HIGH TEMPERATURE KILN DRYING OF HEM FIR STUD LUMBER

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High temperature lumber drying: this is a phrase that brings a different image to each person. For me, it has been a type of lumber drying that caused great trepidation. The lumber I had seen dried at high temperature resulted in poorer grade and had a great deal of downfall. So, when Sun Studs decided to investigate the impact on hem-fir stud lumber of drying at different temperatures, I was very interested in the results. We arranged to do the testing at Oregon State University. The following is a review of the results of that testing combined with comments about how the test data relates to what we see at the mill.

Procedure

Solid-piled packages containing 216 pieces of nominal 2"x 4"x 8' stud lumber were delivered to Oregon State University in three shipments in the summer of 1997. Each shipment was a replication of the experiment and contained enough lumber for four kiln charges. The wood was stored in the shade and covered for up to two weeks until needed.

Drying

Predrying Measurements

Prior to drying, each piece was numbered and weighed to the nearest 0.01 pounds and the width and thickness were measured with calipers to the nearest 0.001 inches. The location at which the width and thickness measurements were made was selected to be away from knots or other wood characteristics. The location was marked on the board so that the measurements could be repeated after drying at the same location.

The wood was stacked on 0.75" stickers at a 4' spacing. Each kiln charge was 12 boards wide (4'), 18 courses high, and two packages (16') long. Four 720-pound concrete weights were placed on the pile providing a top restraint of 45 psf.

Drying Schedules

Four drying schedules were used (TABLE 1) with dry-bulb set points of 180°F, 240°F, 255°F, or 270°F. The initial dry-bulb temperature was ramped as quickly as possible and required 0.25, 1.5, 4, and 10 hours to reach these set points, respectively.

TABLE 1. Drying schedules. The dry-bulb set point was constant during each schedule. The wet-bulb was ramped between set points at the times shown.

Dry-bulb,°F	180	240	255	270
Time, hours	Wet-bulb, °F			
0	150	210	210	210
12	150	210	210	210
24	150	180	190	210
end	150	180	190	210

The wet-bulb set points varied with schedule and time (TABLE 1). There were no equalizing or conditioning steps in the schedules. The wood was dried to a moisture content of 10 to 15 percent, then cooled with the concrete weights in place. The schedules were run in random order within each replication.

Postdrying Measurements

After drying, each piece was again weighed and the thickness and width were measured. Wood properties were measured on one of the end grain surfaces of the board. The ring count (as rings per inch) was obtained by placing a ruler near the center of the end grain face and counting the rings in a one-inch distance. A half-circle plexiglass template with concentric rings (1) was used to estimate the position of the board in the tree. The template was placed over the end grain face of the board so that one of the concentric rings covered a growth ring near the center of the face. The radius of curvature of this ring was the estimate of the distance to the pith when the board was in the living tree. As this was done, the template was held with its flat edge parallel to the face of the board. The angle made between the 0° line and a line from the center of the board to the origin of the template was used as an estimate of the angle of the rings in the board. Zero degrees would indicate a flat sawed board, while 90° indicates a quarter sawed board.

The bow, crook, and twist in each board were measured using a taper gage and a flat surface. The ends of the board were held against the flat surface and the taper gage was slid under the board at the point of maximum distance from the flat surface to measure bow or crook. For boards with twist, it was important to hold the board so that the two corners of the board nearest the person measuring were against the table and make the bow or crook measurement between these corners. Twist was measured by holding three corners on the same face of the board against the flat surface and measuring the distance of the fourth corner from the table.

The moisture content of the board was measured on one face of the board in three places, two feet from each end and in the center. A Delmhorst RDM moisture meter was used so that the data could be directly downloaded to a computer via an RS-232 interface.

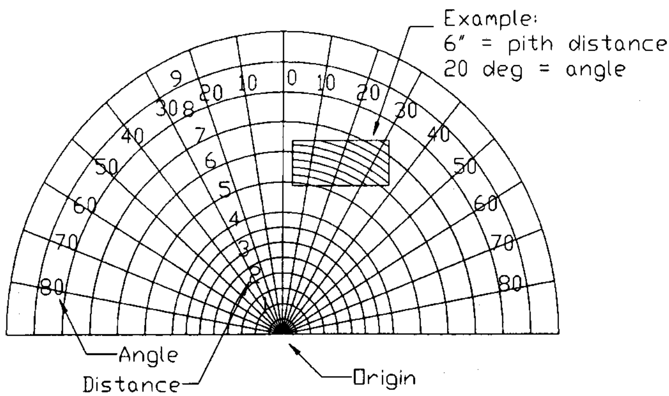

FIGURE 1. Clear plastic template used to determine position of board when it was in the tree.

After these measurements were made, the boards were repackaged in units of 216 boards, banded, and stored under cover for one to five months. The wood was then shipped under tarp to Sun Studs in Roseburg, OR where it was mechanically unstacked, planed, graded as stud lumber, and tallied. At this point, the identity of each board was lost and grade and tally are reported by kiln charge.

Data Analysis

The final moisture content, M_F, of each board was obtained by averaging the three moisture meter readings. Oven-dry weight, W_{OD} was then obtained by dividing the weight of the board after drying by $[M_F/100 + 1]$. Finally, the green moisture content of the board was calculated as $100*(W_G - W_{OD})/W_{OD}$, where W_G was the original board weight.

Thickness or width shrinkage for each board was calculated as $100*(S_G - S_D)/S_G$ where S_G and S_D are the green and dry thickness or width, respectively.

Statistical Analysis

For the experimental design, each shipment of lumber (batch) represents a replication. The analysis of variance is blocked by batch to account for differences in the wood properties. The experimental unit is the kiln charge and each board represents a subsample. The error terms for calculating significance are the drying temperature nested within batch [Temp(Batch)] for properties measured in the lab and the model error for properties measured at the mill. Covariates in the model for properties measured in the lab were pith distance, rings per inch, ring angle, final moisture content, oven dry weight, and green moisture content. Final moisture content was used as a covariate for properties measured at the mill.

Results and Discussion

Wood Received

The properties of the wood received are shown in TABLE 2. The averages at each temperature are similar; however, this is the result of drying one charge from each batch at each temperature. There is some variability among the batches.

TABLE 2. Properties of wood by batch of wood received, temperature in kiln, and by charge of lumber.

Wood property	Batch			Overall study mean
	A	B	C	
Green MC, %	99.2	86.0	82.7	89.3
Green thickness, in.	1.59	1.58	1.58	1.58
Green width, in.	3.71	3.73	3.74	3.73
Ring count, 1/in.	7.0	7.1	6.1	6.8
Ring angle, °	28.7	26.1	26.5	27.1
Pith distance, in.	3.4	3.1	4.0	3.5
Oven-dry weight, lbs.	7.49	7.64	7.80	7.64

Wood property	Temperature, °F			
	180	240	255	270
Green MC, %	87.4	91.3	90.4	88.1
Green thickness, in.	1.59	1.58	1.58	1.58
Green width, in.	3.73	3.72	3.73	3.73
Ring count, 1/in.	6.3	7.3	6.5	6.9
Ring angle, °	27.4	26.3	26.8	27.6
Pith distance, in.	3.47	3.71	3.52	3.25
Oven-dry weight, lbs.	7.80	7.57	7.56	7.64

The moisture content of the first shipment of wood was 99.2% and the moisture contents of the second and third shipments were 86.0 and 82.3%, respectively. This decreasing trend in starting moisture content is probably the result of differing harvesting and storage times. Within a replication there was no trend in moisture content from the first charge to the fourth.

Green width, green thickness, and oven-dry weight were similar among the three batches. Assuming that the wood had the same amount of wane and same average length, this implies that the specific gravity was similar among the batches of wood.

The distance from the center of the board to the pith of the tree when the board was in the tree was statistically similar for the first two batches, 3.4 and 3.1 inches. The third, 4.0 inches, was statistically similar to the second. This indicates that the wood for the third batch came from larger trees than the wood from the first batch ($p=0.03$). Grain angle and ring count were similar for all three replications, ranging from 26.1° to 28.7° and 6.1 to 7.1 /inch, respectively.

Drying Time and Final Moisture Content

The drying times and final moisture content for each charge are shown in TABLE 3. The number of wet pieces is shown three ways - 1) the number of pieces on which at least one of the three pin-type moisture meter readings was greater than 19%, 2) the number of pieces on which the average of the three pin-type moisture meter readings was greater than 19%, and 3) the number of pieces marked as wet at the planer. Comparing the three methods shows that rejecting boards based on one reading gives more wet pieces than on the average of all readings. The time interval between the lab and mill moisture meter readings, two weeks to five months, probably accounts for some of the difference in the number of wet pieces. The moisture in the wood had time to redistribute during the storage interval.

Any four charges with an average moisture content greater than 11% had too many wet pieces to be acceptable with 95% of the pieces less than 19% moisture content. Based on the regression line in FIGURE 2, an average moisture content of 10.4% would have to be reached to have 95% of the pieces at or below 19% moisture content. The average final moisture content for all charges was 11.2%.

A key point to notice is that the number of wet pieces is greater for the wood dried at high temperature. This is not apparent in TABLE 3 because of the final moisture content variability. However, FIGURE 2 clearly shows that the charges dried at 180°F (diamonds) generally have fewer wet pieces compared to charges dried to similar moisture contents at higher temperatures.

The drying times averaged 50, 24, 16.6, and 14.9 hours at 180, 240, 255, and 270°F, respectively. For similar schedules, the drying time in a larger kiln would be longer due to the load width. Also, the lab kiln might heat faster than a commercial kiln, taking 0:15, 1:30, 4:00, and 10:00 hours to reach set point at the four temperatures. It should be noted that initial portion of the schedule at 270°F is not greatly different than the schedule at 255°F because of the time to reach set point; never-the-less the high temperature late in the schedule does accelerate drying by 1.7 hours. The average drying rates during the schedules are approximately 1.6, 3.2, 4.7, and 5.2%/hour. The rates are no doubt higher in the beginning of the schedules and lower at the ends, but it illustrates the point that drying occurs approximately 3 times faster at the higher temperatures. This requires the kiln operator to be three times more precise in deciding when to pull the charge.

TABLE 3. Final moisture content and drying times. Number of wet pieces are those with one reading above 19% moisture content. 22 wet pieces would be 5% of the charge.

Temp-erature	Drying time, hours	Moisture content, %	Number of wet pieces		
			Lab		Mill
			One reading over 19%	Average of 3 readings over 19%	
180	50:00	10.2	6	1	0
240	23:53	13.0	105	62	9
255	16:36	11.3	32	14	5
270	14:53	10.4	33	16	1

Warp

Average warp is shown in TABLE 4.

TABLE 4. Warp by kiln temperature and lumber batch. Each value for bow crook and twist represents an average of 432 pieces.

Temp-erature	MC, %	Bow, in.	Crook, in.	Twist, in.	Number of pieces exceeding			
					0.75"	0.25"	0.375"	Any Warp Limit
					Bow	Crook	Twist	
180	10.2	0.126	0.131	0.078	4	89	25	112
240	13.0	0.107	0.077	0.070	2	62	27	85
255	11.3	0.086	0.086	0.055	2	65	19	79
270	10.4	0.104	0.081	0.068	3	83	28	103

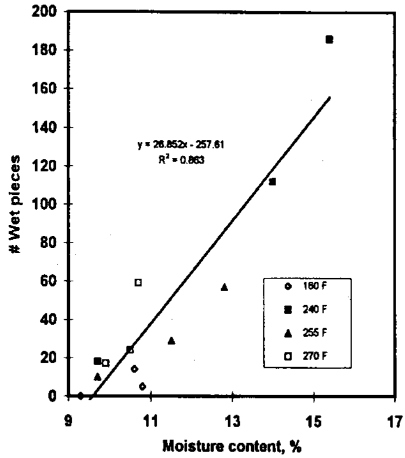

FIGURE 2. Number of wet pieces per charge versus average final moisture content. A wet piece had a moisture meter reading greater than 19%.

Based on an analysis of variance, bow was significantly affected by only the distance from the pith ($p=0.01$) and oven-dry weight ($p < 0.01$) of the piece. Crook was only affected by the oven-dry weight of the piece. Twist was only affected by distance from the pith ($p < 0.01$). Drying temperature had no effect on bow, crook, or twist. Due to the nature of the analysis, the tests for the effect of temperature and batch on warp are rather insensitive because there are only 3 and 2 degrees of freedom, respectively.

TABLE 5 shows least squares estimates for bow, crook, and twist. These are the average measured values adjusted for experimental variables (covariates in the analysis of variance) such as final moisture content and pith distance which affect the warp. Statistically there are no differences in bow crook or twist with temperature; however, inspection of TABLEs 4 and 5 do suggest that warp, particularly bow and crook, are reduced at the higher temperatures.

The number of pieces with warp exceeding that allowed by the grading rules may be a better measure of the warp in the lumber. These are also shown in TABLE 4 and plotted in FIGURE 3. The linear regression shown on the plot suggests that for every one percent decrease in moisture content there is an increase of seven warped pieces per charge, or about 1.6% of the charge. The regression coefficient for this relationship is only 0.23, however. From FIGURE 3 there does not appear to be any relationship between the number of warped pieces and the temperature at which the wood was dried. This at first seems to contrast TABLE 5, but may suggest that the pieces that warp enough to not meet grade will do so regardless of drying temperature.

TABLE 5. Least squares predictions for bow, crook, and twist. Values are adjusted to remove some effects due to factors such as final moisture content. None of the trends are statistically significant at the 95% confidence level.

Temperature	Bow, in.	Crook, in.	Twist, in.
180	0.114	0.121	0.074
240	0.120	0.086	0.082
255	0.090	0.088	0.056
270	0.099	0.079	0.060

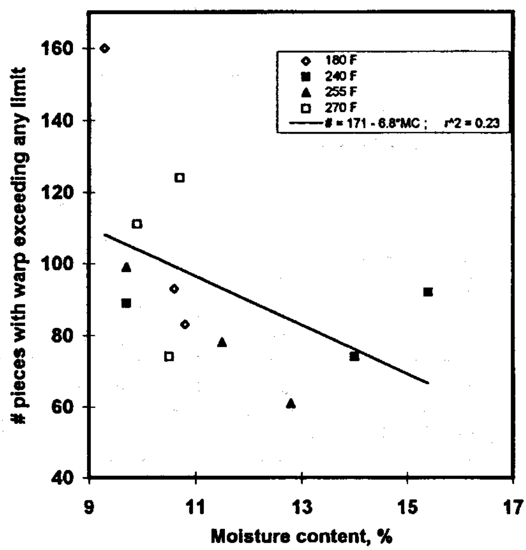

FIGURE 3. Number of warped pieces per charge versus average final moisture content of charge. A warped piece has bow greater than 0.75", crook greater than 0.25", or twist greater than 0.375".

Shrinkage

Thickness shrinkage (TABLE 6) was affected by batch (p=0.02), kiln temperature (p=0.04), final moisture content (p < 0.01), and ring angle (p < 0.01). Width shrinkage (TABLE 6) was affected by final moisture content (p < 0.01), pith distance (p < 0.01), ring angle (p< 0.01), and green moisture content (p=0.01). It is clear that final moisture content should be a factor in shrinkage because it's well known that wood shrinks as it loses moisture. Similarly, an effect due to ring angle can be easily explained by the difference in tangential and radial shrinkage. It is not clear why green moisture content affects shrinkage unless some predrying occurred.

Kiln temperature was not a significant factor for width shrinkage, but did significantly affect thickness shrinkage. TABLE 6 shows least squares estimates for thickness and width shrinkage. These are the average measured values adjusted for experimental variables such as final moisture content. Based on these values, high temperature drying would require no adjustment in the target size for width. The target size for thickness, however, may need to be increased by 0.005 to 0.010 inches (based on a thickness of 1.58") to prevent increased skip on the lumber dried at high temperature.

TABLE 6. Shrinkage by drying temperature. Least squares predictions for width and thickness shrinkage are also shown for the four temperatures. The least squares values are adjusted to remove some effects due to factors such as final moisture content. There are no significant differences among the four temperatures for width shrinkage.

Temperature °F	Measured		Least squares estimates	
	Width shrinkage, %	Thickness shrinkage, %	Width shrinkage, %	Thickness shrinkage, %
180	3.66	3.05	3.60	2.99
240	3.74	3.26	3.84	3.37
255	3.73	3.47	3.72	3.48
270	3.69	3.52	3.66	3.45

Grade and Recovery

The grade and recovery information collected at Sunstuds during planning is reproduced in TABLE 7. There are no statistical differences in percent recovery among the four drying temperatures; however, there may be a nonsignificant (at the 95% confidence level) trend toward decreased recovery after drying at 270°F.

Temperature	Footage, bf/charge	Least squares estimate of footage, bf/charge	Recovery, %	Least squares estimate of recovery, %
180	2254	2245	97.9	97.5
240	2228	2244	96.8	97.5
255	2232	2233	97.0	97.0
270	2210	2202	96.0	95.7

In TABLE 8, the value of the wood is shown. The differences among the temperatures are not statistically significant at the 95% confidence level. The least squares estimates (values adjusted for moisture content) indicate a trend towards higher values at 240°F and 255°F than 180°F. Caution should be used in this interpretation, however, because in this study the high moisture content charge dried at 240°F had a relatively low value making the statistical analysis program "think" that value goes up as moisture content goes down. It should be noted that the wood dried at 180°F had one of the highest values but also had the lowest average moisture content.

Implementation

Recently, an additional boiler was installed at Sun Studs. It is a natural gas-fired, fire tube boiler, capable of 28,000 pounds per hour steam generation. This gave us the capability to test in a production environment the findings from the laboratory testing. Taking into consideration the steam available and the test results, the 240/210 schedule was tried first. Drying time prior to this had ranged from 56-58 hours in our single track kilns and 38-40 hours in the double track kilns.

TEMP	MC, %	Footage, fbm	Recovery, %	Grade												
				C&Btr		Stud						Econ	Rip	Sticker		
				92-5/8	72	92-5/8	88-5/8	84	72	60	48	92-5/8		54	46	27
180	10.2	2254	97.9	10.7	1.6	1754.4	62.3	54.4	126.7	6.6	7.1	220.4	5.3	2.2	0.9	1.3
240	13.3	2228	96.8	8.9	9.3	1707.4	72.9	58.0	133.3	27.7	1.8	193.7	12.0	3.3	0.0	0.0
255	11.3	2232	97.0	8.9	6.2	1858.3	39.2	52.9	61.3	5.5	2.7	181.7	14.7	0.0	0.9	0.0
270	10.4	2210	96.0	7.1	4.7	1669.6	81.8	85.6	106.7	20.0	7.1	209.8	9.3	6.7	1.8	0.0

TABLE 7. Grade and recovery information.

TABLE 8. Average value of the wood from kiln charge dried at the temperatures shown. The lumber prices used in the calculation are in the upper portion of the table.

Grade	C&Btr		Stud				Econ	Rip	Sticker
	92-5/8	72	92-5/8	88-5/8	84	72, 60, 48	92-5/8		54, 46, 27
$/mbf	465	385	350	340	285	275	275	265	135

Temp-erature	MC, %	Total Value, $/charge	Least squares estimate, total value, $/charge
180	10.2	737.72	729.49
240	13.3	730.87	745.49
255	11.3	742.09	742.83
270	10.4	720.87	713.72

We did have a problem reaching the set point temperature, especially in the double track kilns with the schedule sometimes taking as long as 24 hours to get to set point. Consistent with the lab results, stock processed through the planer had excessive shrinkage, which lowered the grade recovery due to excessive skip on the wood surface.

The general appearance of the wood changed to a much darker product which might be unacceptable to customers. It also magnified a problem we had been having with the stickering of units. This showed up in increased warp and collapse. Kiln defect jumped from about 6 to 8 percent of our economy grade as a result of kiln defect to 32 percent using this schedule in our kilns. We have been producing a 9-foot and 10-foot product for about two years and have not upgraded our sticker machine that was originally designed for an 8-foot-long product. A new sticker machine is now on order to remedy this problem.

The next step was to try a schedule that was high temperature but would allow us more kiln control. It was a 212/212 for 4 hours (the time to reach set point); then 220/190 for the balance of the schedule. The results with this schedule were much better. The quantity of kiln defect pieces that were downgraded to economy dropped back to 6 to 8 percent and the general appearance of the stock (because of less skip) was much improved. The drying hours with this schedule were 36-38 and 40 to 42 hours in a double track kiln. We have continued to use this schedule and to run tests with the 240/210 schedule in our single track kilns.

Conclusions

Drying times can definitely be shortened by high temperature without compromising quality. If the kiln temperature is changed from 180°F to 240°F throughout the schedule, the drying time will be approximately half at the higher temperature.

Final moisture content must be maintained at the highest acceptable level, therefore hot checks must be timely and often. As the rate of drying increases this becomes more critical and any quality issues in your current drying process will be magnified.

The number of wet pieces increases dramatically with moisture content. The average charge moisture content should be brought to the 10 to 12% range to have 95% of the pieces under 19% moisture content. However, to minimize degrade a higher final moisture content would be desirable. Wood dried at higher temperature tends to have a greater percentage of wet pieces that wood dried at 180°F when dried to the same moisture content.

There is a trend toward lower warp after drying at higher temperature when the warp is measured against a straight edge, but this was not statistically significant in this study. The percent of pieces which warped beyond the limits allowed in the grading rules shows less of a trend than warp measure with a straight edge suggesting that many of the pieces with a large amount of warp will do so regardless of schedule.

Drying at higher temperature results in greater shrinkage in the thickness direction. It might be necessary to increase target size by 0.005 to 0.010" on a 1.58-inch-thick piece when drying at high temperature.

There is a trend, again statistically nonsignificant, for the wood dried at 270°F to have a lower recover and value than wood dried at the lower temperatures. Conclusions regarding the value of the wood among the other temperatures are difficult to draw. The wood dried at 180°F had the lowest average moisture content and a relatively high value.

It is necessary to keep experimenting with your equipment and schedules and, as conditions change, modify what you are doing to adapt.