Crook and overlength in hardwood lumber: Results from a 14-mill survey

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Abstract

Data on red oak lumber were collected at 14 furniture and cabinet industry rough mills to identify how crook and overlength are related to lumber grade and size from mill to mill. The amount of crook in a sample of dry, 4/4 thickness, red oak lumber was significantly influenced by lumber grade and length, supply region, and mill. There were no differences in crook based on board width. Average overlength, which can pose challenges in lumber drying operations, was influenced by lumber grade, nominal lumber length, source region, and supplier. There were several complex interactions between these variables that are important in modeling overlength. Odd-length lumber, which accounted for 13.7 percent of the lumber sample, generally is trimmed less precisely than even-length lumber. There was no consistency between lumber grade and overlength from mill to mill. In some cases, the 3A grade had the highest average overlength; in other cases, the FAS, Selects, 1 Common, or 2 Common grade had higher overlength. Average log overlength amounts are higher than lumber overlength amounts. Secondary manufacturers who incur increased costs due to overlength lumber or decreased yield due to crooked lumber need to look for these differences in their own lumber supply and learn how they reduce their mill's processing efficiency and yield.

The presence of crook (sidebend) in lumber reduces part yields and processing efficiency in secondary manufacturing operations. This is especially true for gang-rip-first operations and for operations in which a higher percentage of longer length parts is cut (Wiedenbeck 2001). A yield study conducted by Gatchell (1990) on 61 1 Common and 2A Common boards with 1/2 inch or more of crook showed that total yield in gang-rip-first processing is approximately 3 to 4 percent lower for boards with crook than for straight boards (crook removed).

Gatchell's study (1990) showed that the impact of crook on total part yield is minor compared to the impact of crook on other aspects of rough mill efficiency. The most important impact is a decrease in primary yield (yield obtained in initial cutting operations) and an increase in salvage work required to obtain cuttings from boards with crook. Primary part yields in Gatchell's simulations were 12 to 26 percent lower and salvage recovery was 10 to 20 percent higher for boards with crook versus straight boards. Obtaining parts through primary cut-up operations is more productive and less costly than salvage cutting operations.

In some gang-rip-first rough mills, a crosscut sawing station in front of the gang saw is used to cut severely crooked longer boards into two shorter boards effectively "straightening" the board prior to ripping. Some rough mill managers are considering the installation of a crook cutting saw, while others fear that adding this processing station would increase rough mill costs (e.g., for labor and material handling). Gatchell's results (1990) contradict the argument that adding a crook cutting saw would increase costs since salvage operations, which are far more time consuming than a well-designed crook cutting operation, increase dramatically when crooked lumber is sent through the gang-rip-first saw.

Besides deciding whether to establish a station (or use an existing station) to

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cut crook at the front end of the rough mill, managers need to decide whether to make capital expenditures to improve lumber stacking and drying operations so that the incidence of crook is minimized. Managers also need to compare the amount of crook in dry lumber from different suppliers to determine if a supplier change is needed.

The impact of crook on rough mill efficiency may be more or less important depending on the species, grades, and widths of lumber processed, as well as the lengths and widths of parts required to fill part requirements. Information on crook as it relates to hardwood lumber size and quality factors has not been available for a broad segment of the furniture and cabinet industry. The only published survey of crook occurrence was based on lumber from fewer than seven primary suppliers and was stacked and dried more carefully than is common practice by industry (Gatchell et al. 1992).

Lumber overlength is the length of lumber in excess of the nominal (even foot) board lengths. Lumber overlength may also be known as "trim allowance." One or 2 inches of overlength is standard, i.e., the amount that most secondary hardwood manufacturers want and expect. The extra length can be regarded as an allowance to ensure that the usable lumber length, after uneven ends and end checks are cut off, is close to the nominal length required by the lumber buyer.

Secondary processors who buy green lumber typically experience inefficiencies when processing large amounts of overlength lumber. Widely varied lumber lengths in a stack of lumber bound for the dry kilns can lead to: 1) reduced dry kiln volume due to gaps between stacks; 2) increased warpage and end splitting since stacking sticks in variable-length lumber stacks are not always placed at the end of the boards; and 3) slower drying caused by air passing through between-stack gaps rather than through the lumber layers of the stack.

For some secondary-processing mills, length control also has important effects on product yields. These are mills that cut a limited number of part lengths and thus buy lumber of specific lengths to minimize waste and costs. At these mills, extra inches of lumber can add to bottlenecks that often occur in waste-handling systems. However, for most rough mills, overlength lumber that dries without checking and warping provides extra inches of lumber that can be used in cutting parts.

Primary processors (sawmillers) cut overlength lumber when their trimming operation is not designed for quality end trimming and their lumber buyers do not object to uneven lumber lengths. In these mills, when more overlength logs are processed, more overlength lumber is produced. To the primary processor, passing on extra inches of lumber rather than trimming lumber to within 2 inches of the nominal board length means fewer chips are generated in the sawmill. For sawmills that have good markets for green wood chips, this means a loss in sawmill product revenue since lumber buyers do not pay for extra inches of lumber. For sawmills that lack good markets for green chips, the loss of trim-end chip volume may be good for the mill as it may reduce chip-handling expense.

Two additional costs associated with overlength logs affect the sawmill. First, overlength logs can reduce throughput rates for the headsaw, resaw, and edger – key equipment centers that pace mill productivity. Secondly, primary manufacturing operations with drying operations in which lengths per lumber package vary must contend with the same inefficiencies discussed previously.

An important benefit realized by sawmills that buy a significant percentage of overlength logs is the flexibility that the extra inches over nominal lumber length offer the trim saw operator and grader. In a well-designed trimming/grading operation with well-trained personnel, extra inches should produce higher grade lumber on occasion as they can be used to obtain required lumber-grading clear areas. Alternatively, the extra inches can be trimmed off either end to remove a grade-reducing defect.

The amount of log overlength that enters most hardwood sawmills tends to be excessive and, therefore, is one of the underlying causes of variable-length lumber. In a study of six hardwood sawmills, more than 75 percent of the sampled logs had a trim allowance of 6 inches or more (Zavala 1995). In a larger study of sawmills in the Northeast and Midwest, Blackwell (2001) found that the average log overlength was 5.85 inches at 10 band-headrig sawmills and 5.70 inches at 19 circle-headrig sawmills. The lowest mean log overlength recorded at these 29 mills was 3.92 inches. The highest mean log overlength was 7.08 inches. More of the sawmills tended to have mean log overlength results that were on the higher end of the spectrum.

Objectives

The primary objectives of this study were to evaluate:

1. The degree and frequency of crook in kiln-dried, red oak lumber and to determine whether crook is more prevalent in certain lumber grades, lengths, or widths;

2. The overlength component of red oak lumber and identify relationships between overlength and lumber size and quality traits;

3. Whether regional differences in red oak lumber crook and overlength are apparent, and describe the degree of variability between different rough mills for these two lumber quality attributes.

Methodology

Data collection

During the first half of 1996, supervisory personnel were contacted at rough mills in three regions: the West Virginia and western Virginia Appalachian region (WVA), the southern Virginia Appalachian region (SVA), and the North Carolina Piedmont region (NCP). Our contact list included rough mills that met the following criteria: 1) willing to become a research partner; 2) accessible from Princeton, West Virginia; and 3) maintain a significant inventory of red oak lumber. We intended to survey five mills in each of the three regions but only four mills in WVA met all three criteria.

Individual studies were conducted during the spring and summer of 1996. Rough mills were contacted periodically to determine when they would be processing oak lumber. We chose red oak for this study because the primary lumber databank used in lumber cutup studies was red oak (Gatchell et al. 1998). A study crew comprised of three or four people collected lumber grade and size information on lumber as it entered the rough mill. Only 4/4-thickness lumber was sampled.

Prior to each mill study, the lengths of the red oak lumber packages in the rough mill's dry inventory were surveyed to determine the length distribution of the red oak lumber available for processing at the mill that day. An effort was made to ensure that the lumber packages brought out of inventory for processing were representative of the length distribution available in the entire inventory. Due to part requirements and the logistics involved in making accessible certain stored lumber packages, the distribution of lumber lengths usually deviated from the length distribution in rough-dry inventory. Also, on a given day, the length distribution of lumber packages in inventory can be strongly affected by dry-kiln space and drying priorities, kiln discharge schedule, and the prior week's production schedule. Lumber length distributions obtained in these mill studies bear some resemblance to those processed at the sample mills, but are not statistically representative of individual mill lumber lengths or those utilized by the furniture and cabinet industry.

Lumber grade distributions sampled at each mill were subjected to similar biases though generally to a lesser extent. Many furniture and cabinet industry rough mills (including those in our study) buy a portion of their lumber in mixed-grade packages using procurement specifications such as "1 Common lumber not to exceed 10 percent FAS & F1F and 15 percent 2A Common lumber." These packages typically include grade distributions that parallel each rough mill's inputs. These mixed-grade packages were targeted in our sampling at mills that used this type of procurement specification. For mills that tended to buy single-grade lumber packages, we attempted to sample a distribution of packages similar to the rough mill's overall distribution. The sampling biases for lumber grade and length were the same for these mills.

Boards within packages were selected by systematic random sampling. After the first board on the bottom, outside edge of the package was marked as a sample board, every 10th board in the package was end-marked with crayon as a sample board throughout the package. Since board widths are random within most lumber packages (only packages with random width lumber were sampled in this study), the width distribution of the sample board population was not biased.

The grading and measurement of the sample boards were conducted in the rough mill at the input conveyors. One member of the study crew pulled the premarked sample boards from the input lumber stream at a convenient and safe location. One or two members moved the sample boards from the collection pile onto the grading and measurement table and then returned them after the measurements were taken. Crew members also assisted in measuring board dimensions (length and width to the nearest 0.25 in.) and board crook (to the nearest 0.25 in.). They took turns tallying the board data. The width of tapered lumber was measured following National Hardwood Lumber Association (NHLA 1998) grade rules, that is, one-third of the length of the board from its narrow end.

The lumber grader was the key team member. The same grader was used for all mill studies. Our grader had more than 10 years of familiarity with the NHLA grade rules and just prior to the study took a 1-week NHLA sponsored short course.

The sample size for each study represented about 10 percent of the lumber input for a full shift. At rough mills with higher production, the percentage of sampled input boards ranged from 5 to 10 because the volume of lumber passing the study team's puller sometimes exceeded his ability to capture all of the marked boards. The number of boards sampled per mill ranged from 146 to 492 (average: 286 boards). For two mills where the sample size fell below 200 boards, repeated attempts to collect additional red oak data were unsuccessful.

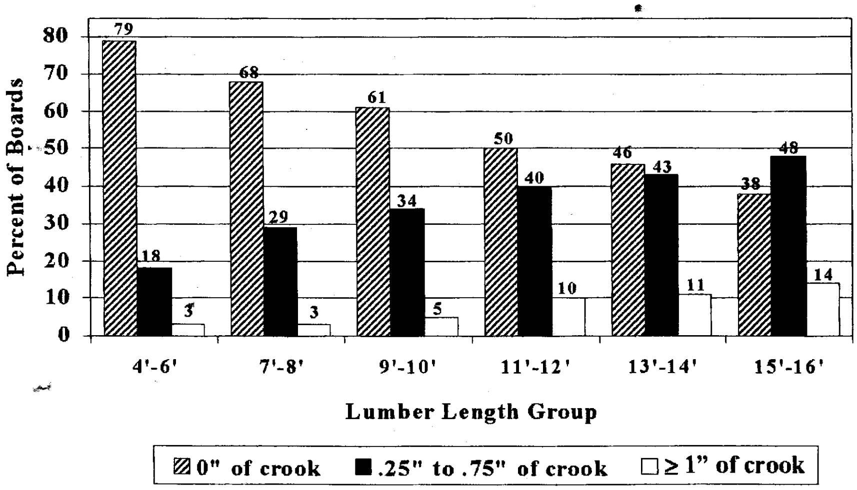

Figure 1. — Crook rates, by lumber length, for 4/4 thickness, red oak boards measured at 14 rough mills.

Data analysis

We used three statistical techniques to determine relationships for crook and overlength: a parametric analysis, analysis of covariance (ANCOVA), and two nonparametric analyses, the Kruskal-Wallis test and Kendall's test measure of rank correlation. ANCOVA was used to examine the relationship between adjusted crook (crook per lineal foot of lumber) and the factors of lumber grade, region, and mill, but the assumption of normality was violated and could not be overcome using transformed data. This led us to use the Kruskal-Wallis test, which examines the rank sums of the observations. The rank sums for all groups of the particular classification variable are used to generate a test statistic that is compared to a critical value from the χ^2 distribution. To measure correlation, the Kendall's tau statistic was used. This test measures rank correlation; there is no requirement that observations be from a bivariate normal distribution. All computations were performed in SAS®. The significance threshold used in these tests was $\alpha = .05$. Similar statistical tests also were performed on lumber width (Wiedenbeck et al. 2003).

Table 1. — Comparison of adjusted crook by region.[a]

Region	n	Mean of adjusted crook	Kruskal-Wallis grouping
		(in./ft.)	
WVA	1,109	0.016	A
SWV	1,227	0.024	B
NCP	1,667	0.025	B

[a]The regions are defined and described in the text.

Table 2. — Percentages of boards with 1/2-inch or more of crook, by length and grade, for two red oak lumber samples.

Nominal board length	1 Com 1992[a], boards with ≥ 1/2-in. crook	1 Com 1996, boards with ≥ 1/2- in. crook	2 Com 1992[a], boards with ≥ 1/2-in. crook	2 Com 1996, boards with ≥ 1/2- in. crook
(ft.)				
4 to 5	3	10	0	12
6 to 7	8	15	5	13
8 to 9	12	17	15	21
10 to 11	21	23	18	17
12 to 13	30	29	27	28
14 to 15	48	38	34	34
16	44	40	46	41

[a]1992 crook data were excerpted from Table 5 in Wiedenbeck et al. (1995).

Results and discussion

Crook

Statistical modeling indicated no difference in the amount of crook per lineal foot of lumber (adjusted crook, in./ ft.) between lumber grades. The nonparametric Kruskal-Wallis rank sum test was used after attempts to transform data on crook per lineal foot of lumber failed to meet the normality and equality of variance requirements for parametric procedures. Also, a logistic regression model was developed in which crook was categorized into two groups: boards with crook amounts less than 0.05 inch per lineal foot of lumber (less than 1/2 in. of crook on a 10-ft. board) and boards with at least 0.05 inch per lineal foot. However, this model was ineffective in explaining the variability in the data (generalized $R^2 < 0.01$).

Only one-way associations could be explored using the nonparametric Kruskal-Wallis test. In addition to testing for a difference between grades (nonsignificant with a p-value = 0.21), differences in adjusted crook (inches per lineal foot of lumber) between mills were tested for each region. For the WVA and SWV regions, between-mill differences were not significant. For NCP, between-mill differences in adjusted crook were highly significant ($p <$ 0.0001); 4 of the 10 pairwise comparisons among the 5 NCP mills were significant. Mean adjusted crook for these mills ranged from .02 to .033 inch per lineal foot. Mean measured crook for the NCP mill with the least amount of crook was 0.19 inch per board. In contrast, mean measured crook at the mill with the significantly highest amount of crook was 0.39 inch per board.

Differences in adjusted crook between sampling regions (WVA, SWV, NCP) were highly significant ($p <$ 0.0001 in Kruskal-Wallis rank sum test). Pairwise comparisons were performed to determine regions that differed. The lumber sample from WVA had significantly different (lower) adjusted crook than either SWV or NCP (**Table 1**). SWV and NCP samples had similar distributions for adjusted crook.

Kendall's tau test was used to test for a significant association between adjusted crook and the continuous variable of lumber length. The association between adjusted crook and lumber length was highly significant ($p < 0.0001$). The association is positive with a correlation coefficient (r) of 0.09. Thus, larger lengths tend to be associated with larger amounts of adjusted crook. The test for a significant association between adjusted crook and lumber width was not significant (p-value = 0.8752).

The percentage of boards in each length group with no crook, minor crook, and larger amounts of crook (actual measured crook per board) are compared in **Figure 1**. In the 4- to 6-foot lumber group, 79 percent of the 180 sample boards had no crook; only 3 percent of these short boards had crook of 1 inch or more. In contrast, only 38 percent of the 253 sample boards in the 15- to 16-foot group had no crook, while 14 percent had crook of 1 inch or more. Not surprisingly, there was a direct correlation between measured crook and lumber length though the Kendall's tau correlation coefficient was relatively low ($r = 0.16$).

Only 10 percent of the 4- to 5-foot nominal length 1 Common and 12 percent of the 2 Common boards measured in this study contained crook of 1/2 inch or more. The increase in the number of boards having 1/2 inch or more of measured crook was consistent as lumber length class increased (**Table 2**). At the upper end of the lumber length range (16-ft.-long lumber), 40 percent of the 1 Common and 46 percent of the 2 Common boards contained 1/2 inch or more of crook.

The 1992 databank for red oak lumber (Gatchell et al. 1992), which contained 1,578 boards compared to 4,003 in the current sample, was surveyed for defect rates by Wiedenbeck et al. (1995). Crook was reported as the percentage of boards with 1/2 inch or more of crook. This threshold was chosen on the basis of earlier work by Gatchell (1990) that indicated that even 1/2 inch of crook can reduce rough mill part yields by 1.5 to 4.5 percent.

Table 2 shows that the crook measured in our study was higher for the short lumber (4 to 7 ft.) and lower for the longest lumber (16 ft.) than the crook measured for lumber in the 1992 databank (Gatchell et al. 1992). The comparison of crook in the short lumber is weak because there were few short boards in our data set but a large number in the 1992 data bank. If these differences are reliable, then a possible explanation for the higher incidence of crook in the industry-based sample is that this lumber was dried more haphazardly (by the many drying operations) than the short boards in the 1992 databank. Or, the lumber in our study may have been cut from a higher percentage of smaller diameter trees containing greater amounts of juvenile/tension wood, which leads to

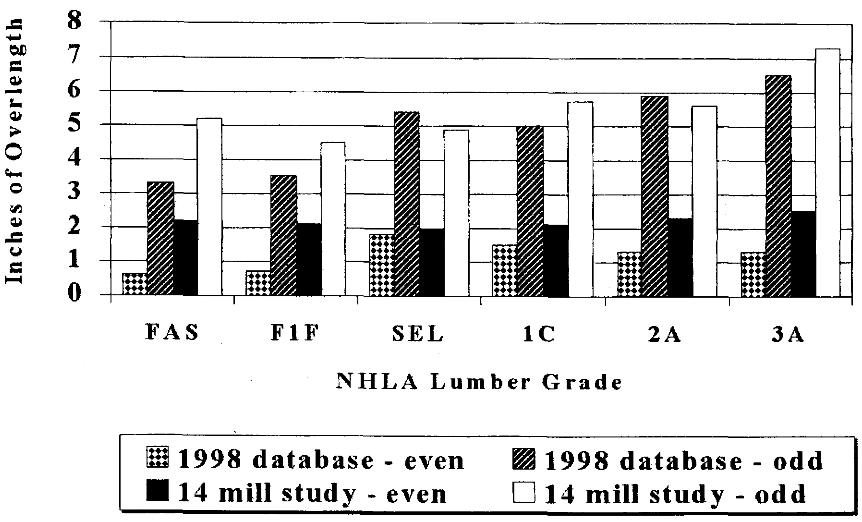

Figure 2. — Average overlength by lumber grade, for 4/4 thickness, red oak boards measured at 14 rough mills.

crook and other forms of warpage during drying. Although our study indicates that shorter lumber tends to have less crook per lineal foot than longer lumber, the industry practice of stacking short lumber in multilength packages (e.g., 4 to 6 ft. stacked together) results in lumber ends that are not aligned and poorly supported. This practice produces boards with crook that otherwise would be free of crook.

It is not entirely clear why the longer lumber in our study had a lower incidence of crook than the longer lumber in Gatchell's 1992 databank. Because of the high value associated with longer lumber, great care is taken during stacking and drying operations (particularly those of secondary manufacturers). Perhaps the fact that only three mills produced the lumber in the 1992 databank accounts for the difference. If one of these mills cut a disproportionate amount of lumber from logs with high growth stresses, the rate of crook might have been strongly influenced by that mill.

Overlength

Average overlength was somewhat higher (2.6 in.) than the desired length, which is typically 1 to 2 inches longer than nominal, but had a high standard deviation (2.7 in. for all 4,003 boards). Mean overlength for the three regions was 2.1, 2.8, and 2.8 inches for WVA, SWV, and NCP, respectively. However, ANCOVA (using transformed overlength data to correct for departures from normality) indicated that the best model for describing overlength is complex, consisting of several higher order interaction terms and their associated (main and lower order) effects. The significant highest order effects are: nominal length × mill (region) ($p < 0.0001$), grade × mill (region) ($p \leq 0.0118$), and nominal length × grade × region ($p < 0.0001$). Thus, in the full model that describes overlength, nominal length, grade, region, and mill within region interact to influence overlength to varying degrees given different levels of the linked variables (model $r^2 = 0.49$ and $p < 0.0001$).

When overlength amounts for odd and even nominal length lumber are compared, the average amounts of overlength are higher for the odd lengths than for the even lengths in all lumber grades (**Fig. 2**). Also, standard deviations for the odd-length lumber's overlength measurements are consistently higher than for the even-length lumber. This was true for our study and for Gatchell et al.'s 1998 databank for kiln-dried red oak lumber. Average overlength for all of the odd-length lumber that we measured (all lumber grades combined) was 5.5 inches. For all even-length lumber in our study, the average overlength was much lower, averaging 2.1 inches (i.e., 3.4 in. less than for odd length lumber). Forty-six percent of the odd-length lumber had 5 or more inches of overlength compared to only 9 percent for the even-length lumber. The impact of the longer and more variable overlength amounts associated with the 5-, 7-, 9-, 11-, 13-, 15- and 17-foot lumber classes cannot be dismissed; 13.7 percent of the dry, red oak lumber measured in the 14 rough mills visited in our study was odd nominal length lumber, which is a sizable portion.

It was not possible to construct a statistical contrast for overlength for odd- and even-length lumber classes. The widely imbalanced design of the nominal length samples and the complexity of the interaction terms containing nominal length contradicted the use of a statistical contrast.

That some secondary processing operations emphasize the importance of precision end-trimmed lumber while others do not was evident in our data. Average overlength measured at 4 of the 14 rough mills was less than 2.0 inches while the average of the overlength measurements recorded at 4 other mills exceeded 3.0 inches (average overlength was 2 to 3 in. at the remaining 6 mills).

Longer amounts of defect-free overlength can provide space for obtaining additional cuttings and increase rough mill yield. However, the costs that can be associated with overlength (diminished drying quality, dry-kiln and dry-storage capacity) might offset gains in cutting yield. Researchers at the University of Tennessee are studying the relative costs and benefits of using precision-end-trimmed lumber versus non-trimmed or rough-trimmed lumber (Bond 2000).

Lumber versus log overlength

By comparing log and lumber overlength amounts we hoped to gain insight on the cause of overlength lumber. Average log overlength exceeded lumber overlength by 3.2 inches (2.6 in. for lumber versus 5.8 in. for logs). This comparison is based on the red oak lumber length data from our study and data on red oak log lengths recorded by Blackwell (2001). In the latter, log lengths were measured to the inch at 12 sawmills.

As with lumber overlength, the average log overlength for odd log lengths is higher than for even lengths. The average "inches longer than nominal" of odd-length logs (multiple species) was 3.26 inches (967 logs) versus 2.71 for even-length logs (3,640 logs; Blackwell 2001). Recalling that average lumber lengths for odd- and even-length logs were 5.5 and 2.1 inches, respectively, it seems that the overlength measured in dry, red oak lumber is more a function of sawing, edging, and trimming in the sawmill than one of log lengths. That the average overlength of the odd-length lumber sample is longer than that of the odd-length logs suggests that overlength may not result from a lack of trimming but from trimming to increase grade. Twenty-one percent of the red oak log sample had odd nominal lengths compared to 13.7 percent of the lumber sample. Again, it should be noted that the lumber data set used in our study was not cut from the referenced log data set.

Measurements of red oak log length by Blackwell (2001) revealed more overlength associated with Grade 1 logs in 5 of 12 studies, with Grade 2 logs in 4 of 12 studies, and with Grade 3 logs in 3 of 12 studies. The notion that higher grade logs are bucked more carefully is not borne out by these numbers. A possible explanation for the greater number of overlength logs measured at certain sawmills is that logs earmarked as veneer logs by the logger are cut with extra inches of trim for some markets (e.g., 8 in.). The fraction of these logs that do not make the veneer-log grade end up as overlength sawlogs.

Measurements of red oak lumber length taken in our 14-mill study are inconsistent as to which lumber grade has more inches of overlength lumber. The 3A Common grade had the highest average overlength component in four mills, but FAS and F1F had the highest at four other mills. Each of the other NHLA lumber grades also had the longest average recorded overlength in at least 1 of the 14 rough mills. The fact that half of the case study rough mills had more overlength in higher grade lumber (FAS, F1F, and Selects) than in lower grade lumber indicates that a loss of lumber value is possible if hypothesized lumber drying degrade losses are more prevalent for overlength boards.

Conclusions

Adjusted crook (inches of crook per lineal foot of lumber) does not vary between NHLA lumber grades for 4/4 thickness, kiln-dried, red oak lumber. Variations in adjusted crook between supply regions are important to consider. Adjusted crook varies by lumber length but not width.

Secondary manufacturers should be attentive to the degree of crookedness of lumber received from different lumber suppliers, particularly when a portion of the mill's red oak lumber is procured from lower elevations (even bottomlands) and another portion is from a supplier located in more northerly or higher elevations. Rough mills that have a gang-rip-first operation and cut a high proportion of longer length boards should monitor the amount of crook and the impact of crook on cutting yields. Also, yield studies conducted on straight lumber only need to be annotated and future yield studies should include a mix of straight and crooked lumber.

Overlength lumber is a concern for many secondary manufacturers (especially those that dry their own lumber) but may be welcomed by others. Average lumber overlength varies based on nominal length, lumber grade, source region, and supplier. Odd-length lumber has appreciably more overlength than does even-length lumber. Some rough mills clearly demand well-trimmed lumber while others do not.

The percentage of odd-length logs entering the sawmill is higher than the percentage of odd-length lumber exiting the sawmill. Average log overlength amounts are higher than lumber overlength amounts. Odd-length logs have more overlength than do even-length logs. Neither log nor lumber grade is a consistent predictor, from one mill to the next, of the amount of overlength.

Literature cited

Blackwell, K.A. 2001. Hardwood sawmill performance comparison. Master's thesis. Univ. of KY, Lexington, KY. 141 pp.

Bond, B.H. 2000. Increasing yield of hardwood lumber through precision end trimming. On file at USDA Forest Serv., Northeastern Res. Sta., Princeton, WV.

Gatchell, C.J. 1990. The effect of crook on yields when processing narrow lumber with a fixed arbor gang ripsaw. Forest Prod. J. 40(5):9-17.

__________, J.K. Wiedenbeck, and E.S. Walker. 1992. 1992 data bank for red oak lumber. Res. Pap. NE-669. USDA Forest Serv., Northeastern Forest Expt. Sta., Radnor, PA. 48 pp.

__________,R.E. Thomas, and E.S. Walker. 1998. 1998 data bank for kiln-dried red oak lumber. Gen. Tech. Rep. NE-245. USDA Forest Serv., Northeastern Forest Expt. Sta., Radnor, PA. 60 pp.

National Hardwood Lumber Association (NHLA). 1998. Rules for the measurement & inspection of hardwood & cypress. NHLA, Memphis, TN.

Wiedenbeck, J. 2001. Deciding between crosscut and rip-first processing. Wood & Wood Prod. 106(9):100-104.

__________,C.J. Gatchell, and E.S. Walker. 1995. Quality characteristics of Appalachian red oak lumber. Forest Prod. J. 45(3):45-50.

__________, J. Brown, N. Bennett, and E. Rast. 2003. Hardwood lumber widths and grades used by the furniture and kitchen cabinet industries: Results from a 14-mill survey. Forest Prod. J. 53(4):72-80.

Zavala, D.Z. 1995. The effect of log length and lumber thickness over-allowance on lumber recovery. Forest Prod. J. 45(2):41-45.