목재공학19(2) : 65~71(原著)
Mokchae Konghak. 19(2) : 65~71. 1991

# The Effects of Drying Schedules on the Bending Properties of Lodgepole Pine Dimension Lumber Treated with CCA*1

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# 건조 Schedule이 CCA처리 Lodgepole Pine 각재의 휨강도 성질에 미치는 영향*1

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## 摘 要

본 연구는 CCA 처리재의 再乾燥시 적용된 건조 스케쥴 (通常 熱氣乾燥와 高溫乾燥 스케쥴)이 처리재의 휨強度 성질에 미치는 영향을 고찰하고자 수행되었다.

彈性係數(MOE), 그리고 非破壞試驗에 의해 얻어진 動的 탄성계수(Dynamic MOE) 및 對數減衰率(Logarithmic decrement)은 처리후 재건조에 의해 큰 영향을 받지 않았다. 반면에 적용된 건조 스케쥴에 관계없이 재건조시 심각한 破壞係數(MOR)의 감소가 파괴계수 분포의 모든 영역에서 초래되었다. 그러나 통상 열기건조(최대 건구온도=71℃)와 고온건조(건구온도=110℃) 서로간에는 감소의 정도에 큰 차이가 없었다.

따라서, 처리재의 재건조시 심각한 파괴계수의 감소가 容認되지 않는다면 CCA로 처리된 Lodgepole pine 각재의 재건조는 미국 연방 임산물 시험장의 Lodgepole pine의 통상 열기건조 스케쥴 (T9-C3)보다 溫和한 조건으로 실시되어야 할 것이다.

## 1. INTRODUCTION

The increasing consumption of waterborne preservatives in treating structural wood members has raised a great concern over how strength properties of treated wood may be altered, especially when the treated wood is kiln-dried. Most current waterborne preservative formulations can cause cell wall hydrolysis due to their quite acidic nature (pH=1.6-4.0), and the addition of heat potentially exacerbates this reaction causing further strength reduction (5, 6, 14).

While air drying after treatment was shown to have no detrimental effects on strength (10, 16), ample evidence was presented to show that higher redrying temperatures can have severe impact on the mechanical properties for CCA-treated full-sized lumber (2, 9, 18, 19). This implies that some temperature

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limitation are definitely required in the post-treatment drying if severe loss in strength are to be avoided. For detailed information on this topic, the reader is referred to the review articles by Barnes and Winandy(3), and Winandy(17). Most research, on the effect of post-treatment drying schedule on mechanical properties, has been limited to southern yellow pine and Douglas-fir. Because no data exist on the influence of redrying schedule on CCA-treated lodgepole pine, it has been presumed that CCA-treated lodgepole pine has approximately the same effect on strength loss as CCA-treated southern yellow pine.

The purpose of this study was to determine the effects upon strength properties when either a high-temperature or conventional drying schedule was used to redry lodgepole pine dimension lumber following treatment with CCA.

## 2. MATERIALS and METHODS

A total of 250 pieces of surfaced, green lodgepole pine(*Pinus contorta* var. *latifolia* Dougl. ex Loud) dimension lumber, nominally 51-×102-mm×2.4-m long, were obtained from the green chain of a local sawill. Approximately 80 percent of the test material was a No. 2 with the remainder being Select Structural and No. 1 under the Westem Wood Produsts Association(WWPA) grading rules for lodgepole pine dimension lumber(15). The material was randomly assigned to one of two groups so that each group had similar quality distributions.

One group was initially dried using a conventional kiln drying (CKD) schedule (T9-C3) at the maximum dry-bulb temperatures of 71℃, recommended by the *Dry Kiln Operator's Manual* (12). The remaining group was initially dried using a high-temperature drying (HTD) schedule at the maximum dry-bulb temperatures of 110℃. Following initial drying, the lumber was treated with CCA-Type C by a commercial treater to an target retention of 4 kg/m$^3$ (oxide basis), using a modified full-cell pressure processs. After CCA-treatment, half of the initially conventionally dried and treated material was combined, and then redried by the CKD schedule. The remainder of the material was redried by the HTD schedule. Additional details of the drying schemes and CCA-treatment of the material have been described previously (8).

Following redrying, the material was stored in a conditioning room at about 21℃ and 66 percent relative humidity (equlibrium moisture content=12%) prior to testing. All samples were tested in edgewise static bending as simply supported beams on a MTS (Material Testing System) testing machine using third-point loadings as described in ASTM Standard D 198 (1). For each group, half of the specimens in that group were tested with the grade controlling defects oriented toward the compression edge and half oriented toward the tension edge. The test span used was about 187cm, with a rate of loading of 7.57mm/min. Centerline deflection was measured by a linear variable differential transducer (LVDT) attached to the center point of the beam through a pulley arrangement. Load vs. mid-span deflection was recorded past the proportional limit load, beyond which only maximum load was recorded. For each specimen, modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated from the load-deflection data.

Prior to destructive testing, all specimens were nondestructively evaluated using free flexural vibration with end supports. Vibration decay graphs along with weight and dimensions measured from each specimen were used to calculate dynamic MOE and logarithmic decrement. Additional details for the nondestructive evaluation have been described previously (7).

## 3. RESULTS AND DISCUSSION

Group means for the destructive static

Table 1. Effect of redrying on the bending properties of CCA-treated lumber[1].

| Property | Control | CKD | HTD |
|---|---|---|---|
| | | Initial drying : CKD | |
| Sample size | 35 | 42 | 45 |
| Destructive parameters | | | |
| MOE | | | |
| Mean(Kg/cm²) | 85,610.00$^{A}$ | 81,423.34$^{A}$ | 80,226.22$^{A}$ |
| CV(%)[2] | 12.7 | 16.6 | 16.2 |
| MOR | | | |
| Mean(Kg/cm²) | 353.68$^{A}$ | 255.47$^{B}$ | 248.27$^{B}$ |
| CV(%)[2] | 27.6 | 40.9 | 36.3 |
| Nondestructive parameters | | | |
| Dynamic MOE | | | |
| Mean(Kg/cm²) | 91,422.00$^{A}$ | 87,778.33$^{A}$ | 86,422.00$^{A}$ |
| CV(%)[2] | 11.5 | 15.4 | 15.4 |
| Logarithmic decrement | | | |
| Mean(Kg/cm²) | 0.0460$^{A}$ | 0.0431$^{A}$ | 0.0473$^{A}$ |
| CV(%)[2] | 14.2 | 21.5 | 16.7 |
| | | Initial drying : CKD | |
| Sample size | 27 | 44 | 45 |
| Destructive parameters | | | |
| MOE | | | |
| Mean(Kg/cm²) | 83,165.19$^{A}$ | 79,171.59$^{A}$ | 77,864.89$^{A}$ |
| CV(%)[2] | 18.7 | 16.9 | 15.8 |
| MOR | | | |
| Mean(Kg/cm²) | 316.06$^{A}$ | 262.69$^{B}$ | 252.26$^{B}$ |
| CV(%)[2] | 41.4 | 37.1 | 36.3 |
| Nondestructive parameters | | | |
| Dynamic MOE | | | |
| Mean(Kg/cm²) | 88,472.22$^{A}$ | 87,094.23$^{A}$ | 85,160.45$^{A}$ |
| CV(%)[2] | 18.8 | 13.5 | 15.0 |
| Logarithmic decrement | | | |
| Mean(Kg/cm²) | 0.0443$^{A}$ | 0.0453$^{A}$ | 0.0471$^{A}$ |
| CV(%)[2] | 19.2 | 21.3 | 15.2 |

[1]Means followed by the same letter are not significantly different one from another at 95 percent significance level using Duncan's multiple range test.

[2]CV=coefficient of variation.

bending and nondestructive flexural vibration data were separated using Duncan's multiple range test, using the Statistical Analysis System(SAS) programming package (13) as shown in Table 1.

Consistent with other reports(2, 11, 16, 18), average MOE values as determined from static bending tests were not significantly different among the three groups, even though the MOE of the treatment groups was a somewhat lower than that of the controls. This shows that CCA-treatment followed by redrying has a negligible effect upon the stress-strain relationships below the proportional(elastic) limit.

As with MOE from static bending test, values of dynamic MOE determined from a free flexural vibration test for the treatment groups were less than the control group. However, this reduction was not statistically significant. Logarithmic decrement, a measure of the damping capacity of a material, was not significantly changed by CCA-treatment and subsequent redrying. These results agree well with the literature(4, 11).

The treatment of lodgepole pine dimension lumber with CCA followed by redrying resulted in a significant reduction in bending strength. The average MOR was reduced 27 percent for the treatment group using the conventional initial drying/conventional redrying combination and 29 percent using the conventional initial drying/high-temperature redrying combination, compared to the untreated control. The reductions, on the other hand, were 17 percent using the high-temperature initial drying/conventional redrying combination and 20 percent using the high-temperature inintal drying/high-temperature redrying combination, compared to the untreated control. Although the high-temperature drying schedule resulted in a somewhat lower average MOR than the group redried using the conventional drying schedule, the two redrying schedules did not singificantly differ in their effect on MOR. This significant reduction in static bending strength by the CCA-treatment and subsequent post-drying found in this study is in agreement with other reports (2, 11, 16, 18). However, when considering strength reductions with initial drying, initial kiln drying using a CKD schedule resulted in greater and more consistent reductions in bending strength after CCA-treatment and redrying than initial drying using a HTD schedule. This result might be attributed to the severe strength reductions at the stage of initial drying in high-temperature dried material compared to in conventionally dried material as shown in Table 2.

Table 2. Percentile estimates for the bending strength derived using weighted average rank order statistics[1].

| | MOR($kg/cm^2$) | | MOR percentile estimate($kg/cm^2$) | | | | |
|---|---|---|---|---|---|---|---|
| Redrying | Mean | CV[2] | 5th | 10th | 25th | 50th | 75th |
| | | | Initial Drying : CKD | | | | |
| Control | 353.68 | 27.6 | 188.02 | 198.59 | 232.61 | 359.17 | 445.97 |
| CKD | 255.47 | 40.9 | 126.35 | 136.71 | 190.12 | 227.05 | 329.07 |
| | (−27) | | (−33) | (−31) | (−18) | (−37) | (−26) |
| HTD | 248.27 | 36.3 | 136.36 | 142.17 | 190.96 | 215.32 | 298.83 |
| | (−29) | | (−27) | (−28) | (−18) | (−40) | (−33) |
| | | | Initial Drying : HTD | | | | |
| Control | 316.06 | 41.4 | 174.72 | 174.72 | 218.19 | 273.56 | 455.70 |
| CKD | 262.69 | 37.1 | 134.75 | 148.26 | 200.73 | 246.40 | 321.44 |
| | (−17) | | (−23) | (−15) | (−8) | (−10) | (−30) |
| HTD | 252.26 | 35.5 | 124.11 | 135.80 | 177.10 | 254.59 | 308.00 |
| | (−20) | | (−29) | (−22) | (−19) | (−7) | (−32) |

[1]Values in parenthesis are % difference from control.
[2]CV=coefficient of variation.

In order to better understand how treatment and redrying affects the distributional characteristics of bending strength and because of the importance of structural reliability, and analysis of bending strength distributions is preferable to an analysis involving only average values. Consequently, the effects of CCA-treatment and subsequent redrying on bending strength were related to percentile

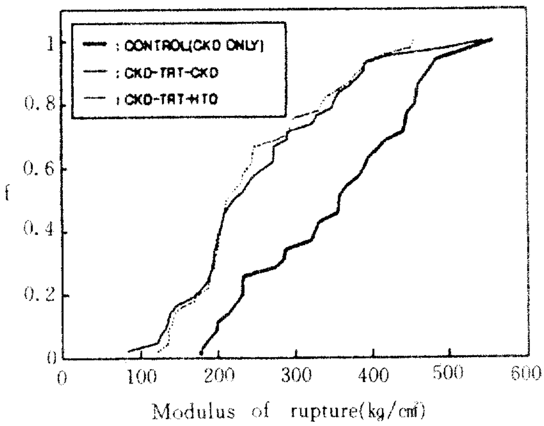


Fig.1. Cumulative frequency distribution of MOR for the control and redried groups which were initially dried using a conventional kiln drying schedule.

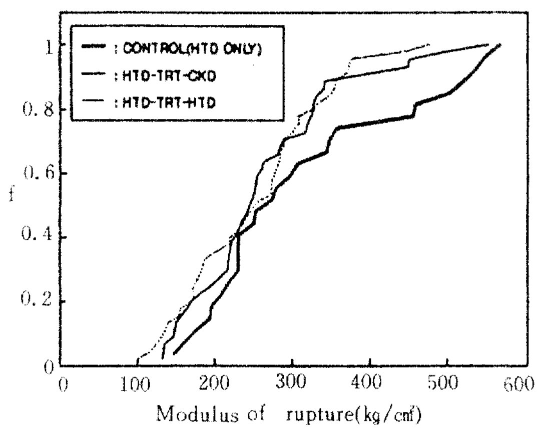


Fig.2. Cumulative frequency distribution of MOR for the control and redried groups which were initially dried using a high-temperature drying schedule.

level within the distribution. A plot of cumulative frequency distribution of MOR is shown in Figure 1 for the groups dried initially using a conventional schedule. This diagram illustrated that CCA-treatment and redrying reduced the strength throughout the whole proportion of MOR distribution as indicated by the leftward shift of the two treatment groups compared to the control values. However, there was little difference between the two treated groups over most of the bending strength distribution. A similar plot is shown in Figure 2 for the smaples which were initially high-temperature dried. The bending strength for the treatment groups was lower than that for the controls. One might reasonably conclude from Figures 1 and 2 that if wood is treated and subsequently redried, any subsequent redrying schedules will cause a substantial loss of strength. These trends are evident when investigating the percentile estimates of MOR calculated using a weighted average rank order statistics (13) shown in Table 2.

Statistical analysis was performed to determine the dynamic MOE as the covariates which significantlyu affect the mean values for the static bending properties, using the SAS programming package (13). Dynamic MOE was chosen the best covariate because it provided the best correlation coefficient and because it is a nondestructive parameter which correlates with the current practice of machine stress rating of lumber. Therefore, an analysis of covariance employing dynamic MOE as the covariate was used to identify where statistically significant differences existed in treatment/redrying groups, and then the adjusted mean values were compared using a least mean square separation method. The results obtained from this analysis (Table 3) was the same as those obtained from Duncan's multiple range test(Table 1), even though the mean values of the bending properties were adjusted.

Table 3. Comparison of adjusted mean values of bending properties using analysis of covariance with dynamic MOE as the covariate[1].

| Property | Control | CKD | HTD |
|---|---|---|---|
| | Initial drying : CKD | | |
| MOE($Kg/cm^2$) | 82,784.74[A] | 81,920.27[A] | 81,959.83[A] |
| MOR($Kg/cm^2$) | 336.48[A] | 258.50[B] | 257.10[B] |
| | Initial drying : HTD | | |
| MOE($Kg/cm^2$) | 81,574.75[A] | 78,793.68[A] | 78,488.60[A] |
| MOR($Kg/cm^2$) | 307.13[A] | 260.48[B] | 257.69[B] |

[1]Values are adjusted mean values and groups not followed by the same letter are significantly different one from another at 95 percent significance level.

## 4. CONCLUSIONS

The effect that CCA-treatment followed by either conventional or high-temperature redrying had on the bending properties of lodgepole pine dimension stock was evaluated. The conclusions from this investigation are :

1. CCA-treatment and subsequent redrying had no a significant effect on static bending MOE and nondestructive parameters-(dynamic MOE and logarithmic decrement) obtained from a free flexural vibration test.
2. A significant reduction in MOR of kiln-dried stock after CCA-treatment was observed throughout the whole proportion of bending strength distribution, although no significant difference in MOR occurred between the conventional (71℃) and high-temperature redrying (110℃) of CCA-treated material.
3. Unless a reduction of mean MOR from 17 to 29 percent, according to the combination of a initial drying and a redrying schedule, is acceptable, redrying lodgepole pine dimension lumber after CCA-treatment at temperatures of 71℃ or above should be avoided.

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