PRESS DRYING AS A MEANS OF CONTROLLING WARP IN LUMBER

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INTRODUCTION

The forest products industry is handling an increasing amount of lumber that is prone to warping during drying. Young growth and plantation-grown timber often contain large amounts of juvenile, compression, or tension wood. These types of wood have abnormally large longitudinal shrinkage, and the amount of longitudinal shrinkage usually varies within boards. When the surface fibers on opposite faces or edges of boards have different longitudinal shrinkage, the boards are likely to bow or crook during drying. Plantation Southern pine, plantation red pine, and young growth ponderosa pine are species that often suffer large grade and value loss during drying because of crook, bow, and twist.

The purpose of this paper is to discuss the use of press drying to restrain warp and thus reduce grade and value loss. Platens of a hot press restrain warp by applying pressure to lumber as well as reduce drying time by providing rapid heat transfer from platens to lumber. In this paper, I will discuss some research results on press drying loblolly pine 2 by 4's and then discuss some current research aimed at reducing variability in final moisture content of press dried lumber.

EXPERIMENTS WITH LOBLOLLY PINE

Experimental Procedure

Freshly cut loblolly pine (Pinus taeda) logs were obtained from a plantation in North Carolina. The trees were 28 years old with small end diameters ranging from 8 to 14 in. These trees are considered representative of the timber supply that will be available to the Southern pine sawmill industry in the future. Twenty-nine logs, nominally 36 ft. long, were delivered to Madison in the winter of 1986-87. The logs and lumber were processed by spring so that they were not subject to the biological deterioration that occurs during storage in summer time temperatures. The logs were bucked into 8-ft plus trim lengths.

The 8-ft logs were sawed into nominal 2 by 4's by conventional cant sawing. A 4-in. cant, centered geometrically in the log, was produced by split taper sawing. Side flitches, nominally 2-in. thick, were sawn from the larger logs and ripped to produce 2 by 4's. The cants were processed by split taper sawing into nominal 2 by 4 thickness. All logs were coded for identification throughout the processing.

Complete details of the experimental procedure and results are given by Simpson, Danielson, and Boone (1), and in this paper I will summarize both the method and results of this study. The study had two main parts: press drying and kiln drying.

In part 1, 2 by 4's were surfaced before press drying to 1.825 in thick. The purpose of the surfacing was to provide a uniform thickness so that all 2 by 4's would receive the same platen pressure and heat transfer rate. We tested three levels of platen pressure--25, 50, and 75 lb/in^2. Platen temperature was 350° F. A total of 480 2 by 4's were surfaced to 1.5 in thick and 3.5 in wide.

In part 2, 2 by 4's were kiln dried to help establish a basis for warp comparison between kiln- and press-dried boards. Four kiln runs were made. Two runs were followed by an equalizing period after drying. The boards were dried at 280° F with 1,200 ft/min of air velocity, and the drying time to the target moisture content of 15 percent was about 13 h. Equalizing was 8 h at 190° F dry-bulb temperature and 175° F wet bulb. A top load of about 50 lb/ft^2 was applied. A total of 523 2 by 4's were kiln dried. After kiln drying, all 2 by 4's were surfaced to 1.5 in thick and 3.5 in wide.

Results

The quality of the 2 by 4's press dried at 75 lb/in^2 appeared good initially. However, it soon became apparent that tree-to-tree variability of response to press drying would adversely affect the quality of a significant portion of the lumber. Thus, the platen pressure of 75 lb/in was abandoned as a study variable before all the planned press runs were completed at that pressure.

We do not conduct a meticulous study of the occurrence of surface or internal checks. No internal checks were seen on the ends of any 2 by 4's. Occasional small (short and narrow) surface checks were seen, but these were minor and would not affect grade. No collapse was seen in any 2 by 4's dried at 25 or 50 lb/in^2. Occasional collapse was seen in those dried at 75 lb/in^2. After surfacing, the 2 by 4's press dried at 25 and 50 lb/in^2 looked no different than those that were kiln dried. While no older growth lumber was included in the study for comparison, the fact that the study material was all sapwood could be an important factor in the lack of collapse or checking.

The press drying time to the target moisture content of 15 percent was 90 min. The initial moisture content averaged about 120 percent for both the press- and kiln-dried 2 by 4's. Thickness loss in press drying ranged from a low of just under 3 percent at 25 lb/in^2 to over 16 percent at 75 lb/in^2.

The results of the warp measurements are given in Table 1 in terms of thirty-seconds of an inch for crook, bow, and twist. Crook and bow can be held to lower levels in press drying than in kiln drying. For example, at 25 lb/in^2 platen pressure, crook averaged 1.8 thirty-seconds of an inch, whereas it was greater than 4 thirty-seconds of an inch in kiln-dried lumber. The average warp values in Table 1 suggest that warp increases with platen pressure. One would expect that warp would decrease as platen pressure increases because of increased restraint. Thus, we cannot explain these results.

Another way to compare the warp results is the percentage of pieces that fall out of grade because of excessive warp. Select Structural, Number 1, Construction, and Stud grades all allow 8/32 in of crook, 16/32 in of bow, and 12/32 in of twist in 8-ft-long 2 by 4's. Number 2, Number 3, Standard, and Utility grades all allow more warp. Table 2 summarizes the percentage of 2 by 4's that would be downgraded because of crook alone, bow alone, or twist alone, as well as the percentage downgraded by any form of warp. At its best (25 lb/in^2 pressure), press drying kept the downgraded lumber to less than 4 percent. In contrast, downgraded lumber in kiln drying was in the 20 percent range.

CURRENT RESEARCH IN PRESS DRYING

Objectives

We believe that the results of the study outlined above have shown that press drying can reduce warp. Our current research is an attempt to optimize press drying in terms of recognizing the variability of the properties of lumber as it enters the press so that variability after press drying is minimized. These properties are lumber thickness, initial moisture content, and specific gravity.

Thickness of lumber entering a press is variable, the degree of variability depending on how precise the lumber has been sawed or whether or not lumber has been surfaced with a planer before drying. Nonuniform thickness causes variability in the degree of restraint each board receives. Inadequate pressure on thin boards may not effectively restrain warp, and excessive pressure on thick boards also has adverse effects. Variable thickness also causes variability in drying time to final moisture content.

Initial moisture content and specific gravity are also variable and affect drying time. Final moisture content after press drying is thus also variable, and both overdrying and underdrying are undesirable. Overdrying is undesirable because of the correlation between final moisture content and warp--the lower the moisture content, the more warp is expected. Underdrying is also undesirable because boards may not meet grade moisture content requirements and because more warp may develop during the additional drying that takes place after boards are removed from the restraint of the press.

The ideal press drying process will minimize warp, variation in final moisture content, and press time. A step in this direction is a segregation system to reduce variability by grouping like boards within the same press cycle. Many factors cause lumber variability, and the broadly stated objective of our research is to develop a relationship between certain wood characteristics and their response to press drying so that a sorting system can be developed. We know that thickness will affect both warp suppression and drying time, that initial moisture content and density will affect drying time, and that final target moisture content will affect both drying time and warp. We hope to develop a sorting system based on these characteristics. Specifically, we want to develop a mathematical model for determining the dependence of drying time on the factors that affect drying, and thus form the basis for sorting boards into groups of similar estimated drying time.

Model For Estimating Drying Time

We want to develop a model that can predict drying time from characteristics that can be easily, quickly, and nondestructively determined from green boards so that the boards can be sorted immediately before drying. The sorting decision must be made at production-line speed to have any practical value. We are currently testing one particular model. It is a slight variation of the heat-transfer model developed by Tschernitz (2) for thick Southern pine and Douglas-fir veneer. The final equation of the model is

$$t = Q(L/2)^n[W_o - W_d(M_f + 1)]^2 / 2\,k\,G_v(W_o - W_d)(T_s - T_c) \quad (1)$$

where

t is time,

Q latent heat of vaporization of water,
L thickness,
n thickness coefficient,
W_o green weight,
W_d ovendry weight,
M_f final moisture content (fractional),
k thermal conductivity,
G_v green volume,
T_s platen temperature, and
T_c temperature at the center of the wood.

Equation (1) takes into account both density and initial moisture content, but expresses them in terms of initial green weight and initial green volume, which can be scanned at production-line speeds. Thickness is also easily measured, and final moisture content and platen temperature are both known quantities. Note that Equation (1) will tend to group thick and thin boards together, which is advantageous from the standpoint of both drying time and warp suppression.

The remaining parameters of Equation (1) that must be estimated are latent heat of vaporization, thermal conductivity, wood temperature, the thickness coefficient, and ovendry weight. These parameters can be estimated in a number of ways, either by physical principles or by making the parameters regression coefficients to be determined by fitting experimental data to Equation (1). In our current research, we will explore how to test Equation (1) with experimental data.

Numerical Example of the Model

Even though we have not thoroughly tested Equation (1) with an experiment designed specifically to determine the parameters, we can test the general ability of this equation to predict the anticipated effect of the variables on drying time. The previously summarized study (1) indicated that at a platen temperature of 350° F, green thickness of 1.75 in, specific gravity of 0.45, and initial moisture content of 120 percent, the drying time to 15 percent moisture content is about 90 min for loblolly pine. This information was used to set reasonable parameter values to observe how the model predictions will be affected by varying the characteristics of the lumber.

Initial Moisture Content

If we maintain a constant specific gravity (0.45) and vary initial moisture content, we expect the model to predict an increase in drying time as initial moisture content increases because there is more water to be evaporated. Figure 1 shows that the model predicts this, and it also shows that we might expect drying time to vary from about 52 to 130 min over a typical range of initial moisture contents of 80 to 160 percent.

Specific Gravity

If we maintain a constant initial moisture content (120 percent) and vary specific gravity, we expect the model to predict an increase in drying time as specific gravity increases because there is more water present for a given moisture content. Figure 2 shows that the model predicts this, with a drying time to 15 percent moisture content of about 81 min for a specific gravity of 0.40 and about 101 min for a specific gravity of 0.50. (In this example, W_o and W_d are adjusted for the varying specific gravity.)

Final Moisture Content

We expect the model to predict an increase in drying time as final moisture content decreases. Figure 3 shows this to be the case--a predicted 103 min to dry to 8 percent and 67 min to dry to 30 percent.

Platen Temperature

Drying time should decrease as platen temperature increases. Figure 4 shows that the model predicts this, with drying times to 15 percent moisture content ranging from 330 min at 250° F to 43 min at 500° F. In our previous study, we press dried some 2 by 4's at 380° F. Our drying cycles were 70 min to an average moisture content of 14.6 percent, which is in reasonable agreement with the 75 min predicted by Equation (1).

Thickness

An increase in thickness should cause drying time to increase, and Figure 5 shows that this is predicted by the model. Drying time to 15 percent moisture content is predicted to be about 33 min for 1-in-thick lumber and about 240 min for 3-in-thick lumber. (In this example, G_v, W_d, and W_o are adjusted for varying thickness.)
the effect of thickness variation around a target thickness on drying time is also of

interest from the standpoint of sorting. In our previous study, the 2 by 4's had a total range from thinnest to thickest of about 1/4 in. Figure 6 shows the effect of this variation. The thinnest boards (1.63 in) are predicted to require about 80 min to reach 15 percent moisture content, while the thickest ones (1.87 in) require about 100 min. Stated in different terms, if the thinnest boards were dried for 100 min, they would be overdried to about 3 percent moisture content. If the thickest boards were dried for only 80 min, they would reach only 27 percent moisture content. By choosing the average time of 90 min, we would expect the thinnest boards to dry to about 8 percent and the thickest ones to about 22 percent.

The above examples show that the effects of the variables in Equation (1) on estimated drying time agree in principle with what we would expect. The examples are not intended to be a thorough test of the model, but they do suggest that the model may be useful as a basis for sorting lumber into drying time groups when the coefficients are determined from an experiment designed specifically for that purpose.

Sorting Example Using the Model

The ability of the model to sort lumber so that final moisture content variation is minimized can be illustrated in a continuation of the example used to estimate the effect of process and material variables on predicted drying time. The three variables that effect the time required to reach final moisture content are thickness, specific gravity, and initial moisture content. Choosing realistic ranges of these variables illustrates the benefits of sorting. A high, medium, and low level was selected for each variable, as follows:

Level	Thickness (in)	Initial moisture content (percent)	Specific gravity
High	1.85	140	0.50
Medium	1.75	110	0.45
Low	1.65	80	0.40

(Note: The nature of the distribution that the variables might have is not considered in this example.)

The 27 combinations of these 3 variables at 3 levels result in calculated drying times (Eq. (1)) to 15 percent moisture content ranging from about 40 min (all 3 variables at the low level) to 140 min (all 3 variables at the high level). Without sorting, we might choose an average of 90 min as the drying time for all 27 combinations. If all 27 combinations were thus dried for 90 min instead of the exact time required for each to reach 15 percent moisture content, we would expect to see a large variability in final moisture content. By solving Equation (1) for final moisture content as a function of press time (90 min), and calculating final moisture content for all 27 conditions, the standard deviation is 12.3 percent moisture content (that is, two-thirds of the boards will lie within $\pm$12.3 percent of the average moisture content of 15 percent). The total range of moisture contents will be from 0 to 38 percent. The total standard deviation is higher than usually observed in drying and probably results from the assumption of an even distribution of thickness, initial moisture content, and specific gravity. In practice, there would probably be fewer boards at the extreme high and low values. However, the purpose of this example is to illustrate how sorting might reduce the standard deviation in final moisture content, rather than to estimate actual values of standard deviation.

The first level of sorting could be into two groups--those whose estimated drying time to 15 percent moisture content is from 40 to 90 min, and those with a drying time from 90 to 140 min. The first group is dried for the average of 40 and 90 min (65 min), and the second group for the average of 90 and 150 min (115 min). With this sort, the standard deviation drops to 9 percent moisture content, and the range of final moisture contents is from 1.2 to 32.6 percent. The next level of sorting would be into three groups, those whose estimated drying times lie in the ranges of 40 to 73.3, 73.3 to 106.6, and 106.6 to 140 min. The drying times for these three groups are the midpoints 56.7, 90, and 123.3 min. The standard deviation now drops to 5.9 percent moisture content, and the range narrows to 4.2 to 26.2 percent. As additional sorts are added, the standard deviation continues to decrease, and it reaches 2 percent moisture content with 10 sorts; the range of moisture contents decreases to 12.2 to 17.7 percent. The number of sorts would be determined by considering both the reduction in variability desired as well as the practical limit for a manageable number of groups.

SUMMARY

Grade loss caused by warp in plantation loblolly pine 2 by 4's was held to less than 4 percent by press drying, compared to an average of over 20 percent in kiln drying. Drying time in the press at 350° F was about 90 min from initial moisture content (about 120 percent) to a target moisture content of 15 percent. A model is proposed to correlate press drying time to platen temperature and lumber thickness, green weight, green volume, and final moisture content. Although the model has not been fully tested as yet, preliminary evaluation suggests that it may be useful as a basis for sorting lumber into drying time groups so that variation in final moisture content is reduced.

REFERENCES

1. Simpson, W.T., J.D. Danielson, and R.S. Boone. 1988. Press drying plantation grown loblolly pine 2 by 4's to reduce warp. Forest Prod. J. (submitted).

2. Tschernitz, J.L. 1985. Empirical equation for estimating drying times of thick rotary-cut veneer in press and jet dryers. USDA Forest Service Res. Pap. FPL 453. Forest Products Laboratory, Madison, WI.

Table 1. Warp of press-dried and kiln-dried 2 by 4 lumber.

Drying method	Warp (1/32 in)		
	Crook	Bow	Twist
Press dried			
25 lb/in^2	1.8	3.1	0.6
50 lb/in^2	2.1	3.9	1.4
75 lb/in^2	3.1	6.6	2.2
Kiln dried			
Equalized	5.9	7.3	3.2
Not equalized	4.1	6.4	1.5

Table 2. Press-dried and kiln-dried 2 by 4 lumber downgraded because of warp.

Drying method	Downgraded lumber (percent)			
	Crook	Bow	Twist	Any warp
Press dried				
25 lb/in^2	3.3	1.3	0	3.8
50 lb/in^2	4.6	2.5	0.4	6.7
75 lb/in^2	5.2	7.3	0	10.4
Kiln dried				
Equalized	20.6	11.6	4.7	29.6
Not equalized	12.6	10.2	0.4	18.3

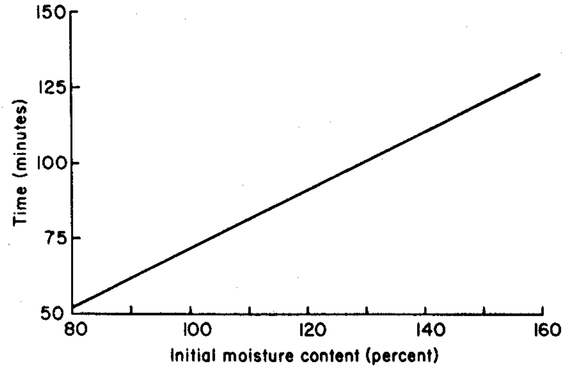

Figure 1. Effect of initial moisture content on the time required to press dry loblolly pine 2 by 4's to 15 percent moisture content at 350° F platen temperature. (ML88 5617)

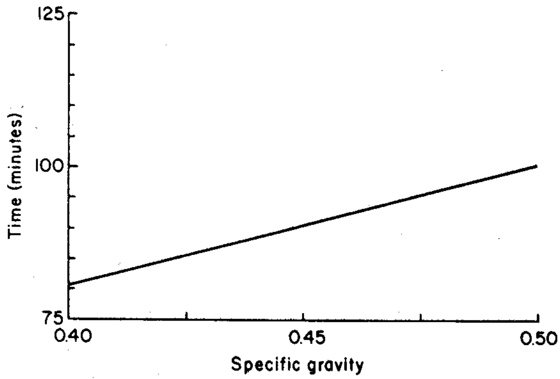

Figure 2. Effect of specific gravity on the time required to press dry loblolly pine 2 by 4's to 15 percent moisture content at 350° F platen temperature. (ML88 5618)

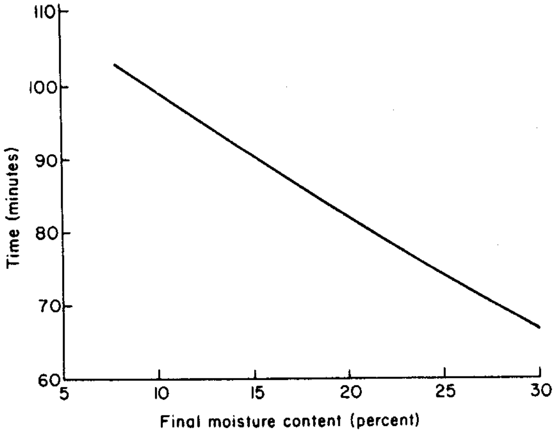

Figure 3. Effect of final moisture content on the time required to press dry loblolly pine 2 by 4's from 120 percent initial moisture content at 350^{0} F platen temperature. (ML88 5619)

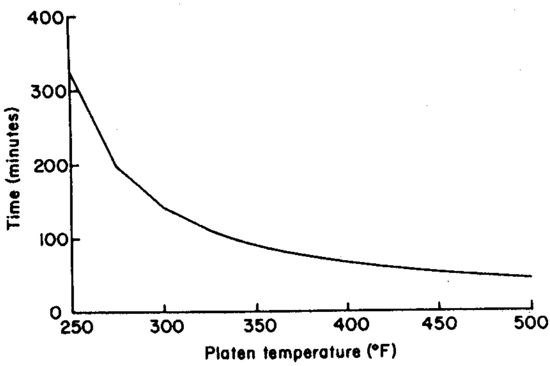

Figure 4. Effect of platen temperature on the time required to press dry loblolly pine 2 by 4's from 120 to 15 percent moisture content. (ML88 5620)

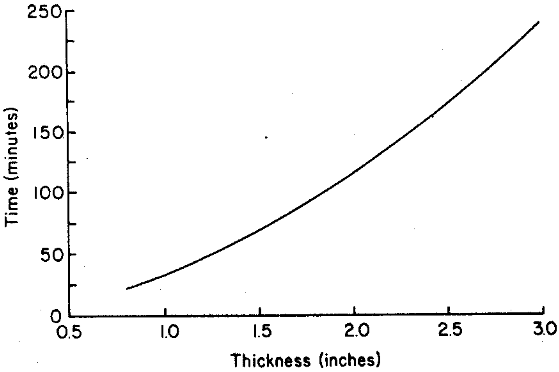

Figure 5. Effect of thickness on the time required to press dry loblolly pine 2 by 4's from 120 to 15 percent moisture content at 350° F platen temperature. (ML88 5621)

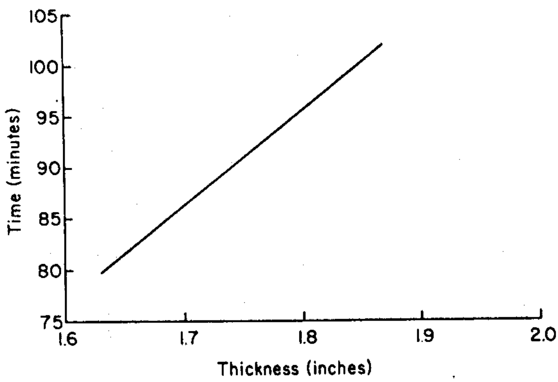

Figure 6. Effect of thickness variation around a target thickness on the time required to press dry loblolly pine 2 by 4's from 120 to 15 percent moisture content at 350° F platen temperature. (ML88 5622)