# A Comparison of Drying Strategies for Spruce–Pine–Fir Dimension Lumber

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## Abstract

Mills producing spruce–pine–fir (SPF) dimension lumber are required to carry out heat treatment before shipping the lumber to markets. Kiln drying/heat treatment is the most common strategy for drying SPF lumber. Currently there is a question about whether to use air drying before or after heat treatment to improve lumber grade recovery and reduce energy consumption. We tested three drying strategies for spruce/pine and sub-alpine fir lumber: heat treatment followed by air drying (HT+AD), air drying followed by heat treatment (AD+HT), and kiln drying heat treatment alone (KD/HT). Results related to final moisture content uniformity, warp, and drying stress were better when air drying was incorporated in the strategy. The standard deviation of the final moisture content was reduced from 3.9 to 1.3 percent for spruce/pine and from 7.2 to 3.1 percent for sub-alpine fir. Warp was reduced by 27 to 42 percent for spruce/pine and 14 to 41 percent for sub-alpine fir. Using the prong tests, drying stress was reduced by 23 to 60 percent for spruce/pine and 35 to 71 percent for sub-alpine fir. Improved final moisture content uniformity, less warp, and lower drying stresses were obtained for the lumber tested under the HT+AD strategy compared with the AD+HT strategy.

In order to be able to use the classification kiln drying and heat treatment (KD/HT), mills producing spruce–pine–fir (SPF) dimension lumber are required to fulfill heat treatment requirements specified by the Canadian Food Inspection Agency. The most common schedules used for KD/HT are illustrated in Table 1. Since there is a large variation in initial moisture content (MC) for SPF lumber, the KD/HT strategy causes various drying defects such as warping, over-drying (MC below 10% to 11%), and under-drying (MC above 19%), which affect grade recovery and impact planer productivity (breakage of over-dried pieces). Thus, improving grade recovery can significantly affect operational costs due to increased revenue. Currently there are two schools of thought in the industry in relation to the application of drying and heat treatment. The first one suggests that heat treatment be carried out prior to drying, and once it is complete, the lumber should be air dried (AD) to an MC between 16 and 19 percent (HT+AD). In this way, over-drying, and consequently drying degrade, could potentially be significantly reduced. In addition, narrower final MC distributions will also improve grade recovery due to the decreased amount of warp. The second school of thought suggests air drying the lumber to an MC in the range of 20 to 25 percent and then proceeding with kiln drying (KD/HT schedules; AD+HT). These different approaches may have different implications regarding total kiln residence time, energy consumption, lumber yard inventory, final MC uniformity, and quality. A comparison of the strategies HT+AD and AD+HT will permit mills to select the best option according to their situation; that is, availability of air-drying yard and inventory and productivity requirements.

During the past two decades there has been an increase in the number of studies regarding air drying and heat treatment. Several studies (Cai 2005, Simpson et al. 2005, Simpson 2006) were carried out to determine the necessary heat treatment time to ensure that the wood was sterilized and therefore protected against biological agents. Air drying can be an attractive alternative for reducing energy consumption in the wood industry. Many studies regarding the relationship between air-drying times and the MC loss have been carried out (Denig and Wengert 1982, Simpson and Wang 2003). In addition, a number of computer models to simulate the air-drying process are available in the literature (Hart 1981, Simpson and Hart 2001, Simpson and Wang 2003). The objective of this study was to evaluate the strategies KD/HT, HT+AD, and AD+HT.

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Table 1.—Heat treatment and drying schedules.[a]

| Schedule | Step no. | Ramp time (h) | Step time (h) | DB-T (°C) | WB-T (°C) |
|---|---|---|---|---|---|
| Heat treatment schedule | 1 | 6 | — | 71 | 50 |
| | 2 | — | 6 | 71 | 50 |
| Drying schedules | | | | | |
| Spruce and pine | 1 | 4 | — | 60 | 57 |
| | 2 | 8 | — | 82 | 76 |
| | 3 | 8 | — | 93 | 81 |
| | 4 | 16 | — | 99 | 77 |
| | 5 | — | 20[b] | 99 | 77 |
| Sub-alpine fir | 1 | 6 | — | 60 | 60 |
| | 2 | 10 | — | 71 | 66 |
| | 3 | 8 | — | 81 | 76 |
| | 4 | — | 12 | 87 | 79 |
| | 5 | — | 24[b] | 90 | 81 |

[a] DB-T = dry-bulb temperature; WB-T = wet-bulb temperature.
[b] Kiln stops when the target moisture content is reached.

## Materials and Methods

Green lodgepole pine, white spruce, and sub-alpine fir lumber (2 in. by 4 in. by 10 ft) was sourced from mills located in the interior of British Columbia, Canada. Two groups of specimens, spruce/pine and sub-alpine fir, were formed. Heat treatment strategies (Fig. 1) were as follows:

1. Heat treatment followed by air drying (HT+AD)
2. Air drying followed by heat treatment (AD+HT)
3. Kiln drying and heat treatment (KD/HT) as the control

The following information was collected prior to each drying run:

1. Individual initial MC ($MC_i$; ovendry method) was determined using 1-inch discs that were cut from each end of the original 10-foot-long lumber resulting in 8-foot-long specimens.
2. Individual warp (bow, crook, and twist) was determined as illustrated in Figure 2.
3. Individual specimen weight.

The following information was collected after each drying run:

1. Individual final MC ($MC_f$). This was obtained by averaging MC values that were obtained by the following measurement methods:

   *Method 1:* The MC values were measured using a Wagner capacitance-type moisture meter (Model L612). Three measurements were made along the length of each specimen and the average MC value was then calculated.

   *Method 2:* The MC values were obtained from ovendried wood discs that were cut from the midlength of each dried specimen.

2. Individual warp [average warp = (bow + crook + twist)/3].
3. Individual specimen weight.
4. Individual drying stress. This was determined by prong test. A prong disc was cut from the middle of the dried specimen and sawn as shown in Figure 3 to allow diagonally opposite prongs to bypass each other. The displacements *a* and *b* (Fig. 3) were determined.
5. Any other defects developed during drying.

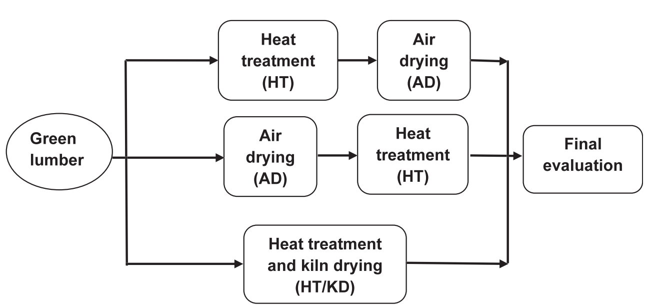


Figure 1.—Heat treatment strategies for both species groups.

During the experiments using HT+AD and AD+HT, intermediate moisture content ($MC_m$) was obtained by determining the weight of each piece of lumber after heat treatment or air drying, respectively.

The air-drying experiments were carried out in the backyard of the laboratory of FPInnovations – Wood Products Division (Vancouver, British Columbia, Canada) and a 2-Mfbm kiln was used for heat treatment and kiln drying.

Two spruce/pine stacks and two sub-alpine fir stacks, consisting of 192 specimens each, were set up for the air-drying experiments in February, April, June, and August. The stacks were covered with plywood to protect the lumber from rain and direct sunlight exposure. The weight of the lumber stack was monitored every 60 minutes with two load beams equipped with a data logger. Based on the weight information and the initial MC, the average MC for the stack was estimated. When the estimated MC reached about 23 percent, air drying was complete and the heat treatment was started right away. The heat treatment and kiln drying schedules for both species groups are illustrated in Table 1.

## Results and Discussions

The drying results for spruce/pine lumber are presented in Table 2. Although there was less than 0.8 percent difference in mean final MC among the three strategies, the standard deviations were reduced from 3.87 to 2.41 and 1.32 using AD+HT and HT+AD, respectively.

Figure 2.—Measurements of warp.

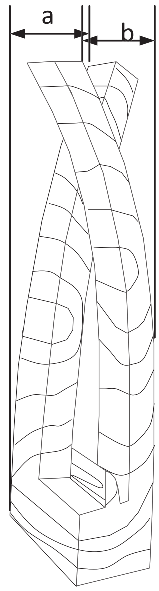


*Figure 3.—Prong for determination of drying stresses.*

Compared with KD/HT, the average value of warp was reduced by 27 percent by using the strategy of AD+HT and by 42 percent by using HT+AD. According to the results of the prong tests, the drying stress was reduced by 23 percent by using AD+HT and by 60 percent by using HT+AD. Warp from the three strategies was tested by ANOVA with $\alpha = 0.05$. Compared with the strategy of KD/HT, warp was significantly reduced when the lumber was dried using the strategies of HT+AD ($P = 0.0231$) and AD+HT ($P = 0.0447$). Due to the incorporation of air drying, the moisture moving rates were slower and the MC gradients were gentler during the drying process, which probably caused the reduction in warp.

Drying stresses were significantly reduced by using the strategies of HT+AD ($P = 0.001$) and AD+HT ($P = 0.001$). With the addition of air drying before heat treatment, case hardening would not have occurred at the beginning of the drying process, which most likely reduced the drying stresses. When air drying was added after heat treatment (HT+AD), case hardening and drying stresses from the beginning of the process could be released during the air-drying stage. It was also found that the lumber dried according to the HT+AD strategy exhibited improved final MC uniformity, less warp, and lower drying stresses when compared with the AD+HT strategy.

As shown in Table 3, the drying of sub-alpine fir also benefited by the air-drying phase of the strategy. The standard deviations of final MC, warp, and drying stress were reduced. Although there was less than 0.4 percent difference in mean final MC among the three strategies, the standard deviations were reduced from 7.21 (KD/HT) to 4.92 (AD+HT) and 3.14 (HT+AD). Compared with KD/HT, the average warp was reduced by 14.9 percent by using the strategy of AD+HT and by 41.9 percent by using HT+AD. The results of the prong tests indicated that the drying stress was reduced by 35.2 percent by using AD+HT and by 71 percent by using HT+AD.

The statistical analysis was carried out using ANOVA tests. The results showed that, compared with KD/HT, drying stresses were significantly reduced by the strategies of HT+AD ($P = 0.001$) and AD+HT ($P = 0.001$). As previously described, case hardening was reduced by adding air drying, resulting in a reduction in drying stress. Warp was reduced significantly by the strategy of HT+AD ($P = 0.001$), but only reduced by an insignificant amount using the strategy of AD+HT ($P = 0.33$). The HT+AD strategy produced the best lumber quality among the three strategies. Sub-alpine fir lumber was air dried in the summer (late June to mid August) and the drying time (Table 3) was shorter than the times for spruce and pine (Table 2) because these were air dried during the winter and spring (early February to late April).

*Table 2.—Results of drying experiments for spruce and pine lumber.*[a]

| Strategy | $MC_i$ (%) | SD | $MC_m$ (%) | SD | $MC_f$ (%) | SD | AD (h) | KD/ HT (h) | Avg. bow (mm) | Avg. crook (mm) | Avg. twist (mm) | Avg. warp (mm)[b] | Prong (mm)[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HT+AD | 52.3 | 26.7 | 32.9 | 9.2 | 15.4 | 1.3 | 1,822 | 12.0 | 0.98 | 1.03 | 2.25 | 1.42 | 2.90 |
| AD+HT | 53.6 | 25.1 | 22.3 | 5.9 | 14.6 | 2.4 | 1,343 | 12.0 | 1.04 | 1.28 | 3.04 | 1.79 | 5.62 |
| KD/HT | 54.2 | 26.9 | | | 15.2 | 3.9 | 0 | 31.5 | 1.78 | 2.03 | 3.59 | 2.47 | 7.31 |

[a] $MC_i$ = initial moisture content; SD = standard deviation; $MC_m$ = intermediate moisture content that was determined after heat treatment or air drying; $MC_f$ = final moisture content; AD = air drying; KD/HT = kiln drying and heat treatment.
[b] Warp = (bow + crook + twist)/3.
[c] Prong = prong displacement ($a + b$) as shown in Figure 1.

*Table 3.—Results of drying experiments for sub-alpine fir lumber.*[a]

| Strategy | $MC_i$ (%) | SD | $MC_m$ (%) | SD | $MC_f$ (%) | SD | AD (h) | KD/ HT (h) | Avg. bow (mm) | Avg. crook (mm) | Avg. twist (mm) | Avg. warp (mm)[b] | Prong (mm)[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HT+AD | 64.2 | 26.0 | 45.6 | 15.6 | 16.8 | 3.1 | 1,155 | 12.0 | 0.76 | 0.71 | 1.63 | 1.03 | 2.57 |
| AD+HT | 58.3 | 26.5 | 23.3 | 7.8 | 17.2 | 4.9 | 643 | 12.0 | 1.46 | 0.99 | 2.06 | 1.51 | 5.75 |
| KD/HT | 57.8 | 25.4 | | | 16.9 | 7.2 | 0 | 45.4 | 2.10 | 1.31 | 1.90 | 1.77 | 8.86 |

[a] $MC_i$ = initial moisture content; SD = standard deviation; $MC_m$ = intermediate moisture content that was determined after heat treatment or air drying; $MC_f$ = final moisture content; AD = air drying; KD/HT = kiln drying and heat treatment.
[b] Warp = (bow + crook + twist)/3.
[c] Prong = prong displacement ($a + b$) as shown in Figure 1.

## Summary

Based on the analysis of the results the following conclusions can be drawn:

1. In general, better results in terms of final MC distribution, warp, and drying stresses were obtained by incorporating air drying in the strategy. Compared with KD/HT, the standard deviations of the final MC were considerably reduced by using the strategy of AD+HT or HT+AD for each species group. The results of the statistical analysis indicated that the drying stresses were significantly reduced for both species groups when strategies of AD+HT and HT+AD were used. Except for the strategy of AD+HT for sub-alpine fir, warp was significantly reduced in all other cases.
2. The HT+AD strategy produced better MC uniformity and less warp and drying stress when compared with the AD+HT strategy.

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## Literature Cited

Cai, L. 2005. An estimation of heating rates in sub-alpine fir lumber. *Wood Fiber Sci*. 37:275–282.

Denig, J. and E. Wengert. 1982. Estimating air-drying moisture content loss for red oak and yellow-poplar lumber. *Forest Prod. J*. 32(2): 26–31.

Hart, C. A. 1981. SIMSOR: Computer simulation of water sorption in wood. *Wood Fiber* 13:46–71.

Simpson, W. T. 2006. Estimating heating times of wood boards, square timbers, and logs in saturated steam by multiple regression. *Forest Prod. J*. 56(7/8):26–28.

Simpson, W. T. and C. A. Hart. 2001. Method for estimating air-drying times of lumber. *Forest Prod. J*. 51(11/12):56–63.

Simpson, W. T. and X. Wang. 2003. Estimating air drying times of small-diameter ponderosa pine and Douglas-fir logs. Research Paper FPL-RP-613. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Simpson, W. T., X. P. Wang, J. W. Forsman, and J. R. Erickson. 2005. Heat sterilization times of five hardwood species. Research Paper FPL-RP-626. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.