

High Temperature Drying of Spruce & Pine

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ABSTRACT

The impact of high temperature drying (HTD) for spruce and pine 2"×4" by 8-ft dimension lumber was investigated in this study. Four drying schedules, Control1 (conservative), Control2 (accelerated), HTD1 (104°C with and without steam) and HTD2 (110°C with and without steam), were evaluated. Drying rates, internal stresses (prong test), warp (bow, crook and twist), modulus of elasticity (MOE) and the modulus of rupture (MOR) were assessed.

Six drying runs were carried out in an 8-ft laboratory kiln and the results of this research indicated: ① The drying rates in HTD1 and HTD2 increased by 2.2 to 3.5 times in comparison with the results obtained for the conservative schedule. ② Both HTD1 and HTD2 schedules with steam resulted in greater internal stresses in the dried lumber when compared to the conservative schedule, but smaller in relation to the accelerated schedule. The standard deviations of final moisture content from HTD1 and HTD2 with steam were higher than that of conservative schedule, but similar to the values obtained for accelerated schedule. ③ Warp was in general reduced by the HTD schedules except for HTD2 without steam schedule. Less crook was observed for HTD1 and HTD2. ④ Reductions in MOE and MOR were found for both HTD1 and HTD2 schedules but were not statistically significant.

INTRODUCTION

Several high temperature drying (HTD) studies of softwood have been carried out in the past. For example, a mixture of spruce and jack pine joists was dried on both a 52-hour conventional drying (82 °C) and a 24-hour HTD (115 °C) by Cech and Huffman (1974). The value loss due to degrade was reduced slightly with the HTD. No significant reduction in modulus of elasticity (MOE) was found due to HTD. However, the modulus of rupture (MOR) was reduced by about 16.5% in jack pine and 10% in spruce.

Koch (1971 and 1974) dried several charges of 2×4 southern yellow pine (SYP) studs in less than 24 hours at high temperatures and concluded that HTD at 115.6 °C under restraint significantly reduced warp in the lumber. Price and Koch (1980) also found that the 2×6 SYP dried at 115.6 °C and 132.2 °C with top load restraint exhibited less warp when compared to the product dried at 82.2 °C.

Aleon et al. (1988) indicated that schedules with high temperatures (120 °C – 130 °C) could dry SPF lumber satisfactorily. The drying times were 3 to 4 times shorter compared to conventional kiln drying (70 °C – 80 °C) when the lumber was dried from 80 % of initial moisture content (MC) to 10 –12 % of final MC. A reduction of warp was also found in dried lumber. Wu and Smith (1998) investigated the effects of elevated temperature and high temperature schedules on warp in SYP. They found that although crook was significantly reduced by the HTD schedule bow and twist were not significantly reduced. Milota (2000) compared 2×4 hem-fir stud lumber dried by conventional (82 °C) and high temperatures (116 to 132 °C) schedules. Bow and crook were slightly reduced.

Several studies seem to indicate that HTD not only increases drying rate but it also can potentially reduce warp. Vansteenkiste et al. (1997) indicated that an initially fast increase of temperature to a high level could make the moist wood softer and enhance the heat conduction from the surface to the core of the wood. Thus, it perhaps can be speculated that lower stress level would be achieved and consequently less warp would be observed.

Current lumber quality requirements are substantially different from those that existed years ago when high temperature drying was being developed and tested to dry various softwood species. Improvements in kiln drying technology over the years enabled kiln operators to exercise better process control and therefore improve drying performance. However, the impact of HTD schedules has not yet been determined for spruce and pine dimension lumber in view of today's stringent quality requirements. The objective of

this research is to evaluate the impact of HTD schedules on drying rates, dried lumber quality and strength properties.

MATERIAL AND METHOD

Drying Experiments

Green spruce and pine 2" × 4" × 10' lumber was supplied by a mill located in the Interior of British Columbia. The specimens were block piled to minimize moisture loss during transportation and storage. A middle size laboratory kiln (8-ft) was used in this study. Each 10-ft specimen was trimmed to 8 feet and each run consisted of 180 drying samples.

Four drying schedules, Control1 (conservative), Control2 (accelerated), HTD1 and HTD2, were used in the study as shown in Table 1. Since steam is not available for most industrial situations, HTD1 and HTD2 were tested with steam and without steam. Thus, six runs for spruce and pine were carried out, namely: conservative, accelerated, HTD1 with steam, HTD1 without steam, HTD2 with steam and HTD2 without steam.

Determinations of Warp and Degradation

Warp including bow, crook and twist, can be quantified and expressed by:

$$\text{Warp} = \text{twist} + \text{crook} + \text{bow}$$

Warp measurements were carried out at three different times:

- (1) Warp 1 was determined before drying (initial warp)
- (2) Warp 2 was determined right after drying
- (3) Warp 3 was determined after four weeks of yard equalization

Determinations of Drying Stress and MC

Prongs were cut from dried specimens and the displacements were determined as described by Oliveira and Cai (2005). Prior to drying both ends of each board were cut and used to obtain the average initial MC (MC_i). Moisture content samples were oven-dried at 103°C ±2°C.

Final MC (MC_f) was estimated as the average of three measurement methods. Method 1 (MC_1) was calculated based on the weight of the individual board before and after drying, and from the known MC_i :

$$MC_1 = \frac{W_{dry} - W_{green} / (1 + MC_i)}{W_{green} / (1 + MC_i)}$$

where, W_{dry} is the weight of the board after drying; W_{green} is the weight of the board before drying; MC_i is the initial moisture content of the board.

Method 2 (MC₂) values were obtained using a Wagner Model L612 moisture meter. Three measurements were made for each sample and the MC₂ was the average of these three measurements. Method 3 (MC₃) values were obtained from MC calculation based on oven-dried wood discs from individual dried board. Thus the average final MC (MC_f) was obtained by averaging MC₁, MC₂ and MC₃.

Lumber Strength Tests

Since the process of HTD can potentially affect the strength properties of wood, modulus of elasticity (MOE) and modulus of rupture (MOR) were determined in bending using a third-point loading test according to ASTM D4761-02A. The dried lumber was planed to accurate size and conditioned to about 12% of MC (room conditions) before conducting the MOE and MOR tests. A load rate of 75-mm/minute (3.0 inches/minute) was used, which gave an average time to failure of 45 seconds. To ensure repeatability of the stiffness test results, each specimen was loaded twice to a load of 1670 Newtons (375 pounds) and then a third time to failure. The deflection was measured at the load points. The stiffness was calculated using linear regression analysis of the load vs. deflection data between a load level of 550 and 1670 Newtons (125 and 375 pounds). The MOE was calculated using the stiffness and the measured dimensions of each specimen. The MOR was calculated using the failure load and the measured dimensions of each specimen.

RESULTS AND DISCUSSION

Drying Rates, Stress and MC Distribution

Average drying rates, stresses and MC distribution for spruce and pine lumber dried using the six different schedules (conservative, accelerated, HTD1 without steam, HTD1 with steam, HTD2 without steam and HTD2 with steam) are shown in Fig.1.

As can be seen in Fig.1, drying rate values were increased 2.2 to 3.5 times using HTD1 and HTD2 schedules. Stresses, as measured using the prong test, showed HTD2 without steam exhibited the highest stress level. Stresses for HTD1 and HTD2 both with steam, were greater than those observed for the lumber dried under the conservative schedule, but smaller than those for the accelerated schedule. The standard deviations (Sd) of final MC in Fig.1 for both HTD1 and HTD2 with steam were higher when compared to the values obtained for the conservative schedule but not significantly

different from the results for the accelerated schedule.

Warp Development

Fig.2 illustrates warp obtained for the different types of drying schedules. As can be seen in the figure, warp (twist, crook and bow) from HTD schedules is reduced except for HTD2 without steam schedule.

Warp Related Degrade

Degrade based solely on development of warp after drying and a 4-week equalizing period is presented in Table 3. The table shows that there is no significant difference in value loss between HTD and conventional drying schedules. Value loss in lumber was reduced after 4-week yard equalization. Accelerated schedule produced the greatest value loss after 4-week equalizing. Due to relatively small sample sizes involved in each drying run, the value loss presented here can only be interpreted as a potential indication of different results that can be obtained for the drying schedules used. Industrial size samples must be evaluated to validate the preliminary results presented below.

Effect of High Temperature Drying on MOE and MOR

The results of MOE and MOR tests are summarized in Table 4. As can be seen from the table, HTD2 schedule with steam causes the greatest reduction in MOE in comparison with the conservative schedule. However, the reductions in all four HTD schedules are less than 5%. Although it was slightly less, MOE for the HTD schedules was not significantly different from the value obtained for the lumber dried under the conservative schedule.

Table 4 also shows the reduction of the average MOR for the lumber dried under HTD2 schedule with steam was as high as 7.5%, but this is not a problem for MSR rule in which only 5% of cumulative frequency for MOR is considered. Fig.3 shows the cumulative frequency for all the samples tested. Although the differences are great at 50% of cumulative frequency, minor changes occur at 5% level as shown in Fig.3. However, the statistical analysis indicated that none of the four HTD schedules resulted in significant reduction in MOR when compared to the results observed for the conservative schedule.

CONCLUSION

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The results of the study indicated that:

- 1) The drying rates in HTD1 and HTD2 schedules were 2.2 to 3.5 times faster in relation to drying rates for the conservative schedule.
- 2) Stresses observed for HTD1 and HTD2 (both with steam) were greater than that of conservative schedule, but smaller than that of accelerated schedule. The standard deviations of MC from HTD1 and HTD2 with steam were higher than that of conservative schedule but not significantly different from the values observed for the accelerated schedule.
- 3) Warp was in general reduced for all high temperature schedules except for HTD2 without steam schedule
- 4) HTD1 and HDT2 schedules did not show any significant reductions in MOE and MOR.

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Table 1 Drying schedules

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Run #	Step #	Ramp Time (hrs)	Step duration (hrs)	Dry-bulb T (°C)	Wet-bulb T (°C)	EMC (%)	Air Velocity (m/s)	Note
Controll (Conservative)	1	4		60	60	24.6	3.3	
	2	6		71	68	15.6	4.2	
	3	6		82	78	12.4	4.5	
	4		12	88	79	8.5	4.5	
	5			91	76	6	4.5	

Control2 (Accelerated)	1	4		60	57	16.1	3.3	
	2	7		82	76	10.2	4.5	
	3	7		93	81	6.8	4.5	
	4	8		99	77	4.2	4.5	
	5			99	77	4.2	4.5	
HTD1	1	3		104	92	6.4	3.3	
	2		7	104	92	6.4	4.8	
	3			104	88	5.1	4.8	
HTD2	1	3		104	96	8.1	3.3	
	2		5	104	96	8.1	4.8	
	3	2		110	96	5.6	4.8	
	4			110	91	4.4	4.8	

Table 2 Lumber dollar (US) values and warp tolerances

	Dollar (US)/Mfbm	Dollar (US)/piece	Crook (in)	Bow (in)	Twist (in)
J-Grade	450	2.40	≤0.1	≤0.1	≤0.1
No.2 & Btr	342	1.82	≤0.375	≤0.75	≤0.5
No. 3	265	1.41	≤0.5	≤1.0	≤0.75
Economy	186	0.99	>0.5	>1.0	>0.75

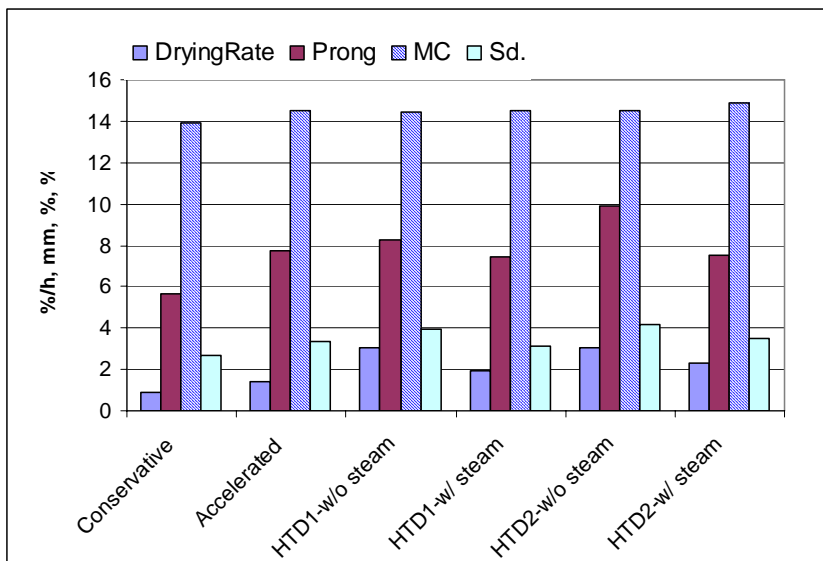


Fig.1 Comparisons in Drying Rates, Stresses and MC

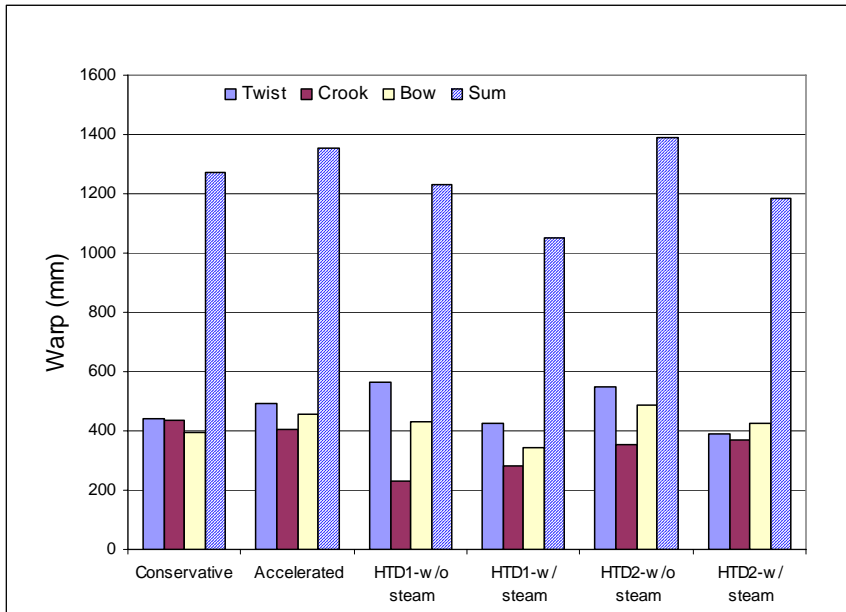


Fig.2 A Comparison in Warp

Table 3 Dollar (US) devalued due to warp development

Run No.	Green Value ¹	Value ¹ After Drying	Devalued ² (%)	Value ¹ 4-week Equal.	Devalued ² (%)
Conservative	342	298.9	12.60	336.3	1.67
Accelerated	349.3	301.6	13.66	333.9	4.41
HTD1w/o steam	338	295.9	12.46	335.1	0.86
HTD1w/ steam	343.2	301	12.30	339.8	0.99
HTD2w/o steam	344.9	301.1	12.70	337	2.29
HTD2w/ steam	345.2	304.1	11.91	340.3	1.42

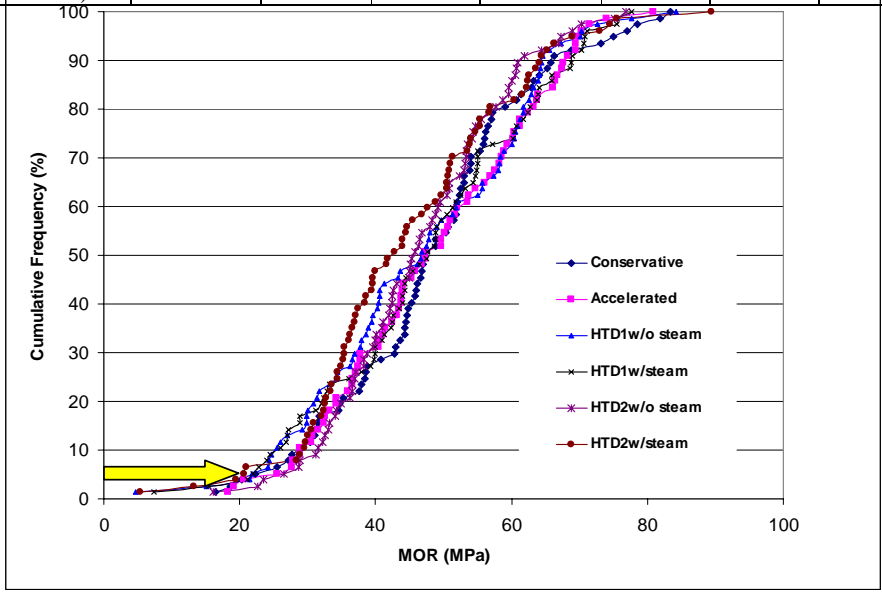
1. Lumber value (US Dollar/Mfbm) determined using Table 2

2. Devalued = Values reduced from the values of green lumber listed in column 2

Table 4 Effects of High Temperature Drying on MOE and MOR

Schedules	Density	MOE (MPa)	Change ¹	MOR (MPa)	Change ¹
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	(kg/m ³)	Ave.	Sd. ²	(%)	Ave.	Sd. ²	(%)
Control1 (conservative)	416	10268	1793	-	48.4	14.7	-
Control2 (accelerated)	417	10180	1646	-0.9	48.6	14.7	0.4
HTD1 (w/o steam)	407	10062	1790	-2.0	46.8	16.1	-3.5
HTD1 (w/ steam)	411	10078	2349	-1.9	47.5	16.9	-1.9
HTD2 (w/o steam)	411	9964	1455	-3.0	46.5	12.6	-3.9
HTD2 (w/ steam)	419	9757	1789	-5.0	44.8	15.3	-7.5



1. Change = Reduction comparing with the values from conservative schedule
2. Sd. = Standard deviation

Fig. 3 Cumulative distribution for MOR