

GROWTH STRESS IN HARDWOOD TIMBER

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ABSTRACT.—Longitudinal growth stress, particularly in small diameter trees, can result in severe splitting and warping of lumber and can even ruin veneer quality logs. This phenomenon is well documented in the literature. The problems it causes are common and occur wherever wood or veneer is being processed. However, foresters, industrial managers, and researchers generally do not understand its significance. This paper will present examples of wood manufacturing problems resulting from longitudinal growth stress. It will also briefly review the literature and present findings from a study measuring longitudinal growth strain in different plantations of pole sized yellow poplar and the relationship of growth strain to warp and checking in lumber. Growth strain should be considered in future genetic studies.

Longitudinal growth stresses are present in all standing timber and cut logs. In fact, if they did not exist, trees could not maintain a vertical position. Growth stresses are not visible although they can be measured and are called growth strain (GS). When trees are felled and cut into logs and logs processed into lumber the results of growth stresses being released, particularly in small diameter timber become evident. Growth stress-related degrade includes splits, cracks and warp and thus loss of potential economic value. This degrade is so commonplace that many individuals will dismiss it as being “characteristic of wood” or “wood just does that”.

Heart checks in the butt of felled trees and cut logs are the first evidence of the presence of longitudinal growth stress relief in timber. These checks will occur as soon as the tree is felled or the log is bucked and may increase with time. In severe cases, logs may literally quarter themselves (fig. 1). “S” or “C” irons or plastic “I” pieces are commonly used on high valued logs to help control the problem.

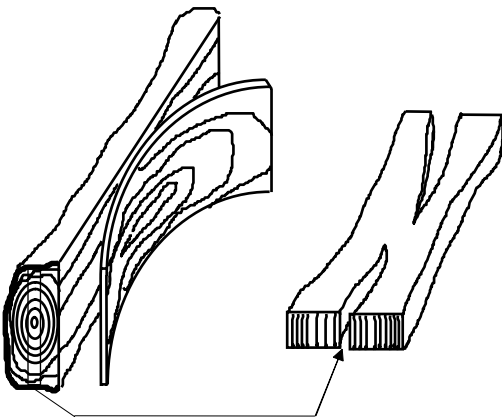


Figure 2.—Bow from longitudinal growth stress release in a flat sawn board (left). Tension in the outer portion of the log pulls the ends of the board outward and together. Longitudinal growth stress release in a diametrical edge grained (quartersawn) blank resulting in deep end splits and crook.

Chain saws may bind when cross cutting logs (Wilhelmy 1971) due to stress. As the saw first enters the cross cut, tension in the outside of the log pulls the wood away but as the cut deepens the center portion of the log which is in compression is now free to expand and the saw is pinched.

Bow in flat grained lumber occurs when tension in the outer part of the log cause boards to pull outward as they are cut loose from the log or cant (fig. 2). The log or cant will curve slightly in the opposite direction. If another board is cut on the same log face, it will be thinner on the ends and thicker in the middle due to movement of the cant. At mills which cut logs one board at a time, the cumulative effect of thin ends and thick middles is seen as a slight or low arch at the top of tall lumber stacks on the air drying yard. The effect is particularly noticeable in long lumber



Figure 1.—High quality walnut veneer log which has been severely degraded due to the release of growth stress.

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Crook often occurs in edge grained or quartersawn lumber. The region near the bark is in tension and tends to shrink while the region near the pith expands due to release of compression forces. The region near the bark ultimately ends up in compression (Jacobs 1965).

Boards and timbers cut with a centered pith or boxed heart may also develop deep end checks or splits (fig. 2), sometimes with an explosive force. Simply dropping one of these pieces during processing can result in the split developing.

Although growth stresses can often explain at least in part bow and crook, warp is usually the result of several growth characteristics, processing procedures, and wood properties interacting with growth stresses. These may include juvenile wood, pith, drying stresses, wood density and stiffness as well as anatomical alterations. Some drying stresses may act to offset growth stresses. Because several factors may be interacting it is difficult to identify a single cause for splitting and warping.

In order to better understand longitudinal growth stress and its effect on logs and lumber a series of experiments were conducted. Unlike previous reports, this research measured longitudinal growth stresses in standing trees and cut logs and then related the amount of stress to warp and checking in the lumber produced. Serrano (1999) provides additional information on the relationship of stress to warp and end checking in air dried and surfaced lumber. A complete statistical analysis and model are presented in the same document.

Literature Review

Jacobs (1945, 1965) defined growth stresses as the forces found in green stems disregarding stresses due to the weight of the tree's crown and sap tension. According to Post (1979) growth stresses are the forces that develop in the wood of growing plants. These stresses are different from those developed as a consequence of drying, although they may interact (Jacobs 1965, Chafe 1979A and B, Kubler 1987). Growth stresses in wood are distributed orthotropically in longitudinal (axial), tangential (ring, circumferential) and radial directions in the stem. Growth stresses originate when growing wood cells contract in the longitudinal direction and expand in the transverse direction (Munch 1938). Since the contraction is restrained by older cells, the new cells generate longitudinal tension, while obstruction of the lateral expansion by neighbor cells leads to tangential compression stress (Kubler 1987). The longitudinal tension force compresses the adjacent interior layer and reduces the tension of older cells (Jacobs 1939). The macro-cumulative effect of additional woody layers is converted to severe compression near the pith.

The tree generates growth stresses in response to mechanical requirements. Growth stresses are important in that they help reorient stems and branches. For example, reaction wood generally tends to exhibit high levels of longitudinal growth stresses that allow leaning trees to regain a vertical position. Growth stresses are present in the tree as internal or residual stress even without the action of external forces. As a result, the mean growth stress in vertical standing trees and the corresponding felled trees differ only slightly (Nicholson 1973). Conversely, the pattern of stress distribution around the circumference changes significantly due to lean and wind. The release of growth stresses during processing generates many complications such as splits and distortions in both logs and lumber.

Stress appears in woody plants in the form of tension and compression. The stress acting on wood produces strain, which is a change in dimension. Since stress cannot be measured directly, strain is used to evaluate defects caused by growth stress (Kubler 1987). In the longitudinal direction, the tree is pre-stressed in tension on the periphery and in compression near the center. Compressive longitudinal growth stresses tend to increase toward the pith and when felling and crosscutting, the internal-stress balance is altered resulting in splits and heart checks in the log ends (Malan 1979). Longitudinal growth stresses are largest in magnitude and the most serious in processing because they result in warp (Boyd 1950, Hillis 1984, Maeglin 1987, Kubler 1988). Warp in lumber is fundamentally driven by growth stresses, and differences in shrinkage within the wood as it dries (Simpson 1983). Warp in sawn green timber occurs essentially due to differential or asymmetry in growth stress levels. Since growth stress release causes warp and splits in green lumber, researchers are interested in finding ways to predict or to reduce its impact. To predict lumber warp, surface longitudinal strain measurements in standing trees and felled logs have been suggested as an

alternative to the more complicated inside-stem strain determination method (Okuyama and Sasaki 1979, Archer 1986 and Kubler 1987). Because growth stress release will occur during the conversion process, sawing pattern plays an important role in warp development. Longitudinal position in the tree may also influence lumber warp (Balaban 1982, Maeglin and Boone 1983, Koch 1986). Other causes of lumber warp might be due to the anisotropic nature of wood as well as the variability of wood properties within and among trees. As a result, growth stresses and growth factors may increase or decrease the tendency of lumber to warp. Kubler (1987) and Archer (1986) note that large variations of surface growth stresses occur within and between species, around the tree circumference especially in leaning trees (reaction wood) as well as with tree height, silvicultural treatments and seasons. However, only limited experimental information has been generated. In addition, surface growth strains have been found to be closely related to variations of wood properties such as, MOE, basic density, shrinkage, fiber wall thickness, lignin/cellulose content, and microfibril angle (Nicholson et al. 1975, Okuyama et al. 1994, Bailleres et al. 1995, Hillis 1997, Malan 1997). Most of these wood properties show strong relationships with growth stress when evaluated in leaning trees.

Today, second growth forests along with fast growth plantations represent an important source of many commercially important species. As a result, the size and quality of logs are continuing to decrease, resulting in utilization of smaller and smaller trees with less mature, clear wood. Moreover, wood which was initially managed for pulp is being processed for lumber even at younger ages (Senft et al. 1985). These younger trees have a higher proportion of juvenile wood, reaction wood, and growth stress as compared to older trees (Maeglin 1987). Growth stresses are more critical in smaller logs from young fast growing trees because of steeper growth stress gradients (Boyd 1950, Hillis 1997). In addition, growth stress release in hardwoods is of a much greater magnitude than in softwoods (Archer 1986, Kubler 1987). Well documented differences have been observed among the properties of wood from second growth forests, plantations, and old growth forests (Rendle 1960, Bendtsen 1978, Lewark 1985, Zobel and van Buijtenen 1989). As timber demand and resulting economic pressures impose short rotations, more quality problems with shrinkage, warping, low strength and other factors, impacting the performance of wood products will be found.

Materials And Methods

Surface longitudinal growth strain (GS) of 36 trees was measured during May and September on the west and east side of a sample of plantation grown yellow poplar (*Liriodendron tulipifera* L.) trees from three different plots at the Purdue University Martell Forest in Tippecanoe County, Indiana. Trees in the plots were planted in 1965 and initially spaced at 6x6 or 6x9 feet. Dominate trees were selected. The plots were on level ground. An additional set of the GS values were taken in August and included measurements on the west, east, north and south sides of the stem. Twenty of these trees were felled and processed into lumber. GS measurements were taken at diameter breast high (DBH) on the butt logs as well as at 12.50 feet from the ground on the second logs. Side-matched GS measurements were obtained on the felled trees (two 8 foot logs). A slightly modified Nicholson's method (fig. 3) was employed to determine GS measurements (Nicholson 1971 and Serrano 1999). Growth strain is measured as $\mu\epsilon$ or micro-strain. " ϵ " is the change in length divided by the original length and " μ " is equal to 10^6 thus micro-strain. By using GS average values measured on the butt logs, the trees were grouped into HI and LOW GS trees. Those trees with GS levels above the mean value were considered "high GS level", and below the mean value "low GS level." In order to avoid the effect of outliers the trimmed (Tr) mean¹ was used. The trimmed mean was (1301.9 $\mu\epsilon$; and the range was from 500 to 3420 $\mu\epsilon$). Tree samples from the three plots of yellow poplar that were harvested during August were processed using the balanced sawing technique by means of the (SDR) process and the CANT sawing



Figure 3.—Huggenberger tensotast (accurate to 0.001mm) used to measure growth stress. It is the movement of the two Phillips head screws (bottom) which is measured after the wood is cut free on each side. The instrument is provided with calibration bars.

¹Removes the smallest 5% and the largest 5% of the values (rounded to the nearest integer) and then averages the remaining values.

pattern. This technique is based on the alternate cuts of similarly located pieces from opposite sides of the log or flitch in order to counterbalance the longitudinal stress release. Figure 4 is a graphical presentation of these sawing patterns. In both sawing patterns, a portable sawmill with thin-kerf bandsaw blades was used. The bandsaw blades produced a 1/16 in. nominal saw kerf. The taper of the logs was split which permitted full thickness for the pieces obtained from the center of the log. For the SDR process, the opening face was at least 4 inches wide in order to produce a nominal 4 inch stud from the subsequent flitch.

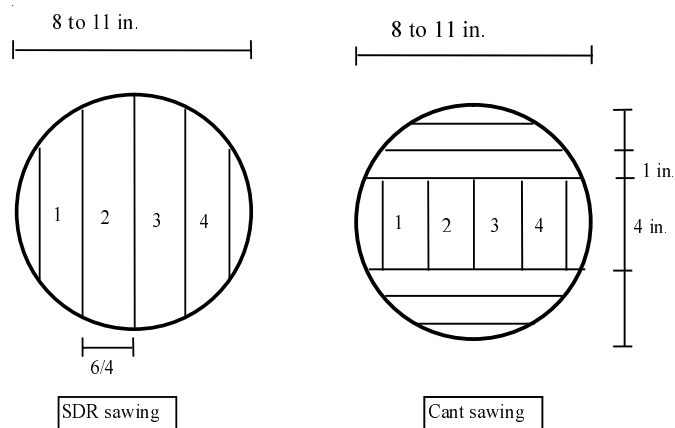


Figure 4.—Typical sawing patterns to produce 2 by 4 yellow poplar studs.

It was estimated that a bolt diameter inside bark (DIB) of 8 to 11 inches (Figure 4) would be required to apply the sawing patterns proposed in this study.

The diameter breast high (DBH) of the study trees ranged from 8 to 13 inches. As a result, some studs containing wane were produced. Only material from the butt and the second eight foot log was used.

Stud position in the tree was evaluated through log position or height (butt and second log) and radial (flat and quartersawn pieces) differentiation. From the sawing pattern in Figure 4, stud position 1 and 4 produced “flat grained” pieces while positions 2 and 3 generated “edge grained or quartersawn” pieces from the juvenile wood zone of the log.

Warping measurements in the green condition included crook and bow. These measurements were determined according to Hallock and Malcolm (1972), Milota (1995), and Serrano (1996). The number of end checks and the length of the longest end check were also determined. For the cant sawing process, these measurements were taken on 2 x 4's but for the SDR process, they were taken on flitches which still contained the waney edges.

Results And Discussion

Table 1 shows that the magnitude of GS increased significantly from May to September (p -value 0.0001). The GS for August was in an intermediate position. At the same time, the average GS readings on the west side were significantly higher than the east side (p -value 0.0263). Thus, harvesting and processing the trees before the dormant period will result in lower GS values and perhaps less warping and end checking in the lumber. This recommendation is further supported because fewer difficulties in debarking logs from May to August as compared to September were encountered. Okuyama et al. (1981) reported similar results in an experiment with the conifer tree sugi (*Cryptomeria japonica*), and Nicholson (1973) indicated the existence of some seasonal and other periodic variations of longitudinal GS. Archer (1986), based on theoretical premises, suggests that softwoods would start with slightly negative or nearly zero GS at the beginning of a growth season and then increase to some maximum value in the latewood near the end of the growing season. However, this GS seasonal change may be less pronounced in hardwoods, based upon the small microfibril angle variation over the annual ring. Kubler (1987) rejected the idea of GS seasonal change, arguing that without a new stimulus, GS should be the same in earlywood as well as in latewood. However, his position is not supported with experimental data. Okuyama et al. (1981) indicates that lignification is the most important process for growth stress generation. It is also known that the lignification process occurs over a period of time. Therefore, this time factor must be considered in the models (Yamamoto 1998).

The GS averages of the butt logs were significantly lower than the second logs (p -value 0.008, table 2). The interaction of plot and log position generated important effects. The significance level for this interaction effect was 7.10 % (p -value 0.071). The GS averages of the second logs tended to be higher than the butt logs, but in the case of plot number 2 the mean value was much higher. GS differences by polar points

Table 1.—Surface longitudinal growth strains (GS in $\mu\epsilon$) at DBH on standing trees for two polar points and three time periods.

Polar points	Time Periods		
	GS May	GS Aug.	GS Sep.
East	1099	1169	1743
West	1286	1639	1978
N	36	20	36

Note: -GS May and GS Sep. are side-matched observations on the same tree, while GS Aug. were taken on a sample of the 20 trees that were harvested and processed by the SDR and cant sawing method.

-GS Aug. means were adjusted by plot size.

Table 2.—Surface longitudinal growth strains ($\mu\epsilon$) on standing trees according to plot number and log position.

Log position	Plots			Average
	1	2	3	
Butt	1404	1333	1455	1397
Second	1481	1826	1541	1616
Average	1443	1580	1498	1507
N	80	40	40	160

Note: -Mean values by plot number include all 4 polar points for both the butt and the second log.

-GS values in this table were adjusted by plot size.

regardless of log position for the standing trees were only significant at 6.80 % (p -value 0.068, table 3). The mean values for the butt logs tended to be systematically lower than the second logs for all polar points. This large GS difference between the butt logs and the second logs from trees of plot number 2 was consistently reflected in higher levels of crook and end checking in the lumber specimens produced from this plot (table 2, figures 5 and 6). Log end split percentages were also significantly higher in the logs produced from trees of plot 2. Yao (1979) and Chafe (1981A and B) have reported similar results. However, other authors have not found a significant variation of GS with height (Sasaki et al. 1981A and B, Trenard and Gueneau 1975). Kubler (1987) stated that in a stable, immediate environment, peripheral strains are probably height-independent.

The plot number or the source of the trees affected the level of crook found in the green 2 x 4's and flitches (figure 5). The mean value of crook from plot 2 was significantly higher than from plots 1 and 3 (p -value 0.0315). The interaction of plot and GS level (HI and LOW) was significant (p -value 0.0406). Therefore, the level of crook found in the green material was dependent on the plot number and GS level. Processing trees with low levels of stress will reduce crook in green lumber. Since crook averages for that condition (Plot 2 and HI strain trees) include lumber pieces from the butt and the second logs, it is likely that the large difference of GS between these two log positions found in plot 2 explain such a high level of crook.

Crook in the green 2 by 4 studs was significantly higher than that in the flitches. In other words, the CANT sawing pattern generated higher levels of crook than the SDR process (p -value 0.0001) (fig. 7). On average, the amount of crook found in green 2 by 4 studs was around 3/32 in., but only 1/32 in. in the green flitches.

Just as with the crook results, the 2 by 4 studs had a higher level of green bow than the flitches (p -value 0.0102, fig. 7).

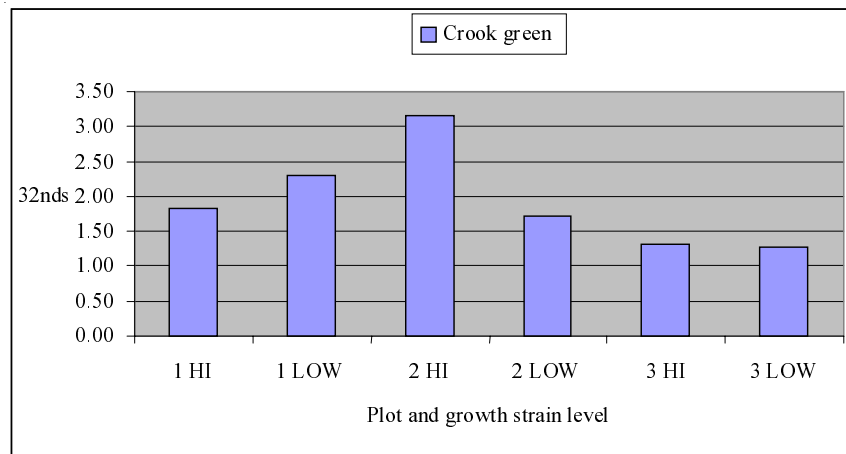


Figure 5.—Crook by plot number and growth strain level in the green condition.

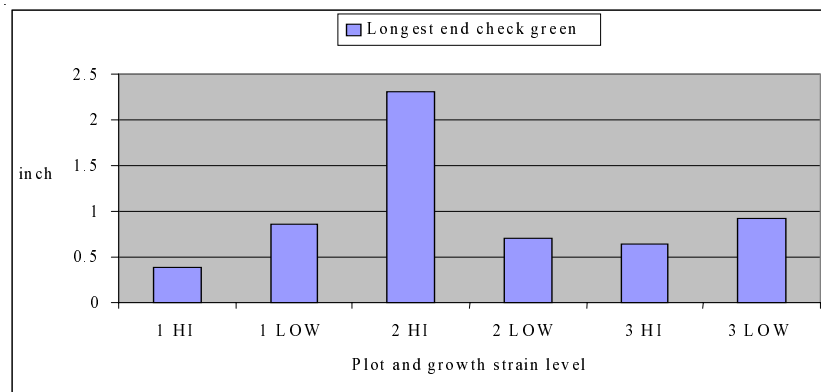


Figure 6.—Length of the longest end check by plot number and growth strain level in the green condition.

Bow in the green condition was affected by radial position. Higher levels of bow were found in the flat sawn pieces as compared to the quartersawn ones (p -value 0.0001). The interaction between radial position and plot number was also significant (p -value 0.0372). The flat sawn pieces from plot 2 exhibited the highest level of bow. Again, the large GS difference between the butt and the second logs from plot 2 may also explain such behavior. By subtracting the GS differences for the butt and second log (table 2) differences are 77, 493 and 86 μE for plot 1, 2 and 3 respectively. The trees from all three plots of yellow poplar were grouped according to LOW and HI growth strain gradient. The trees classified as LOW had an average GS gradient between the butt and the second logs of 266 me as compared to 626 me for the trees classified as HI, and the average bow was 1/4 in. and 13/32 in. for LOW and HI respectively. An increase of about 135 % of the GS gradient from LOW to HI generated an increase of 63 % of bow in the green lumber specimens.

The longest end checks in the green state appeared only in the studs and flitches from quartersawn pieces. Another important factor was the significant interaction between plot and GS. Specimens from HI growth strain trees from plot 2 presented the highest level for the end check defect (fig. 6). This result also confirms the benefits of processing trees with low levels of stress in order to reduce the length of the longest end check in the green state, which is in complete agreement with the literature. Considering that the averages for this end check defect included pieces from both the butt and the second logs, it is conceivable that the large GS difference between these two log positions found in plot 2 (table 2) explain such a high level of end checks.

Table 3.—Surface longitudinal growth strains ($\mu\epsilon$) on standing trees according to the four polar points and two log positions.

Bolt	Polar points			
	west	south	east	north
Butt	1639	1313	1169	1469
Second	1719	1499	1668	1578
Average	1679	1406	1418	1524
N	20	20	20	20

Note: -GS values in this table were adjusted by plot size.

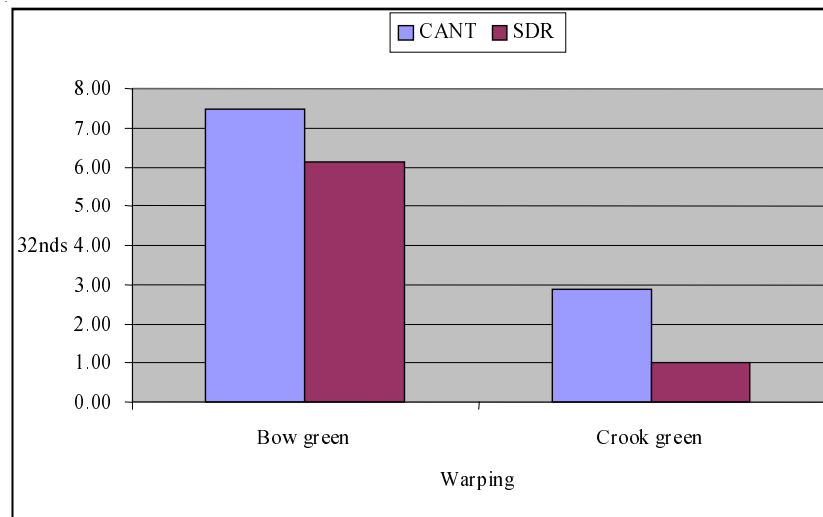


Figure 7.—Bow and crook level by sawing pattern in the green condition.

Conclusions

Longitudinal growth stress results in tension toward the outside of a tree stem or log and compression towards the center. These stresses are measured as growth strain. As the tree is processed first to logs and then to lumber, the stresses are unbalanced and log splitting, lumber warp, and checking occur. This study has demonstrated that yellow-poplar trees with higher GS produce green lumber with greater amounts of bow, crook and end checking and that these results are also affected by sawing pattern.

Crook found in the green specimens, as a result of growth stress release, was very important. Sixty percent of the crook in the 2 by 4 studs from the cant sawing pattern appeared right after the sawing operation as compared to 35 % for the unedged flitches from the SDR process. This also indicates a higher stress release as a result of the sawing operation in the green 2 by 4 studs than in the flitches.

From the merchantability point of view, quarter-sawing produces lower quality 2x4 studs than flat-sawn pieces. The important challenge is to overcome the poor performance of these pieces.

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