,231 hours, than realized. However, it was thought that the Vanicek calculation was proper for standard-sized boards, such as the thickness/width ratio was generally 1/2 such as 50 x 100 mm cross-section. If the curves of graphic from Perré and Turne (1999) was investigated, when the width doubled (15 to 30 mm

Table 6: Score and degree of end checks (EDG, 1994; Ciniglio, 1998; Maria et al., 2022).

Ciniglio (1998) & Maria et al. (2022)			EDG (1994)	
Score	End Check		Degrees of end checking/splitting	Allowable length and percentage of boards
	Length (mm)	Width (mm)		
1	Absent		Low	Length not more than 50 mm in more than 10% of the load
2	< 5.0	< 0.5		
3	> 5.0	< 0,5	Moderate	Length between 50 - 200 mm in more than 10 % of the load
4	< 5.0	0.5 < Width < 1.0		
5	> 5.0	0,5 < Width < 1.0	Severe	Length more than 200 mm in more than 10 % of the load
6	> 5.0	> 1.0		

Table 7: Degree of internal checking (honeycombing) and surface checks (EDG, 1994).

Degree of internal checking	Allowable	
	Percentage of boards with internal checking	Maximum depth of surface checks
Severe	internal check in more than 10 % of the load	Depth greater than 5 mm (on each face)
moderate	internal check in 2 – 10 % of the load	Depth 2-5 mm
low	internal check in not more than 2 % of the load	Depth less than 2 mm (on each face)



*Avr: Average, EMC: Equilibrium moisture content, FSP: Fiber saturation point, T: Temperature, TMC: Timber moisture content.

Figure 8: Drying graph.

7.8	12.4	8.0	10.1	9.8	7.3	9.8	8.0	10.3
7.4	11.5	10.7	8.9	10.1	7.5	8.6	11.1	10.9
10.8	13.3	9.4	12.0	12.2	10.7	11.1	8.0	12.1
7.7	9.2	11.0	9.1	10.8	9.5	12.0	7.0	10.3

*Values were in the same order and red to green means higher to lower values.

Figure 9: Moisture profile of the lumbers*

Table 8: Moisture distribution evaluation criteria according to EDG (1994).

Quality class	Allowable range of MC, for target MC is 11 %:		Experiment MC (%)	
	EDG (1994)	EN 14298 (2017)	Range:	Mean:
S (standard)	7.7 – 14.3		7.0 – 13.3	9.9
Q (quality dried)	8.8 – 13.2	9.5 – 12.5	**EDG:** S - Standard	**EDG:** N/A
E (exclusive)	9.9 – 12.1		**EN 14298:** Out of range	**EN 14298:** Within the range

Table 9: The data during the passing from drying to conditioning phase.

Date	I.T.	Avr T.	I.EMC	EMC	Avr TMC	TMC1 (2cm)	TMC2 (2cm)	TMC3 (2cm)	TMC4 (2cm)	Phase
11.2.23 17:40	75	76	2	1	11	14	10	11	8	3-Drying
11.2.23 17:55	75	74	2	0	11	15	10	11	8	3-Drying
11.2.23 18:10	75	74	10	7	11	15	10	11	8	4-Conditioning
11.2.23 18:25	75	75	10	9	11	14	10	11	9	4-Conditioning

*Avr: Average, I: Ideal, T: Temperature, EMC: Equilibrium moisture content, TMC: Timber moisture content.

and 30 to 60 mm), the drying time (from 65% to 10% MC) increased 1.3 times after on average. If the coefficient was used for Vanicek calculation, the predicted time would decrease to 357.7 hours (465 / 1.3). However, the predicted time was still longer, 123 hours than realized.

Hadi and Terazawa (1984) suggested 1.3 days for drying 2.7 cm-thick boards. If the time was correlated with the coefficient of Vanicek, it would be 4.84 days (116 hours). However, the applied temperatures were lower in this study and they studied lower density (370 < 574 kg/m^3) subspecies. If the hourly drying rate of Vanicek according to density calculation was applied, the drying time would increase to 290 hours, similar to this study's drying time (234 ~ 290 hours).

Evaluation of Drying Quality

For case-hardening control, a total of 12 prongs were cut from each lumber. No internal check was observed in the cut area that was evaluated E (Exclusive) class for EDG (1994). Additionally, no splitting was observed on both ends of the lumbers. As seen in Figure 10, diamonding was observed in some samples. However, EDG (1994) and many standards did not evaluate it for drying quality control but rather as part of timber quality. Because the anisotropy of shrinkage inevitably causes diamonding and cupping.

In total 39 lumbers, a total of 31 end checks were observed on both ends. Their length was 111.6 mm (11.0 – 460.0), width was 0.51 mm (0.10 – 1.75), and depth was 25.0 mm (5.0 – 45.0) on average. On the other hand, the lumbers had been placed in a relatively dry atmosphere (Relative humidity: 40%, Temperature: 10 °C, Equilibrium moisture content: 8%) for measurement while they were green. There was no air circulation (< 0.5m/s), so the current end checks were developed until the measurement was observed. However, five check dimensions were decreased, four checks stayed with the same dimensions, 19 were closed entirely and only three check dimensions stretched after drying. The closing and decreasing of the dimensions (Figure 11) could arise from a long conditioning period and shrinkage with a protective drying schedule.

When the check were evaluated according to the table of Ciniglio (1998), 90% of them were under the score "3" (1 to 6 score was best to the worst). Higher-scored (worse) checks were in the lumbers before the drying. According to EDG (1994) degree of surface checking (EDG, 1994) could be evaluated as "low". Because there was no expansion for surface checking, except for pith checks and radial knot checks (Figure 12).

Table 10: Drying stress evaluation according to prong samples.

Criteria	Immediately	After 24 hours
a) TRADA pattern area (EDG, 1992)	Light (1): 8 samples Moderate (2): 3 samples	Light (1): 5 samples Moderate (2): 6 samples
b) Total displacement (mm) (Cai and Oliveira, 2011)	1.60 (0.44)*	1.94 (0.45)*
c) Stress value (%) (Zhan and Avramidis, 2017)	2.19 (0.60)*	2.64 (0.48)*

*The values in parenthesis are standard deviation.

Figure 10: Internal check control immediately after drying.

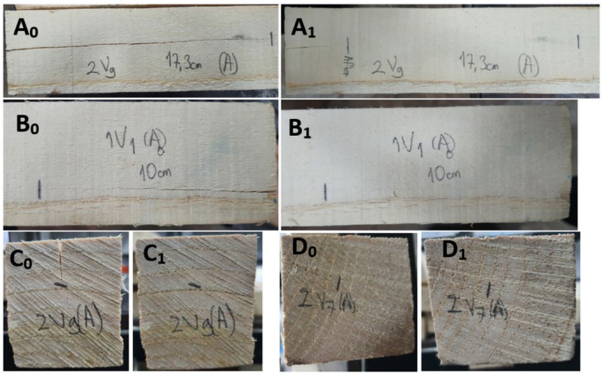


Figure 11: Decreasing dimensions (A, C) and closing (B, D) in checks (0: Before, 1: After).

Figure 12: Check development on the knot (A) and pith (B & C).

As seen in Figure 11, the prong deflections in 11 lumbers were measured to evaluate drying stresses (one sample was broken while sawing due to pith occurrence). The results are shown in Table 10.

There were three criteria for drying stress evaluation on prong samples. According to the EDG (1992), the stress level could be evaluated as moderate. When the study of Cai and Oliveira (2011) was considered, air drying, kiln drying and heat treatment (for sterilization) combinations were evaluated. Minimum total displacement of all combinations and tested softwoods (spruce, pine, fir) was higher (2.57 mm > 1.94 mm) than the values of this study. However, additional heat treatment processes and higher dry-bulb temperatures (> 90°C, below fiber saturation point) could increase the drying stress in that study. When the study of Zhan and Avramidis (2017) was considered, they found different stress values shortly after and 12 hours after drying for larch timber (without thermal treatment). They used similar temperatures for drying, but thinner lumber (25 mm and 40 mm) had higher values (2.5 % and 2.0 % in average, respectively). Although thicker (~60 mm) and denser lumbers were used in this study, similar stress values (2.4 % in average) were obtained. It could be said that longer (12 to 24 hours) stress relief treatment might decrease the values in this study.

CONCLUSION

In this study, a fast-growing tree species, Tree-of-heaven, were dried on an adjusted schedule. Although the reference schedule was moderated to get protective, the species could be dried in a shorter period according to other hardwood species. Although the shorter drying period, the drying stresses could be evaluated as a moderate-protective drying quality using three different methods. The relatively shorter drying time and mid-ranged density could be a good indicator to evaluate this species in industry. If the species' usage is widespread in the solid wood industry, the shorter drying cycles will be more profitable for sawmills.

Moreover, it will be more energy-saver when drying kilns' energy consumptionis considered. On the other hand, there were different methods for evaluating drying quality and stresses. Due to different results could be obtained, so a standard test method such as EDG criteria should be determined to evaluate and compare the results. For a suggestion, prong geometry should be standardized, and annual ring direction should be noted. Because prong thickness is a major influence in determining prong response and the stress profile is complex, as the Fuller (2000) indicated. Additionally, the drying check evaluation criteria didn't evaluate current checks before drying. Current checks on green lumber were not evaluated. It was suggested that check width, depth and/or length development ratios after drying could be evaluated according to a scale.

AUTHORSHIP CONTRIBUTION

Project Idea: HVG, OU

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Database: HVG

Processing: HVG, OU

Analysis: HVG, OU

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