FACTORS THAT INFLUENCE THE PRONG TEST

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ABSTRACT

The transverse prong test has been used for many decades to evaluate the degree of drying stresses in lumber, which can then be used to assess the duration of conditioning time. However, little work has been directed at the proper procedures or interpretation of the prong test. The objectives of this research were to systematically study factors that influence the prong test, thus providing information to properly interpret prong response. Tests obtained during conditioning of red oak showed the strong influence thickness has on prong response. The thinnest prongs permanently turned out early in the conditioning treatment, while the thickest prongs never turned out, with gradations in response to the intermediate thicknesses. The time of cutting the prongs, whether immediately following removal from the kiln or delayed for 1 week, had no substantial effect on prong response.

INTRODUCTION

Wood is used for both structural and esthetic purposes. When intended for interior use, wood must be properly dried prior to use. Failure to do so will result in dimensional changes while in-service. This drying results in the wood containing internal stresses, typically called casehardening, a phenomenon in which the surface is in compression and the center is in tension. The development of casehardening is well characterized in the literature (McMillen 1963). When lumber is surfaced unevenly or resawn, the final shape can be distorted. These newly formed parts will not lay flat or fit properly. This distortion causes loss of material and production time, thus a decrease in profit. To help avoid this distortion, at the end of drying, the lumber can be exposed to an environment in the kiln that has an equilibrium moisture content 4% greater than the final moisture content. This process, called conditioning, alters the developed strains, thus relieving internal stresses.

A literature survey disclosed that the processes that develop internal strains during drying have received extensive testing and evaluation. These studies looked at recording strain and moisture content distribution through the board and numerical computation using shrinkage and modulus of elasticity data. However, the alteration of the internal strain during conditioning has not been well characterized. The theories that try to explain strain alteration during conditioning (adsorption) use the information gained from desorption studies, thus providing unsatisfactory answers.

The transverse prong test is used to determine if conditioning achieves relief for all internal stresses. This test consists of a 0.75-m- (0.19-m-) long cross section with the center cut out, leaving two side surfaces and one edge that form a wooden U-shaped prong. If the alteration of the internal strain during conditioning is not fully understood, the prong response to these altered strains cannot be certain. As shown in Table 1, a survey of several manuals on drying shows no consistency concerning the geometry and desired prong response. These sources do not give adequate consideration to (1) the interaction of prong response with both prong length and thickness and (2) the influence of the immediate change in the surface layer moisture content, caused by the moisture gradient within the prongs or the prongs not being in equilibrium with the air after the prongs have been cut, which has been suggested to yield false results (Churchill 1954, McMillen 1963). In addition, a wide range of prong geometry used by kiln operators has been observed during industrial visits, indicating the lack of explicit directions.

The specific objectives of this study were to determine how (1) the prong test responds to the alteration of the internal strains during conditioning and subsequent storage as a function of prong thickness, (2) the prong response changes a short time after the prongs have been cut, and (3) different klin schedules influence prong response. With this information, an important step can be accomplished in determining the proper geometry and interpretation of the prong test.

TABLE l-Prong geometry and response given in various manuals.[a]

Manual	Board thickness (in.)	Prong		Prong response
		Number	Thickness[b]	
Bramhill and Wellwood 1976	2	6	–	–
Cech and Pfaff				
1977 (a)	1	2	50%	All prongs are to be of equal length
1977 (b)	–	2-5	–	
Cech and Pfaff 1979	1	6	–	Slight outward bow
Page 1973	l-1/2	2	0.25 in.	–
Simpson 1991	<l-1/2	2	–	Straight prongs
Wengert				
1990 (a)	<l-1/2	2	24%	
1990 (b)	>l-1/2	>2		Bow outward by 0.25 in.

[a] –, not stipulated in manual.

[b] Percentage or inches of board thickness; 1 in. = 0.03 m.

PROCEDURES

For all three drying runs, the material used was 1.25-in. (0.03-m) red oak. Three boards were monitored in each run because that was the maximum number that could be processed in a reasonable length of time for each sampling time. For the second and third kiln run, sample boards were precut into blocks and end-sealed before each run to increase the ease and reduce the time of obtaining the blocks.

To determine how the prong test responds to stress development during conditioning as a function of prong thickness and time, four prong specimens were cut at each sampling time from each board. Each specimen was cut such that the two prongs were of equal thickness, and the prongs were either 10%, 20%, 35%, or 50% of the board thickness. These specimens were measured immediately and 45 min after being cut. The prong test geometry is depicted in Figure 1.

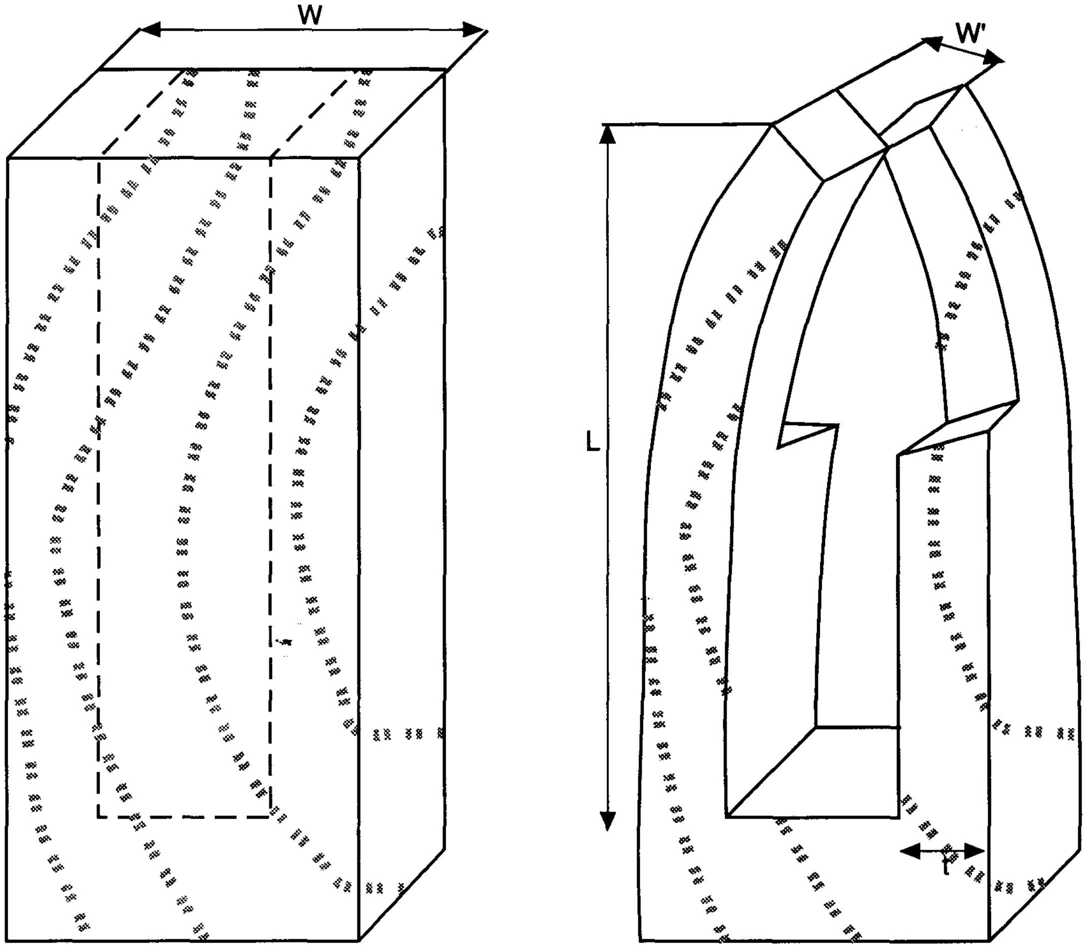

FIG. l-Prong test sample with linear dimensions.; *W* is distance between the outer prong edges before processing; *W'* is distance between the outer prong edges after processing; *L* is prong length; t is prong thickness.

To determine how the prong test responds to the changes in the stress profile during storage, the remaining material from each block was wrapped in plastic for 7 days at room temperature. Prong tests were then processed identically to the first set cut.

To evaluate how a kiln schedule influences stress relief, three drying runs using different drying-conditioning schedules were conducted. The three kiln schedules were chosen to represent typical drying and conditioning schedules used in various regions of the country (Table 2). The first schedule was one that is suggested to avoid degrade and help reduce the moisture content variation. The schedule has a reduced dry-bulb setting, and the equilibrium moisture content is not reduced below 4%. The second was the suggested schedule in the *Dry Kiln Schedules for Commercial Woods* for red oak T4-D2 (Boone et al. 1988). The third schedule had the T4-D2 drying settings for the dry and wet bulbs. However, the conditioning was controlled to reproduce the temperatures and equilibrium moisture content values encountered during kiln overheat, which is when the dry-bulb temperature is greater than the setting due to the heat of condensation and absorption. Kiln overheat causes a loss of control of the equilibrium moisture content during the first few hours of conditioning. Each of these drying-conditioning schedules may result in different adsorption rates, thereby causing different mechano-sorption strain gradients.

TABLE 2–Three drying methods using typical conditioning schedules.[a]

Moisture content or time (%)	Modified (°F)		T4-D2 (°F)		Kiln overheat (°F)	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
>50			110	106	110	106
>40	95	92	110	105	110	105
40-35	95	91	110	102	110	102
35-30	100	94	110	96	110	96
30-25	110	100	120	90	120	90
25-20	120	95	130	90	130	90
20-15	130	110	140	90	140	90
15-10	150	110	180	130	180	130
11	160	120	180			
Equalize			180	140	180	140
Conditioning	160	149	180	170		
1 h					190	165
2 h					193	167
3 h					195	170
4 h					190	170
5 h					182	170

[a] (°F - 32)/1.8 = °C.

RESULTS AND DISCUSSION

The prong response is not a simple lateral displacement or a rotation of the prongs at the base, but a deflection following a second degree curve as a function of the prong length. Therefore, to analyze the results, all data must be reduced to the same basis. For this, the following was used to account for the prong length. The unit for the prong response value is mm^{-1}.

$$\text{Prong response} = \frac{W - W'}{L^2} \quad (1)$$

where W is distance between outer prong edges before processing; W' is distance between outer prong edges after processing; L^2 is prong length (Fig. 1). Figure 2 shows the prong response for the three kiln schedules. Although the magnitude varies slightly, the same general patterns are displayed. Prior to conditioning, the 10% prongs showed the greatest deflection, and the 50% prongs displayed the least deflection. Within 1 hour of conditioning, the 10% prongs displayed reverse casehardening, recorded as a negative value. The 20% prongs displayed the same reversal between the 5 and 12 h. The 35% and 50% prongs never achieved zero casehardening or reverse casehardening. The behavior of the greatest deflection shown in the thinner prong was attributed to (1) increased section modulus of the thicker prongs that restricted the deflection and (2) all the mechano-sorptive strain that occurred in or near surface layers, with the inner layer stresses changing only in response to the decreased stresses in the outer layers.

A third factor may have influenced the prong response: the quick loss of the surface moisture during the time between pulling and processing the specimen as a result of the high temperature. This would cause a shrinkage in the surface layer, enough to influence only the thin prong response. A close look at the stress alteration and a study designed to restrict flashing of moisture before processing the prong test and stress measurements would be needed to determine what actually influenced the prong response.

Before proper interpretation of the prong test can be made, the influence that surface moisture loss has after processing and the reduction of the moisture and temperature gradients, but prior to a reading, need to be determined. Figure 3 shows the prong response of three processing and reading times. The specimens showed obvious differences between the processing and reading times. However, the differences were not substantial within a single prong thickness, because when one processing and reading time measurement showed casehardening, the other processing and reading times also showed casehardening, with the exception of the sensitive 10% prongs. The same was true for the specimens displaying reverse casehardening. This indicates that it is not important how quickly you cut the prongs or when you measure the prong response. However, the kiln operator needs to know the results of the prong test as soon as possible; therefore, the best reading is when the prongs are cut. Our results indicate the importance of picking a stable and reliable prong thickness that displays the needed information.

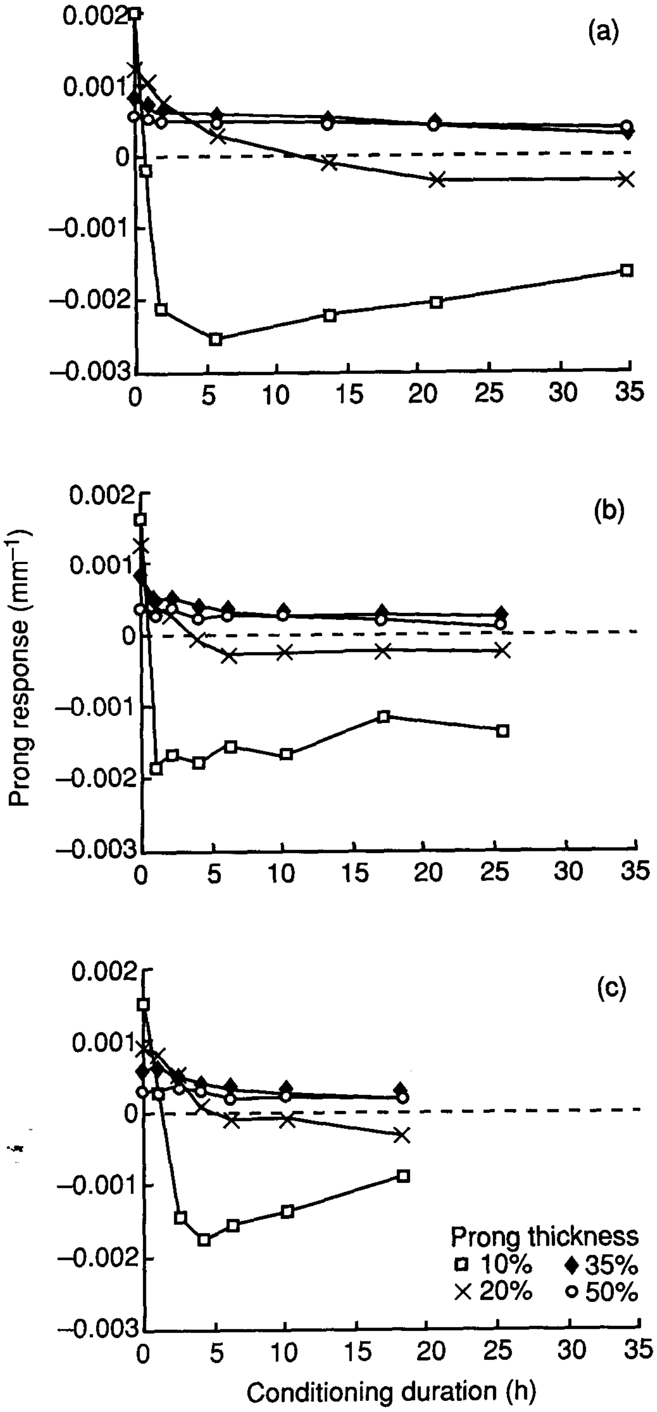

FIG. 2–Prong response by thickness for each drying and conditioning schedule: (a) modified, (b) T4-D2, (c) kiln overheat.

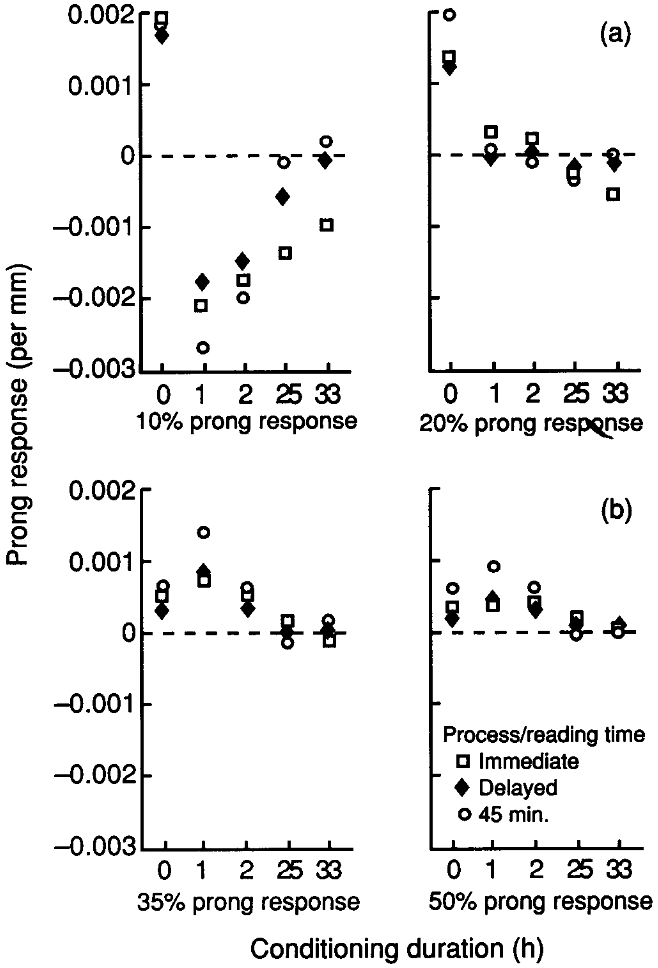

FIG. 3–Comparison of three prong responses for four prong thicknesses (a) 10% and 20%, (b) 35% and 50% at selected conditioning durations.

CONCLUSIONS

Results from this study show that prong thickness is one primary determining factor of prong response. At any time during conditioning, the prong test can give the response you want, depending on the prong thickness. Results indicate that neither the prong test processing time nor the reading time is important. In addition, data show the need for a suggested optimum geometry and interpretation if the prong test is determined to be valid, despite the possible problem of quick surface moisture loss. This study demonstrates the need for further research on the stress development during conditioning and the influence flashing of surface moisture has on prong response.

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