

PROCESS FOR RAPID CONVERSION OF RED OAK LOGS TO DRY LUMBER*

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Lumber is traditionally dried by processes that often take several weeks or more to complete. Long drying times translate into high processing costs because of the expense of holding large lumber inventories. For many years, researchers have investigated more rapid drying processes. Among these rapid processes, press drying has shown promise (1,3-5). One-inch-thick lumber can be press dried in 1 to 2 hours instead of several weeks in a kiln. However, press drying has had limited success commercially because intolerable drying defects usually accompany such rapid, high-temperature drying in commonly produced flatsawn lumber.

The purpose of this experiment was to verify a hypothesis that quartersawn lumber can be rapidly press dried with fewer drying defects than flatsawn lumber, and to test a technique for converting logs to dry 1-inch lumber in only a few hours.

DEFECT SUPPRESSION IN PRESS DRYING

BACKGROUND

There are several types of drying defects that occur in lumber. Many of these defects involve wood failure and can be traced either to differential shrinkage, to stresses caused by liquid tension forces, or to both these causes.

Differential shrinkage can cause internal honeycomb fractures. In differential shrinkage, the shell of lumber dries and attempts to shrink, while the core has not yet begun to dry and shrink. Consequently the shell is restrained from shrinking by the core. The shell goes into tension and the core into compression. If drying in the shell progresses too rapidly, it is stretched irrecoverably and dries in a permanently stretched condition, without attaining full shrinkage. Sometimes surface fractures occur during this stage of drying. As drying progresses, the core begins to dry and attempts to shrink. However, the shell is set in a permanently expanded condition and prevents normal shrinkage in the core. This causes the stresses to reverse--the core goes into tension and the shell into compression. The tension stresses in the core may be severe enough to cause or contribute to internal honeycomb fractures. Honeycomb can occur in conventional kiln drying as well as in the more rapid drying processes.

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Liquid tension forces sometimes lead to collapse and honeycomb. They also contribute to and may even be a major cause of honeycomb. Liquid tension is set up in cell lumens that contain water or both water and air bubbles according to the capillary pressure equation

$$P_0 - p = 2\sigma/r \quad (1)$$

where P_0 = air pressure
 p = liquid pressure
 σ = surface tension of liquid and
 r = radius of air-water interface.

When a cell lumen contains no air bubbles, the air-water interface is at the pit openings in cell walls. As evaporation progresses from the menisci of these pits, large tension forces develop according to Equation (1) and pull inward on the cell walls, collapsing them and often causing honeycomb.

SUPPRESSING DEFECTS

How lumber is sawn from logs and how some of the key anatomical features of wood relate to sawing patterns are critical to defect development in lumber during press drying (6,7). Manipulation of sawing pattern in combination with press drying between heated platens offers a way to reduce or eliminate honeycomb and at the same time reduce drying time to only 1 to 2 hours. The mechanism of honeycomb suppression can be explained with reference to Figure 1. Figure 1a shows the cross section of a flatsawn board with growth rings parallel to the wide face and ray tissue perpendicular to the wide face. Because the ray tissue is the plane of failure in honeycomb fractures, the critical internal tension is parallel to the wide face of a flatsawn board and honeycomb develops as shown. Figure 1b shows a quartersawn board with growth rings perpendicular to the wide face and ray tissue parallel to the wide face. In this case, the honeycomb fractures that develop are oriented parallel to the wide face. Figure 1c represents a flatsawn board being press dried between heated platens. The critical internal tension is parallel to the wide face, and the compression of the platens is perpendicular to the wide face. Honeycomb fractures still develop during drying. Figure 1d illustrates a quartersawn board being press dried. The critical internal tension is now perpendicular to the wide face of the board and is counteracted by the compression of the press. The previous research (6,7) has shown that the compression force of the press is effective in suppressing honeycomb in press-dried quartersawn red oak lumber (Figs. 2 and 3).

In practice it is not always feasible or desirable to manufacture lumber that is perfectly quartersawn, i.e., where the growth rings form a zero-degree angle with the narrow edge of a board, because production of quartersawn lumber is less efficient than production of flatsawn lumber. Processing time is

longer because of more complicated log turning, and yield is often less. Thus we should search for more efficient ways to produce quartersawn lumber and determine how much deviation of ring angle from zero degrees we can tolerate and still effectively suppress honeycomb. Research did show (Simpson, in press) that as ring angle deviates from zero degrees, the amount of honeycomb increases. However, if the deviation is not too great, honeycomb suppression is still effective (Fig. 4).

LOG-TO-DRY LUMBER PROCESSING SYSTEM

The fact that slight deviations from perfectly quarter-sawn lumber can be tolerated (Simpson, in press) opens the way for a rapid technique to produce quartersawn lumber where deviations are kept to a minimum. In this technique (Fig. 5) a log or bolt is first quartered, with the pith as the center of symmetry. Each quarter is then gang ripped to produce quarter-sawn boards in one pass. With this orientation of sawing boards from log or bolt quarters, the maximum that the ring angle can be in a perfectly round log or bolt is 45 degrees (Fig. 6). The exact angle depends on log diameter and width of the opening face of the first board, and in fact can be calculated from the equation shown in Figure 6b. As the width of the opening face (position 4 in Fig. 6a) increases, the maximum ring angle decreases. For example, in opening a 1.5-inch face on a 12-inch diameter log the maximum ring angle is 34.6 degrees, but in opening a 2-inch face from the same 12-inch diameter log, the maximum ring angle is 30.4 degrees (Fig. 7).

As log diameter decreases, the maximum ring angle also decreases (Fig. 7). For example, in opening a 2-inch face from a quarter of a 24-inch-diameter log, the maximum ring angle is 38.2 degrees, but in opening a face of the same width from a 12-inch-diameter log the maximum ring angle is only a 31.4 degrees (Fig. 7). Thus the process should be more effective for small logs than for large logs because platen pressure will be more effective in suppressing honeycomb.

EXPERIMENTAL PROCEDURE

The purpose of this experiment was to determine the extent of honeycomb and ring failure in northern red oak lumber produced by the method shown in Figures 5 and 6. Twelve 8-foot-long northern red oak logs 12 to 18 inches in diameter were obtained in Wisconsin, bucked into 4-foot lengths and quartered. Because no gang-sawing facilities were available, boards were produced on a conventional circular mill. The boards were numbered according to position in the quarter (Fig. 7a), edged to the closest half inch in width, surfaced to 1-1/4 inches thick, and end trimmed them to 42 inches long. There were 385 boards in the study, ranging from 1-1/2 to 6-1/2 inches wide. The numbers at each position from 1 to 4 were 104, 138, 126, and 17, respectively.

Twenty-four of the boards were oven-dried in the press to determine a drying rate curve. This curve established the drying time from green to 6 percent moisture content. Platen pressure and temperature were 100 psi and 350°F. The aluminum cauls used had 1/8-inch holes on 1-inch centers with back channels connecting the holes and leading to the edges. Thickness and width were measured on all experimental boards in three places before and after press drying.

After press drying, each board was cut into five equal-length pieces to expose four internal cross sections where honeycomb and ring failure could be counted.

RESULTS AND DISCUSSION

DRYING TIME

The oak boards dried from an average of 75.6 percent initial moisture content to 6.4 percent final moisture content in approximately 110 minutes (Table 1, Fig. 8). Typical commercial drying times for 1-inch red oak are 4 weeks for kiln drying, 5 to 6 weeks for predrying plus kiln drying, and 3 to 6 months for air drying plus kiln drying (10).

HONEYCOMB

As expected, honeycomb increases progressively from position 1 to 4 (Fig. 10). This reflects the decreasing effectiveness of honeycomb suppression by the press as ring angle proceeds from zero degrees (quartersawn) in position 1 to about 35 degrees in position 4. The honeycomb results in Figure 10 correspond very closely to those of Figure 4 from previous research (7), where ring angle control was by actual measurement rather than simply by position in a log quarter.

We did not measure honeycomb width because most honeycomb fractures were too narrow to measure practically. The average height of the honeycomb in positions 1 to 4 was 0.31, 0.29, 0.27 and 0.27 inches, respectively. Although these values suggest a decrease in honeycomb height from the center to the edges of the quarters, they are not statistically different.

The amount of honeycomb is difficult to quantify. The quantity shown in Figure 10 is the number of honeycomb failures per square inch of cross section. This is based on a sample of four cross sections per 42-inch-long board. The values range from approximately 0.1 failure per square inch in position 1 to 1.1 failures per square inch in position 4. In practical terms, these values estimate how many honeycomb failures one would expect to see on any section exposed by cross cutting. For example, one would expect a board from position 2 to have about 0.25 honeycomb failure per square inch. Thus, if a board 1 inch thick by 4 inches wide were crosscut at any random point, we would expect to see one honeycomb failure on the newly exposed cross section.

Caution is necessary in interpreting these values for two reasons. First, the values say nothing about how far any honeycomb failure extends lengthwise. Failures might only extend a few inches, or they might extend the full length of a board. Second, all honeycomb checks are included in the count--even though some honeycomb failures might only be a quarter of an inch high (i.e., along the ray tissue) and so narrow that an opening is barely apparent and other failures might be so high as to extend almost the full thickness of the board and have opened up to be 1/8 to 3/16 inch wide. The first failure would not prevent the board from being used for almost any conceivable end use. Very few end uses, at least those that would require drying at all, would tolerate very many failures of the second type. Thus, the main purpose of the values shown in Figure 10 is comparison. The data show, with statistical significance, that honeycomb failure is related to position in a log quarter and, thus, to growth ring orientation. They also strongly suggest the exciting possibility that by controlling ring angle orientation in a simple way, we can then press dry 1-inch-thick red oak lumber in less than 2 hours and still keep drying defects within tolerable limits. The ultimate test of the process will have to be an evaluation of press-dried lumber for specific end uses.

RING FAILURE AND COLLAPSE

Ring failure is also shown in Figure 10. Platen pressure suppresses ring failure in flatsawn boards by a mechanism similar to the one that suppresses honeycomb in quartersawn lumber (Fig. 1). The difference is that ring failure happens in the growth ring interfaces or, perhaps, the earlywood bands, whereas honeycomb failures occur in ray tissue, at 90 degrees to growth rings. We therefore expect that ring failure would decrease with increasing ring angle. This general trend is apparent in Figure 10, and was also apparent in earlier research (7). Except for position 1, ring failure was less severe than honeycomb failure. When it did occur, collapse was usually also present.

Evaluation of collapse was not as quantitative as evaluation of honeycomb and ring failures, but the analysis does give some indication of the severity. I categorized collapse in three qualitative levels of severity:

1. Severe--Very deep collapse usually accompanied by ring failure and a darkening of the wood, usually in streaks parallel to the length of the boards.
2. Minor--Not associated with ring failure, and shallow enough that it could be removed by surfacing.
3. None--No discernible evidence of collapse.

Of all the boards press dried, 60 percent had no collapse, 31 percent had minor collapse, and 9 percent had severe collapse. On many boards minor or bad collapse was continued to a small portion of the surface area, and the remainder of the board was collapse free.

The reason for the severe collapse in 9 percent of the boards is not clear. One explanation for the severe collapse is the possible presence of bacterial infection, which makes lumber from some oak logs more susceptible to drying defects than noninfected oak (8, 9). The results of this study showed clearly that defect development was log-dependent. Boards from 4 of the 12 logs developed considerably more drying defects than boards from the other 8 logs.

THICKNESS AND WIDTH LOSS

Shrinkage is significant in this processing concept for two reasons: First, compression by the press and the larger thickness shrinkage coefficient of quartersawn lumber combine to produce large thickness loss during press drying. Shrinkage ranges, on the average, from about 18 to 25 percent (Table 1). Second, the shrinkage and mechanical properties of lumber in the thickness direction change as the ring angle changes from position 1 to 4. The shrinkage coefficient decreases as ring orientation changes between positions 1 to 4. I found no literature to predict the change in relevant time-dependent mechanical properties, but it is likely that they do change. The significance is that boards from different positions will decrease in thickness by different amounts during drying. If boards with widely different thickness loss are present in the same press load, the platen pressure will vary widely between boards, producing variation in heat transfer (and thus drying rate) and honeycomb suppression. Final moisture content will not be uniform. Honeycomb will not be suppressed in boards receiving too little pressure, and boards receiving too much pressure may suffer increased ring failure, darkening, and collapse (7). In this study, boards from different positions were not mixed in the same press load, so unequal shrinkage between boards was minimized. Final moisture content was uniform (Table 1). The severe collapse and darkening noted in 9 percent of the boards may or may not be related to excessive platen pressure.

Thickness loss in each of the four positions is also shown in Table 1. The loss is nearly the same--24.5 and 24.6 percent--in positions 1 and 2. However, thickness loss decreases to 21.3 percent in position 3 and 18.3 percent in position 4. Part of this decrease is due to the drop in thickness shrinkage as the ring angle progresses from zero degrees toward 45 degrees. The normal reported shrinkages of red oak from green to 6 percent moisture content are 6.9 percent in the tangential direction and 3.2 percent in the radial direction (2). Thus the expected thickness shrinkage would change from 6.9 percent in position 1 to approximately 5 to 6 percent in position 4. The difference in thickness loss between positions 1 and 4 is approximately 6 percent and thus cannot be explained entirely by shrinkage. The loss in

thickness caused by time-dependent mechanical compressive strain must also decrease as ring angle increases between positions 1 and 4. Based on the data in Table 1, it seems likely that segregation by position number would help maintain quality.

Whereas the compression of the press causes excessive thickness loss, it also restrains width loss. Width loss in each of the four positions is also shown in Table 1. In position 1, the width loss is only 1.2 percent, compared to the expected 3.2 percent width loss for a quartersawn board (2). In position 4, the width loss was only 2.3 percent, compared to an expected loss of approximately 5 to 6 percent for the growth ring angle of position 4.

SUMMARY AND CONCLUSIONS

This paper has described a process for converting red oak logs or bolts to dry, 1-inch-thick lumber in a matter of only several hours. The key to this process is the use of the compressive force of platens in rapid press drying to counteract internal tension drying stresses that cause honeycomb. This requires production of lumber that is quartersawn to within certain limits of growth ring orientation. In this study, I produced lumber by simulated gang sawing quarters of bolts. The lumber from the center of the quarters was perfectly quartersawn. Deviations from perfectly quartersawn increase progressively from the center to the edges of the quarters, and thus honeycomb suppression during press drying was most effective in these center boards, but progressively less effective towards the edges of the quarters.

Most of the boards produced in the study appear to be suitable for most end uses, although the defect level in boards from the edges of quarters might be too high in practice. The process seems to have high potential, and further research should concentrate on refining techniques, conducting yield studies that evaluate the quality of the dried lumber in terms of specific end uses, and determining if the economic benefits from reduced drying time can offset the cost of press-drying equipment.

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TABLE 1.--Statistical information on initial and final moisture content, thickness loss, and width loss during press drying

	Average (%)	Standard deviation (%)	Range (%)
	- - - - - % - - - - -		
Initial moisture content	75.6	4.45	54.1 - 87.5
Final moisture content	6.4	2.09	2.1 - 12.5
Position 1 thickness loss	24.5	1.67	20.6 - 27.6
Position 2 thickness loss	24.6	1.97	20.8 - 30.8
Position 3 thickness loss	21.3	1.49	18.8 - 25.2
Position 4 thickness loss	18.3	1.41	16.8 - 20.8
Position 1 width loss	1.2	.36	0.3 - 2.4
Position 2 width loss	1.5	.55	0.3 - 4.0
Position 3 width loss	2.2	.76	0.5 - 4.0
Position 4 width loss	2.3	.79	1.3 - 4.7

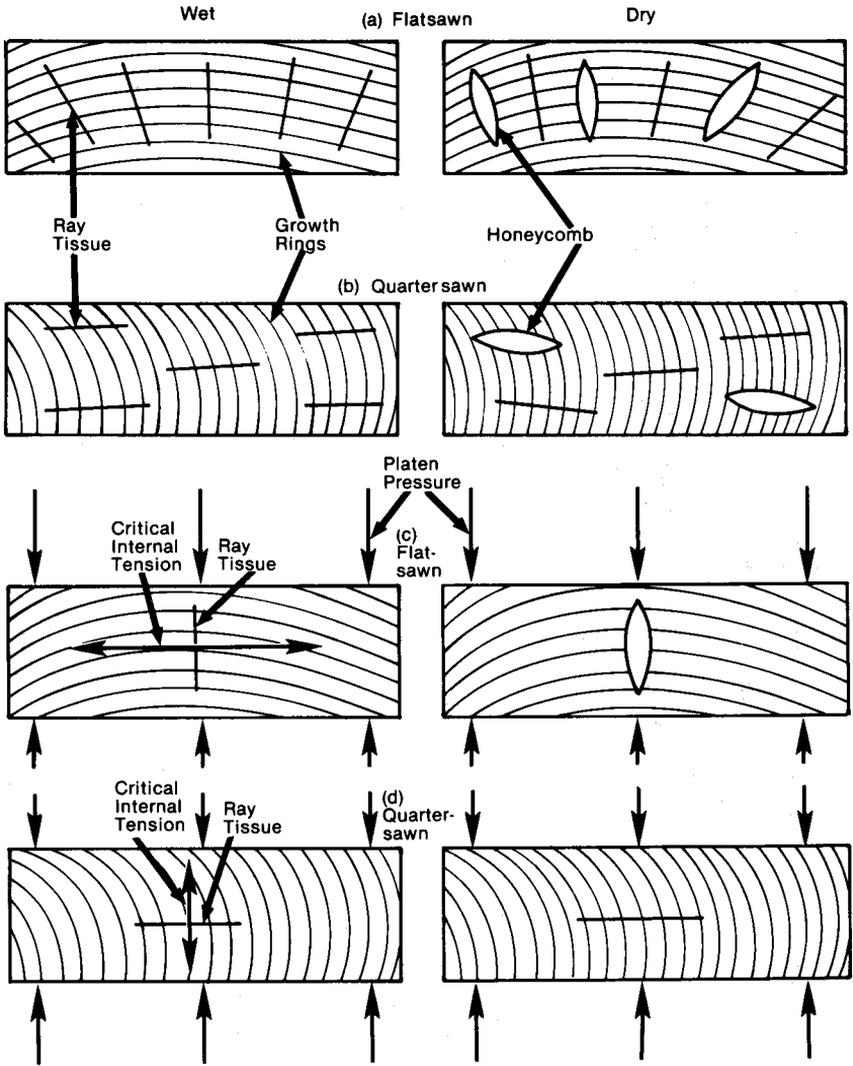


Figure 1.--Schematics showing how honeycomb can be avoided in press drying by manipulating sawing pattern: (a) flat-sawn board developing honeycomb, (b) quartersawn board developing honeycomb, (c) press-dried flatsawn board developing honeycomb, (d) press-dried quartersawn board free of honeycomb.

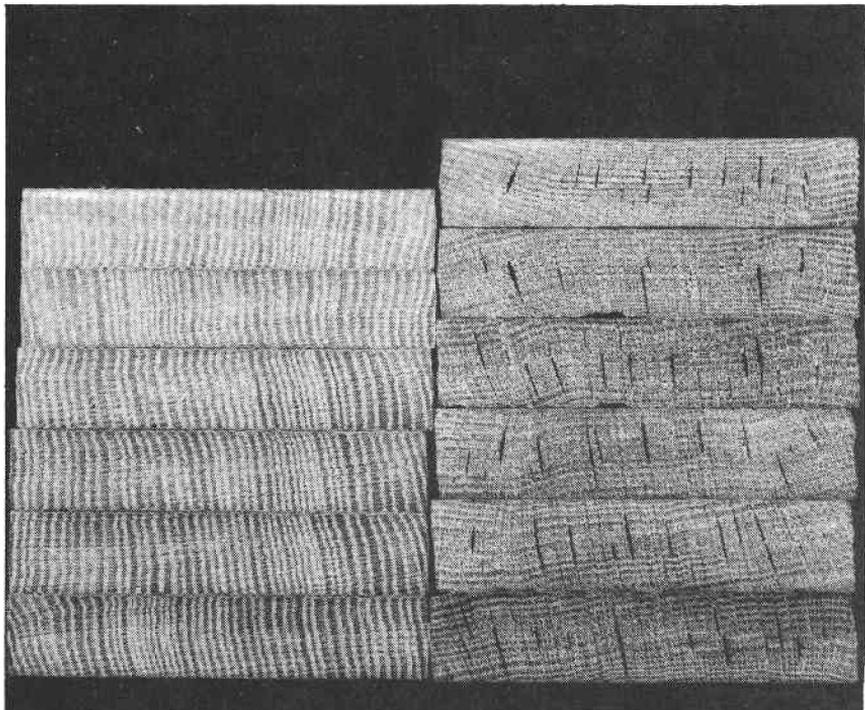


Figure 2.--Comparison of quality in red oak boards after press drying. Quartersawn boards (left) are free of honeycomb, while flatsawn boards (right) have extensive honeycomb (6, 7).

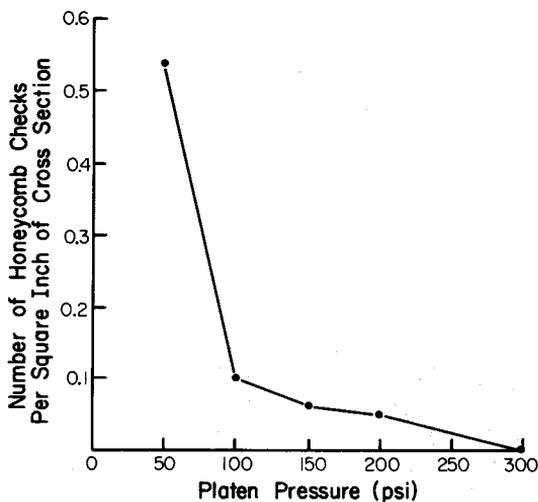


Figure 3.--Effect of platen pressure on number of honeycomb fractures in quartersawn red oak during press drying (7).

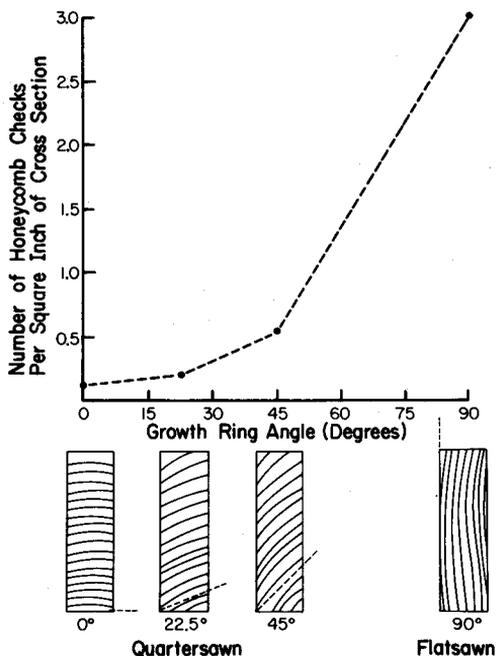


Figure 4.--Effect of ring angle on number of honeycomb fractures in quartersawn red oak lumber during press drying (7).

Press Dried Quartersawn Lumber

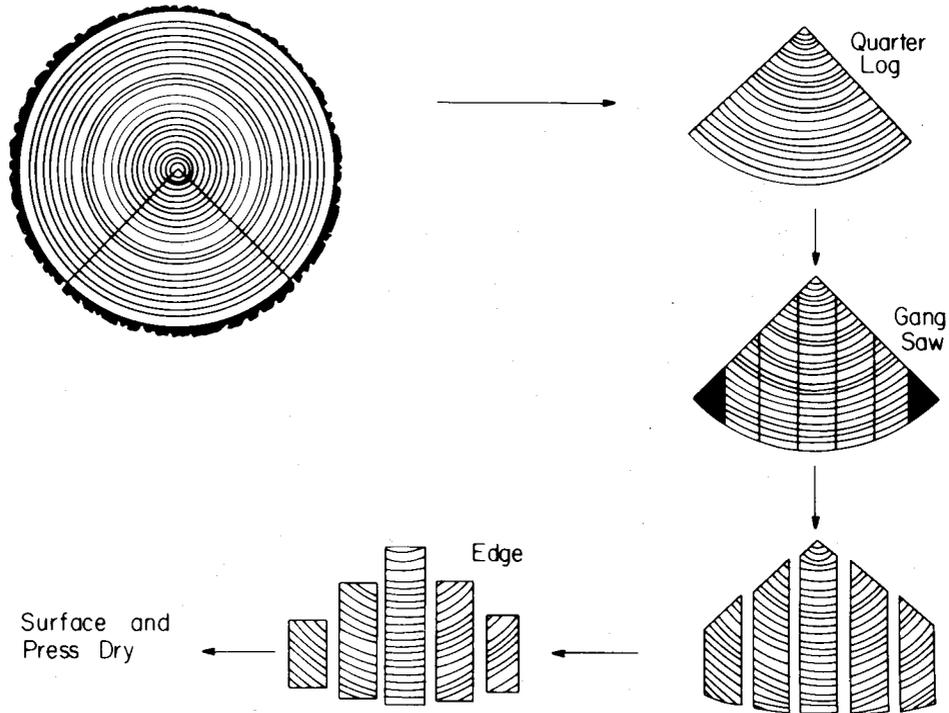


Figure 5.--Schematic of process to rapidly produce quartersawn lumber from logs or bolts.

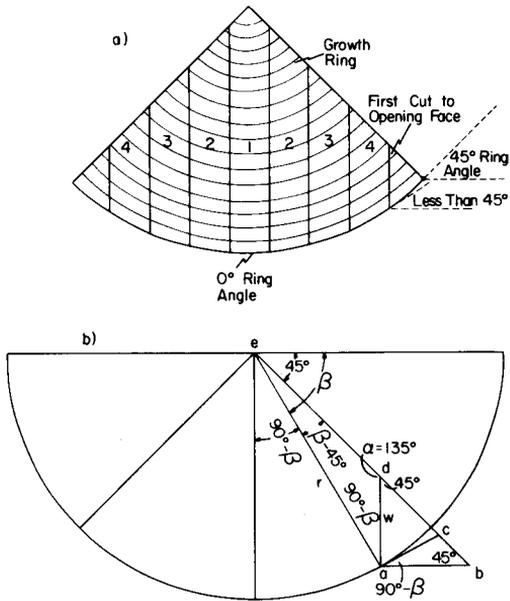


Figure 6.--(a) Schematic showing decrease in ring angle with position of cut. One board is produced from position 1, and two boards are produced from each of positions 2 and 3. (b) Schematic showing method of calculating maximum ring angle. The radius of the log is r , and width of the first board face is W . The maximum ring angle is $90^\circ - \beta$ in triangle abc . Triangle ade can be used to solve for β by the following formula:

$$\sin(\beta - 45) = \frac{W \sin 135}{r}$$

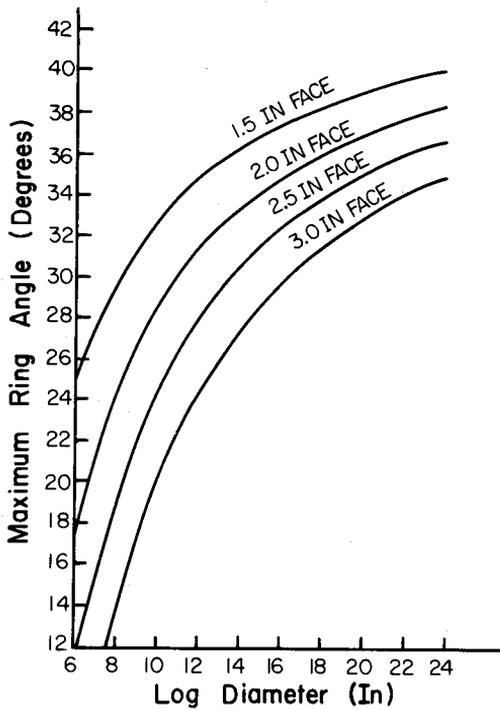


Figure 7.--Dependence of maximum ring angle on log diameter and width of first face.

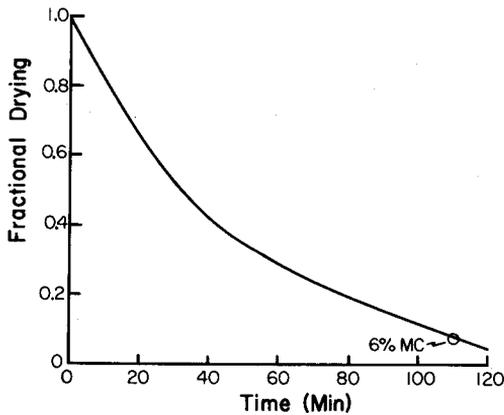


Figure 8.--Drying time curve for press drying nominal 1-inch-thick northern red oak. Drying time for green to 6 percent moisture content was approximately 110 minutes.

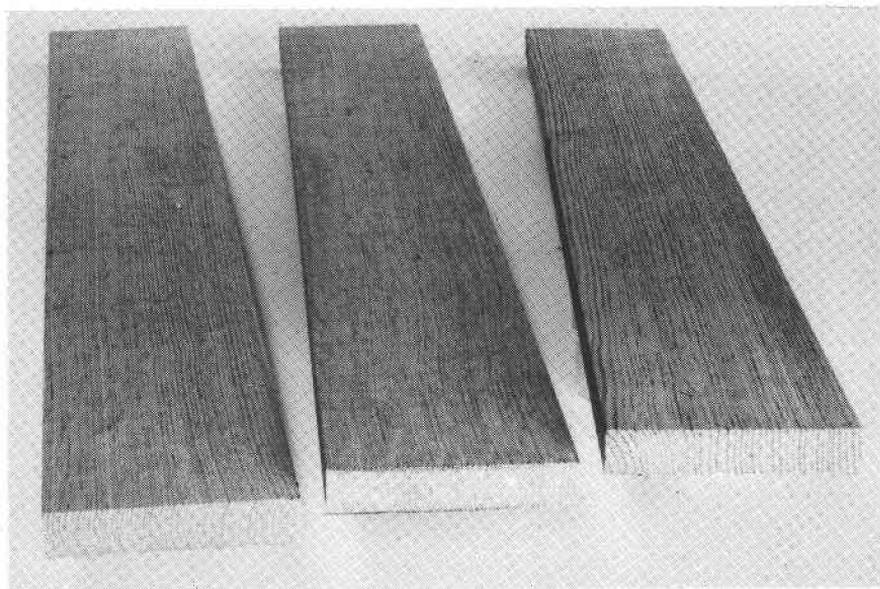


Figure 9.--Examples of good quality of press-dried red oak.

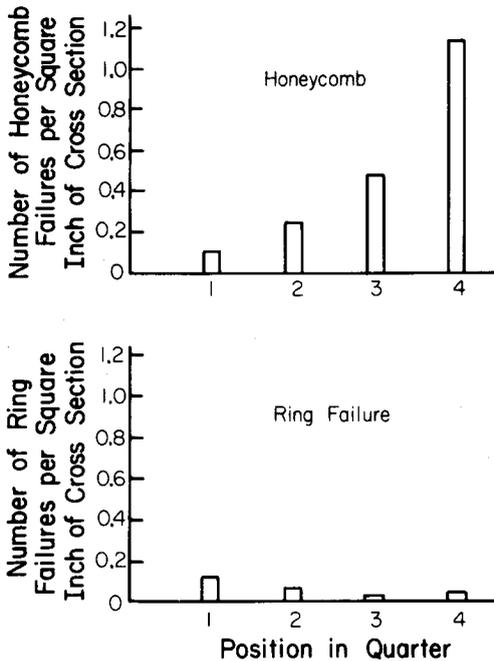


Figure 10.--Amount of honeycomb and ring failure occurring in press-dried red oak as a function of board position in log quarter.