Effect of high temperature drying on permeability and treatment of western hemlock lumber

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Abstract

The effect of drying conditions on gas permeability and preservative treatability was assessed on western hemlock lumber. Although there were no differences in gas permeability between lumber dried at conventional and high temperatures, there were differences in preservative penetration. High-temperature drying was associated with improved penetration of ammoniacal copper zinc arsenate and reduced penetration of chromated copper arsenate. The reasons for these effects are unclear.

The wood of most species grown in the western United States is dried with relatively long, mild kiln cycles designed to minimize stress development, checking, warping, and variability in the final moisture content (MC) distribution (USDA 1991). The use of lower temperature kiln cycles stems from early work suggesting that higher temperatures degrade western wood species (Kozlik and Hamlin 1972).

Recently, a number of commercial drying facilities in the Pacific Northwest have begun to use more aggressive drying cycles for drying western hemlock lumber (*Tsuga heterophylla* (Raf.) Sarg.). Although this process sharply reduces drying times, there is little information on the impacts of these cycles on basic wood properties. Rapid drying could have significant effects on the permeability of the finished product, by increasing the frequency of pit aspiration and reducing the ability of the finished product to take up preservatives or finishes. Western hemlock is generally viewed as being among the more treatable of the western wood species (Kumar and Morrell 1989), and any changes in permeability as a result of drying could have important implications for the preservative treating industry. In this report, we evaluate the effects of conventional and high temperature drying on permeability and treatment of western hemlock lumber.

Materials and methods

We obtained 160 freshly sawn pieces of 42-mm by 147-mm by 4.8-m-long (nominal 2 by 6 in.) western hemlock dimension lumber from a mill located near Tillamook, Oregon. The pieces were cut into two 2.4-m-long samples and labeled. One end was assigned to each treatment. For every other board, the sample to the right of the sawblade went to the high temperature charge. This distributed the wood properties between the two charges in the event that the boards in the original package were oriented due to handling in the mill (e.g., the end of the board closest to the ground in the living tree always at the same end of the package).

Each charge was stacked on 19.5-mm wood stickers at a 0.6-m spacing. The piles were 8 boards wide and 20 layers high, and were top loaded to 2.25 kPa with concrete to reduce warp. One charge was dried with a high temperature schedule (**Table 1**). The other was dried with a conventional schedule (**Table 2**). The air velocity was 4.5 m/s through the sticker slots. The charge dried with a conventional temperature was started 1 day after the charge dried with a high temperature to minimize any

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Table 1. — High temperature drying schedule used to dry western hemlock lumber.[a]

Run time	Dry-bulb	Wet-bulb	EMC
(hr.)	----------- (°C) -----------		(%)
0	38	32	11.8
6	104	88	5.3
12	116	82	2.6
end	116	82	2.6

[a]Temperatures are linearly ramped between the setpoints shown. Actual drying time was 24 hours.

Table 2. — Conventional temperature drying schedule used to dry western hemlock lumber.[a]

Run time	Dry-bulb	Wet-bulb	EMC
(hr.)	----------- (°C) -----------		(%)
0	38	32	11.8
6	71	60	7.9
12	82	54	3.3
36	82	60	4.4
48	82	68	6.5
end	82	68	6.5

[a]Temperatures were linearly ramped between the setpoints shown. Actual drying time was 48.5 hours.

effect of storage time on the experimental results. After drying, each charge cooled while remaining on stickers and top loaded.

After drying, the samples were cut into two 1.15-m-long specimens, leaving a 0.1-m-long section from the middle for later analysis. All the specimens that were positioned at one end of the kiln in a layer were assigned to a preservative treatment. The assignment was reversed for the subsequent layers. This assured that the 1.15-m pieces assigned to each preservative treatment came in equal proportions from all parts of the kiln and from all four possible positions of the original 4.8-m piece.

A 25 percent subset of the 0.1-m-long sections was selected by taking every third board from the middle 16 layers of the kiln, thus avoiding the two top and bottom layers. This subset was used to assess the effect of kiln temperature on shell-to-core MC difference, residual stress, and wood permeability. The shell-core MC test was conducted as described in the Dry Kiln Operator's Manual (USDA 1991). A stress sample, 2.5 cm along the grain, was cut from the 0.1-m section, then cut in half to simulate resawing. The space between the halves was measured with calipers and was indicative of the residual stress.

The effect of drying on permeability was assessed by cutting cores 12.5 mm in diameter by 12.5 mm in length from the 0.1-m sections. Permeability was measured by placing a core into a predrilled No. 8 rubber stopper and placing this assembly into a tapered steel cylinder. The lid on the cylinder pushed the stopper into the taper so that a tight seal was formed around the sample. Nitrogen was applied at 150 kPa to the top of the sample and the flow through the sample was measured using a bubble meter. Gas permeability was calculated from the following expression (Comstock 1967):

$$K_g = \frac{Q}{A} \times \eta \times \frac{L}{\Delta P} \times \frac{p}{p'} \times 10^2$$

where:

K_g = gas permeability (σm^2)
Q = gas flow rate (cm^3/s)
A = specimen area (cm^2)
ç = gas viscosity (Pa·s)
L = specimen length (cm)
ΔP = pressure drop (Pa)
p = pressure at flowmeter (Pa)
p' = pressure in sample (Pa)

The MC of the remaining 0.1-m sections was determined by ASTM D 4442 Method B (ovendry method) (ASTM 1999). This, plus the shell-core MC samples, provided a kiln-dry MC value for every sample in the study.

The transverse faces of the 1.15-m-long specimens were then end-coated with an elastomeric film (GacoFlex) to retard longitudinal fluid penetration. After curing, one specimen set from each charge was treated with chromated copper arsenate (CCA), while the other was treated with ammoniacal copper zinc arsenate (ACZA) (AWPA 2000a).

The CCA cycle consisted of a 30-minute vacuum at 87 kPa, followed by addition of a 1.5 percent CCA Type C solution. The pressure was raised to 1050 kPa and held for 1.5 hours. The pressure was released, the solution was withdrawn, and the wood was subjected to a 30-minute vacuum to relieve internal wood pressure and hasten solution recovery. The wood was removed from the vessel and stored under cover for 48 hours to allow any surface fixation reactions to proceed.

The ACZA cycle consisted of a 2-hour initial steaming period at 115°C followed by a 30-minute vacuum at 87 kPa. The treating solution (2% ACZA) was then added and the pressure was raised to 1050 kPa and held for 3.5 hours. The pressure was then released, the solution drained, and the wood was subjected to a short vacuum, as described above. The wood was held under cover for 48 hours after treatment, then stickered and air-dried outdoors under cover.

Preservative penetration was used as the primary measure of the effect of kiln cycle on treatment. Two 50-mm-long increment cores were removed from the narrow face near the midpoint on either side of each board. The depth of preservative penetration was measured visually to the nearest millimeter. The AWPA standards for treatment of western hemlock lumber require that 80 percent of 20 increment cores removed from lumber in a given charge have at least 10 mm of penetration (AWPA 2000b). Preservative penetration was averaged for each board, then compared between matched boards.

Results and discussion

Drying

The average kiln-dry MC was 13 percent for the charge dried with the conventional schedule and 11 percent for the charge dried at high temperature, with shell-core MC differences of 5.1 percent and 6.4 percent, respectively (**Table 3**). Drying times were 48.5 and 24.0 hours, respectively. Based on past work (Lebow et al. 1996), the average MC difference between charges, though significant ($p < 0.01$, paired t-test, $\zeta = 0.05$), should not impact penetration and

Table 3. — Characteristics of western hemlock lumber kiln-dried using conventional or high-temperature drying schedules.

Lumber characteristic	Conventional drying	High-temperature drying
Moisture content (%)		
Average	13.3 (13.1)[a]	10.8 (3.3)
Shell	10.8 (3.3)	8.3 (1.9)
Core	15.9 (4.8)	14.7 (5.9)
Stress[b] (in.)	0.31 (0.13)	0.38 (0.16)
Drying time (hr.)	48.5	24.0
Permeability (σm^2)	0.022 (0.026)	0.024 (0.015)

[a]Values in parentheses represent one standard deviation.
[b]Deflection during prong test.

Table 4. — Effect of kiln-drying conditions on treatment of western hemlock lumber with CCA or ACZA.[a]

	CCA		ACZA	
Drying condition	Preservative penetration	Percent of samples > 10 mm penetration	Preservative penetration	Percent of samples > 10 mm penetration
	(mm)	(%)	(mm)	(%)
Conventional temperature	13.2 (8.7)	63	19.3 (12.3)	83
High temperature	9.9 (6.2)	46	31.1 (21.9)	93

[a]Values represent means of 160 replicates. Values in parentheses are standard deviation.

is unlikely to affect retention. The difference in shell-to-core MC was not significant (p = 0.09, t-test, ζ = 0.05) and probably would not affect treating because the elapsed time between drying and treating, both experimentally and commercially (1 to 2 weeks), allows the gradient to be reduced. The effect of the difference in residual stress (p = 0.02, t-test, ζ = 0.05) on treatment is not known. Residual stress may affect the equilibrium MC; however, fluid uptake occurs by liquid flow and should be less affected by stress.

The wood dried at high temperature had greater permeability than the wood dried at conventional temperature, 0.024 σm^2 compared to 0.022 σm^2; however, this difference was not significant (p = 0.28, paired t-test, ζ = 0.05; **Table 3**). This test should be the best indicator of the treatability of the material.

Preservative penetration

CCA treatment produced shallower preservative penetration than did ACZA for wood from both of the drying cycles (**Table 4**). Ammonia-based solutions generally produce deeper penetration of components for a given species. Neither of the CCA-treated charges met the American Wood-Preservers' Association Standard C2 (AWPA 2000b) for treatment of western hemlock lumber, although the mean preservative penetration for the conventionally dried boards exceeded 10 mm. None of the boards tested were incised prior to treatment. Incising improves preservative treatment to the depth of the incision, but does not enhance treatment below this depth. This practice is required for treatment of western hemlock in AWPA Standard C2 (AWPA 2000b), although most hemlock decking on the market is not incised because of consumer concerns about surface appearance of the finished product.

Average preservative penetration of conventionally dried boards treated with ACZA was more than double the required depth, and 83 percent of the boards met the required 10-mm penetration. Clearly, the use of ammonia-based solutions would allow for successful treatment of this species without incising.

Preservative penetration in boards subjected to high temperature drying decreased with CCA and increased with ACZA, compared with boards subjected to conventional drying. Penetration of CCA declined nearly one-third in boards dried at high temperature, and the overall percentage of acceptably treated boards declined by over 25 percent. The declines were of particular concern with CCA because the treatment results found with conventionally dried materials were already unacceptable. These results suggest that high temperature drying may further exacerbate the difficulty of obtaining adequate treatment with CCA. Similar studies are underway with southern pine lumber (Winandy et al. 2001).

Penetration in ACZA-treated boards increased 61 percent in boards dried at high temperature, and the percentage of acceptably treated boards rose from 83 to 93 percent. The reasons for the contrasting effects of drying temperature on the two treatments are unclear. In general, high temperatures should affect free sugars and short chain carbohydrates to a greater extent than other wood components; however, it is unclear how these materials interact with either preservative during the treatment process. Clearly, however, high temperature drying did not adversely affect treatment with ACZA.

There was no relationship between the permeability measured on the 0.1-m sections and the treatability of the adjacent 1.15-m specimens. For linear regression, r^2 was less than 0.06 for each of the four combinations of chemical and drying temperature (**Fig. 1**). Pits have a major influence on softwood permeability (Siau 1995). Flow across pits can be impeded by aspiration or occlusion by deposition extractives on the membrane. Drying conditions can significantly affect pit condition, sometimes inducing aspiration that blocks both air and fluid flow (Bao et al. 2001). Pressure treatment is presumed to enhance preservative uptake and flow across pits, but the exact impact of pit condition (i.e., open or aspirated) is unknown. Drying conditions may also alter the state of materials deposited on pits, thereby altering the effects of pressure and perhaps the nature of preservative wood interactions (Forsyth and Morrell 1990). The latter effect may be especially important, since changes in wood chemistry could affect the rates of preservative fixation, which could produce more rapid preservative deposition on pit membranes that would slow further fluid ingress.

Conclusions

High temperature drying significantly reduced drying time, but did not appear to affect permeability or shell-to-core MC differences compared with drying at conventional temperature. Despite the absence of measurable effects, high temperature drying was associated with shallower CCA penetration and deeper ACZA penetration. These results suggest that high temperature drying may increase the difficulty of achieving industry standards for CCA treatment of western hemlock.

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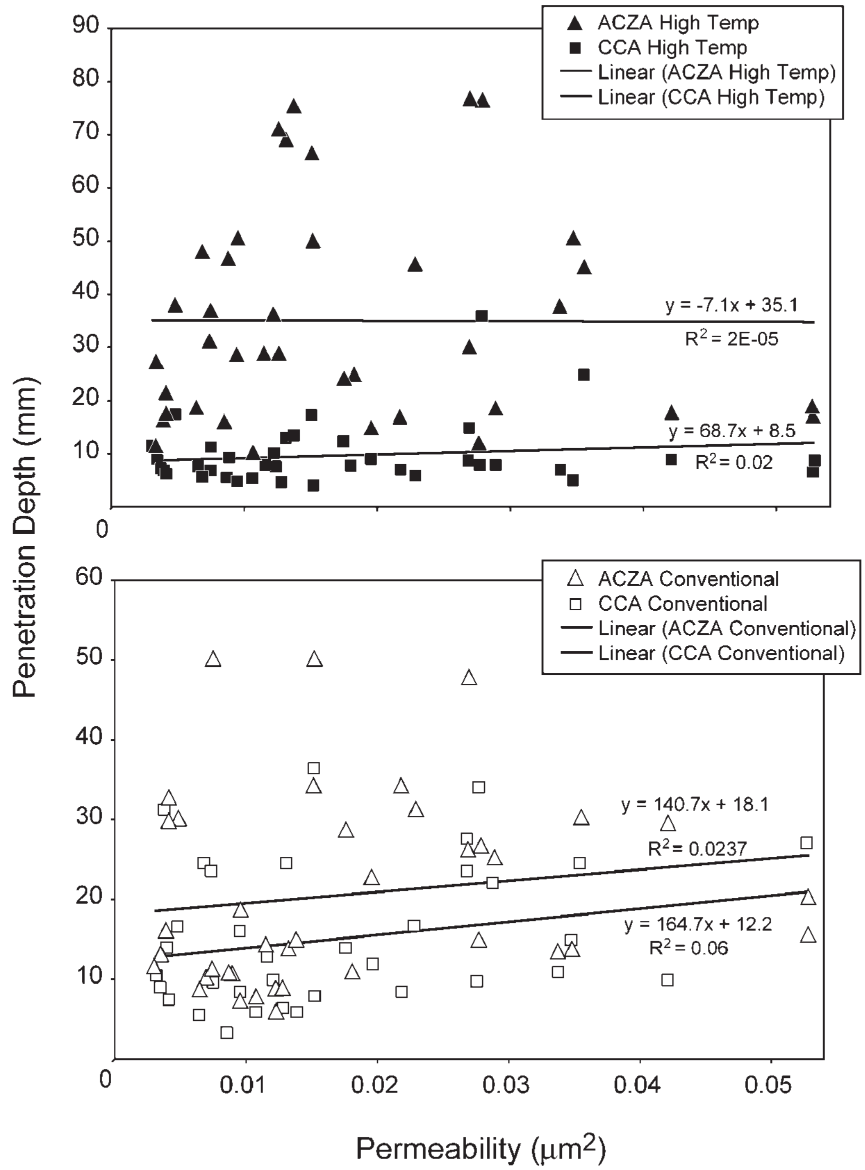

Figure 1. — Permeability of western hemlock lumber kiln-dried using conventional and high-temperature schedules versus depth of penetration of ammoniacal copper zinc arsenate (ACZA) or chromated copper arsenate (CCA).