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# Structural Lumber Properties of Hybrid Poplar

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# Abstract

The Lake States of Michigan, Minnesota, and Wisconsin consist of 49.4 million hectares (122 million acres) of land, 19.8 million hectares (49 million acres) of which are forested, with 6% of those having been removed by law from timber production. Aspen (*Populus tremuloides*) is an important component of this resource. In recent years, a concern that the aspen cut will exceed its growth has surfaced. That is, Will the aspen supply be adequate to support the growing solid-wood, composite, and paper industries in the Lake States region? To satisfy the increased demand for forest products, it is expected that much of the future timber supply will be from improved trees grown on managed plantations. It is critical that the mechanical properties of this resource are clearly understood so that alternative uses of this material can be evaluated. A study was conducted using full-size lumber tests on 243 38- by 89-mm (2- by 4-in.; hereafter called 2 by 4's) boards cut, using two methods, from 50 logs to determine selected mechanical and physical properties of the Wisconsin-5 hybrid poplar clone. The material was either kiln dried or partially air dried followed by kiln drying. The 2 by 4's were assigned grades according to four grading rules: Light Framing, Structural Light Framing, Structural Lamination, and Machine Stress Rating. Results suggest that this poplar clone would produce visually graded material that is similar in properties and characteristics to the native aspen and cottonwood resource. Close to 65% of the material produced made grades of either Standard and better or No. 2. The Machine Stress Rating grade most likely to be produced from this material would be 1450f–1.3E. To avoid excessive degrade as a result of warping during drying, this material should be dried in flitch form.

Keywords: hybrid poplar, mechanical properties, bending, MSR

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# Contents

# Structural Lumber Properties of Hybrid Poplar

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## Introduction

The Lake States of Michigan, Minnesota, and Wisconsin consist of 49.4 million hectares (122 million acres), 19.8 million hectares (49 million acres) of which are forested. An important component of this resource is trembling aspen (*Populus tremuloides*). There is concern that the aspen cut will exceed growth, and the aspen supply will not be adequate to support the growing solid-wood, composite, and paper industries in the Lake States region (Youngquist and Spelter 1989). To satisfy the increased demand for forest products, it is expected that much of the future timber supply will be from improved trees grown on managed plantations. This fast-growth resource tends to be harvested in short rotations, if these trees follow the trend of similar species (Bendtsen and Senft 1986), and it will contain greater proportions of juvenile wood compared with current harvests. It is critical that the mechanical properties of this resource are clearly understood so that the proper uses of this material can be determined.

## Background

In the past, most harvested aspen was used for pulp, lumber, hardboard, and insulation board. With the introduction of waferboard and oriented strandboard (OSB), aspen utilization increased threefold from 1975 to 1989 (Youngquist and Spelter 1990) and is now five times greater than the 1975 level (McKeever and Spelter 1998). During the past 30 years, much work has been conducted in forest genetics on *Populus* species (Riemenshneider and others 1996a,b) to develop improved hybrids. Several experimental plots have been planted across the Lake States to investigate improved *Populus* clones. In most improvement programs, the focus has been on growth rate, form, adaptability, and disease resistance. Additional emphasis needs to be placed on the effect of improvements on utilization properties of the material. It is possible that wood from these hybrids that have been developed to have superior growth, improved form, adaptability, and improved fiber characteristics for paper may be less suited to solid-wood processing than wood from either parent tree. Some work has been done to investigate the mechanical properties of hybrid poplars (Bendtsen and others 1981, Hall and others 1982), but many hybrid types are being developed and planted on experimental plots and each has its structural characteristics.

One such series of experiment hybrid poplar plots was planted at the University of Wisconsin–Madison, Hancock Agricultural Experiment Station. In the late 1970s, Wisconsin-5 hybrid poplar trees were planted in several experimental plots as windbreakers to protect potato fields. The parentage of Wisconsin-5 is a mystery; it is thought to be a hybrid tree that was found in someone's yard in a small Wisconsin town. Wisconsin-5 probably originated in Europe and was brought to North America by immigrants. In these experimental plots, special silvicultural measures were not applied to the hybrid poplar trees. This material was harvested in the winter of 1996–1997 to make more room for larger agricultural plots. The material that was cut offered a good opportunity to analyze the material properties of a common clone-type planted in Wisconsin.

The objective of this study was to investigate the mechanical and physical properties of the Wisconsin-5 hybrid poplar clone and compare those properties with previously full-size (In-Grade) properties of native aspen and cottonwood.

# Experimental Methods

## Material Selection

Three plots of hybrid poplar were harvested at the University of Wisconsin–Madison Hancock Agricultural Experiment Station during the winter of 1996–1997. Approximately 600 trees were harvested, resulting in more than 2,000 2.7-m- (9-ft-) long logs. These logs ranged from 76 to 330 mm (3 to 13 in.) in small-end diameter. Fifty saw logs were selected from these logs, which had a small end-diameter range of 95 to 292 mm (6.75 to 11.5 in.). The logs were selected based on limb size and log diameter. An effort was made to select only logs that would be representative of material grown in a plantation setting where the crown closure would limit limb size development. Therefore, logs with limbs greater than 152 mm (6 in.) in diameter were not selected. Detailed information on length, small-end minimum and maximum diameters, and large-end minimum and maximum diameters was recorded for each log. This information was used to sort the 50 logs into two roughly equivalent groups (A and B) based on diameter. A summary of the dimensions of these logs is given in Table 1. The actual length of the log varied from 2.4 to 3.0 m (7.9 to 9.7 ft).

## Log Scale

This diameter information was then used to determine an estimate of the expected number of cubic meters (board feet) of 2 by 4's to be produced using the IMPROVE system log analysis routine (USDA 1990b) and Best Opening Face sawing simulation analysis routine (USDA 1990a). The predicted values based on Scribner Decimal-C log scale and the Best Opening Face sawing simulation are given in Table 2.

## Sawing

The sawing was done at a sawmill in Hancock, Wisconsin, in June 1997. The first group of 25 logs was cut directly into 2 by 4's (Fig. 1A). The actual dimensions of the green 2 by 4's were 44 mm (1.75 in.) thick and, because of limited settings on the edger, a full 102 mm (4 in.) wide.

The other group of 25 logs was cut using the Saw–Dry–Rip method (Boone 1990; Maeglin 1990). The logs were cut into

**Table 1—Summary of log diameter information for group A and B logs**

| Diameter | Mean A mm (in.) | Mean B mm (in.) | Minimum A mm (in.) | Minimum B mm (in.) | Maximum A mm (in.) | Maximum B mm (in.) |
|---|---|---|---|---|---|---|
| Small-end minimum | 214 (8.43) | 213 (8.42) | 171 (6.75) | 178 (7.00) | 267 (10.5) | 292 (11.5) |
| Small-end maximum | 224 (8.83) | 222 (8.76) | 1.84 (7.25) | 184 (7.25) | 279 (11.0) | 292 11.5 |
| Large-end minimum | 248 (9.76) | 251 (9.87) | 190 (7.5) | 203 (8.0) | 330 (13.0) | 356 (14.0) |
| Large-end maximum | 263 (10.34) | 264 (10.40) | 210 (8.25) | 203 (8.0) | 356 (14.0) | 375 (14.75) |

**Table 2—Cubic meters (board feet) of poplar logs**

| | Number of logs | Scribner Decimal-C (min/max) cubic meters (board feet) | Predicted number of 2 by 4's | Predicted cubic meters (board feet) | Actual number of 2 by 4's | Cubic meters (board feet) nominal dry lumber tally |
|---|---|---|---|---|---|---|
| Group A (2 by 4) | 25 | 0.99 (420) | 140 | 1.76 (747) | 110 | 1.39 (587) |
| Group B (flitch) | 25 | 0.99 (420) | 145 | 1.82 (773) | 133 | 1.68 (709) |
| Total | 50 | 1.98 (840) | 285 | 3.58 (1,520) | 243 | 3.07 (1,296) |

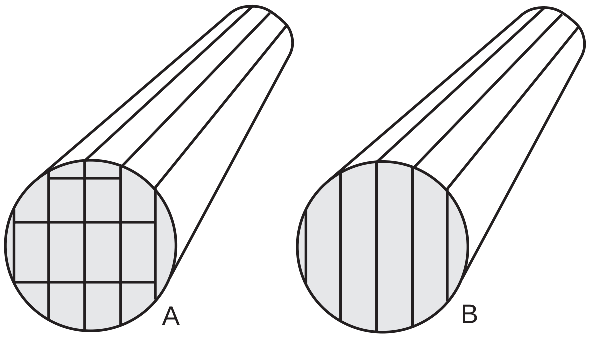


**Figure 1—Two sawing patterns were used: (A) 2 by 4 and (B) flitch.**

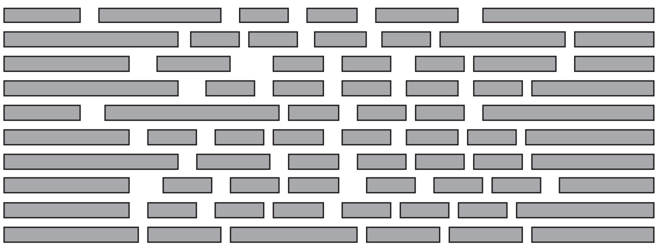

**Figure 2—Stacking procedure used to dry kiln was wide flitches on the exterior and 2 by 4's on the interior.**

44-mm- (1.75-in.-) thick flitches of random width (Fig. 1B). The green material from the two methods of sawing was combined and stickered in two equivalent groups. These flitches were edged to provide a more compact kiln load. The edging was sufficient to square up the edge of the flitch and to remove "butt flare" but did not remove considerable wane. The stickering method is shown in Figure 2. Wider flitches were kept to the outside of the stacks, and the 2 by 4's were stacked in the interior.

## Drying

The material was dried between June and August of 1997. Two methods of drying were used. First, a combination of group A and B material was placed in the dry kiln immediately after sawing under a maximum temperature of 54°C (130°F). A second combination of group A and B material was placed outside for an initial air drying of 1.5 months before kiln drying.

## Test Procedures

The dry poplar was shipped to the USDA Forest Service, Forest Products Laboratory (FPL), for additional processing into kiln-dried 38- by 89-mm (1.5- by 3.5-in.) lumber. The poplar was then graded by a quality supervisor from the West Coast Lumber Inspection Bureau (WCLIB) using four grading rules: Light Framing, Structural Light Framing, Structural Lamination, and Mechanical Stress Rated lumber. Detailed information on the poplar was recorded for warp characteristics (crook, bow, and twist) and defect locations. Just prior to testing, a transverse vibration dynamic modulus of elasticity (MOE) was determined for each board. The material was tested in bending according to D4761 (ASTM 1996). Data were collected on modulus of rupture (MOR), MOE, specific gravity, and moisture content according to D2395 (ASTM 1996).

# Results

The following sections summarize results for sawing yields, the four grading systems investigated, mechanical properties, machine stress rating potential, and sawing and drying effects on warp.

## Sawing Yields

The two far right columns of Table 2 show the actual and nominal lumber tallies of 2 by 4's produced and the cubic meters (board feet) of the study logs. The large difference between the predicted and actual volume was due to the width limitations on the edger.

## Visual Grades

Table 3 shows the breakdown of visual grades by group and total. In the Light Framing grades, the majority of the material was Construction grade. In the Structural Light

**Table 3—Number of pieces by visual grade and group**

| | A | B | |
|---|---|---|---|
| Grade | 2 by 4 | Flitch | Total |
| **Light Framing** | | | |
| Construction | 69 | 53 | 122 |
| Standard | 17 | 28 | 45 |
| Utility | 15 | 27 | 42 |
| Economy | 9 | 25 | 34 |
| All | 110 | 133 | 243 |
| **Structural Light Framing** | | | |
| SS. | 31 | 25 | 56 |
| No. 1 | 31 | 25 | 56 |
| No. 2 | 19 | 30 | 49 |
| No. 3 | 19 | 29 | 48 |
| Economy | 10 | 24 | 34 |
| All | 110 | 133 | 243 |
| **Structural Lamination** | | | |
| L1 | 37 | 41 | 78 |
| L2 | 28 | 29 | 57 |
| L3 | 23 | 12 | 35 |
| Reject | 22 | 51 | 73 |
| All | 110 | 133 | 243 |

Framing grades, slightly less than half the material was No.1 or better. In the Structural Lamination grades, about the same amount of material was in the top grade as was rejected. These results suggest that a sizeable amount, more than 65%, of the material cut from the hybrid poplar logs, would make either Light Framing grades of Standard or better or Structural Light Framing grades of No. 2 or better.

## Mechanical Properties

The mechanical property results for Light Framing and Structural Light Framing are summarized in Table 4. The results are presented by grade and overall. The relationships of dynamic MOE to static edgewise MOE and edgewise MOE to MOR are also presented. Dynamic MOE is a method of determining MOE for the entire length of the board using the flatwise vibrational frequency of the board. Edgewise MOE is determined by measuring the deflection of the board while under edgewise loading. For this sample, long-span flatwise dynamic MOE tended to be greater than the measured edgewise static MOE.

## Comparison With Other Visual Grade Data

The comparison of hybrid poplar with native aspen and cottonwood is of particular interest to potential hybrid poplar lumber producers. To make the comparison, the Select Structural and No. 2 test results for hybrid poplar were compared with the 2 by 4 aspen and cottonwood values in the *National Design Specification Supplement* (NDS) (AF&PA 1997) and the North American In-Grade Testing Program results for aspen–cottonwood (Green and Evans 1987). Table 5 displays the results of this comparison. The results suggest that Wisconsin-5 poplar would produce visually graded material that is similar in properties and characteristics to current NDS aspen and cottonwood values but less than In-Grade results for aspen–cottonwood.

## Sawing and Drying Effects on Warp

Warp characteristics were measured to the nearest 0.79 mm (0.031 in.). The allowable warp for a 2.44-m (8-ft) long 2 by 4 according to the WCLIB grading rule is listed in Table 6.

**Table 4—Summary of mechanical property test results**

| Grade | Moisture content (%) | COV (%) | Specific gravity[a] | COV (%) | Avg dynamic MOE (GPa) ($10^6$lb/in$^2$) | COV (%) | Avg MOE (GPa) ($10^6$lb/in$^2$) | COV (%) | Avg MOR (MPa) ($10^3$ lb/in$^2$) | COV (%) | $5^{th}$ % MOR (MPa) ($10^3$ lb/in$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Light Framing** | | | | | | | | | | | |
| Construction | 10.8 | 2.8 | 0.40 | 6.8 | 10.8 (1.57) | 14.3 | 9.2 (1.34) | 15.2 | 42.4 (6,147) | 28.9 | 23.1 (3,357) |
| Standard | 10.7 | 3.0 | 0.40 | 7.0 | 9.8 (1.43) | 20.3 | 8.5 (1.24) | 20.4 | 37.1 (5,376) | 37.0 | 16.0 (2,324) |
| Utility | 10.8 | 2.7 | 0.41 | 8.6 | 10.1 (1.46) | 20.7 | 8.4 (1.22) | 23.0 | 37.5 (5,442) | 37.0 | 11.5 (1,667) |
| Economy | 10.7 | 3.4 | 0.40 | 6.8 | 9.2 (1.34) | 21.0 | 8.4 (1.22) | 22.9 | 36.3 (5,273) | 37.6 | 14.1 (2,051) |
| **Structural Light Framing** | | | | | | | | | | | |
| SS. | 10.7 | 2.7 | 0.39 | 5.8 | 11.5 (1.67) | 10.7 | 9.7 (1.40) | 14.7 | 45.1 (6,542) | 24.0 | 27.0 (3,923) |
| No. 1 | 10.8 | 2.9 | 0.40 | 7.9 | 10.2 (1.48) | 16.1 | 8.9 (1.29) | 15.2 | 40.0 (5,795) | 29.4 | 23.0 (3,331) |
| No. 2 | 10.7 | 3.0 | 0.40 | 7.6 | 10.1 (1.46) | 19.5 | 8.7 (1.26) | 19.9 | 37.4 (5,421) | 40.8 | 15.2 (2,204) |
| No. 3 | 10.8 | 2.5 | 0.41 | 7.8 | 10.1 (1.46) | 19.7 | 8.5 (1.23) | 20.4 | 39.3 (5,697) | 31.5 | 18.9 (2,742) |
| Economy | 10.7 | 3.5 | 0.40 | 6.7 | 9.4 (1.36) | 21.4 | 8.3 (1.21) | 24.7 | 34.4 (4,992) | 42.1 | 9.8 (1,415) |
| All | 10.8 | | 0.40 | | 10.3 (1.50) | | 8.9 (1.29) | | 39.7 (5,760) | | 18.3 (2,662) |

[a]Specific gravity based on ovendry weight volume at time of test.

**Table 5—Comparison of Wisconsin-5 poplar study results to other existing 2 by 4 full-size data**

| Grade | Sample | Moisture content (%) | Specific gravity[a] | MOE (GPa) ($\times 10^6$ lb/in$^2$) | 5$^{th}$ % MOR (MPa) (lb/in$^2$) |
|---|---|---|---|---|---|
| Select Structural | Hybrid poplar | 11 | 0.41 | 9.7 (1.4) | 27.0 (3,920) |
| | NDS[b] aspen | 12 | 0.39 | 7.6 (1.1) | 19.0 (2,760) |
| | NDS cottonwood | 12 | 0.41 | 8.3 (1.2) | 19.0 (2,760) |
| | In-Grade aspen–cotttonwood | 12 | 0.43 | 10.3 (1.5) | 35.8 (5,190) |
| No. 2 | Hybrid poplar | 11 | 0.42 | 8.7 (1.3) | 15.2 (2,200) |
| | NDS aspen | 12 | 0.39 | 6.9 (1.0) | 13.0 (1,890) |
| | NDS cottonwood | 12 | 0.41 | 7.6 (1.1) | 13.6 (1,970) |
| | In-Grade aspen–cotttonwood | 12 | 0.46 | 9.0 (1.3) | 22.1 (3,200) |

[a]Specific gravity based on ovendry weight and ovendry volume.
[b]AF&PA 1997.

**Table 6—Amount of allowable warp according to the West Coast Lumber Inspection Bureau grading rule**

| 2 by 4 material | Allowable warp for grade of lumber (mm (in.)) | | |
|---|---|---|---|
| | Bow | Crook | Twist |
| No. 1 | 13 (0.50) | 6 (0.25) | 9 (0.375) |
| No. 2 | 19 (0.75) | 9 (0.375) | 13 (0.50) |
| No. 3 | 25 (1.0) | 13 (0.50) | 19 (0.75) |

**Table 7—Percentage of pieces that were rejected for warp**

| Drying method | n | Bow (%) | | | Crook (%) | | | Twist (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | No.1 | No. 2 | No. 3 | No. 1 | No. 2 | No. 3 | No. 1 | No. 2 | No. 3 |
| 2 by 4 air dry | 43 | 0 | 0 | 0 | 41.9 | 18.6 | 7.0 | 0 | 0 | 0 |
| Flitch air dry | 80 | 3.7 | 1.2 | 0 | 11.1 | 1.2 | 0 | 0 | 0 | 0 |
| 2 by 4 kiln dry | 56 | 3.6 | 0 | 0 | 26.8 | 14.3 | 3.6 | 0 | 0 | 0 |
| Flitch kiln dry | 64 | 6.3 | 1.6 | 0 | 12.5 | 3.1 | 0 | 0 | 0 | 0 |

Table 7 is a summary of the warp characteristics measured on the cut material. The numbers shown represent the percentage of all pieces that did not make the warp characteristic specified for a given grade in the WCLIB grading rule.

None of the boards had problems making a grade because of twist, and only a few pieces would have been eliminated from No.1 because of bow. The sawing method had a significant impact on the number of pieces eliminated from a grade category. There was considerable improvement in the crook characteristics of the material allowed to dry in flitch form. In addition, kiln drying can substantially reduce the amount of crook problems.

## Property Relationships

### Dynamic MOE–MOE Relationship

The relationship between dynamic MOE and static edgewise MOE is shown in Figure 3. The lower than expected $r^2$ value ($r^2 = 0.58$) can partially be explained by the limited range of MOE data. Normally an $r^2$ value between dynamic MOE and edge MOE would be in the range of 0.7 to 0.85 or greater. However, dynamic MOE can clearly be used as a predictor of edgewise MOE.

### MOE–MOR Relationship

The MOR was positively correlated to edgewise MOE, and the $r^2$ value ($r^2 = 0.42$) was similar to other $r^2$ values reported for hardwoods (Green and others 1994). The relationship between static edgewise MOE and MOR is shown in Figure 4. The relationship shown is

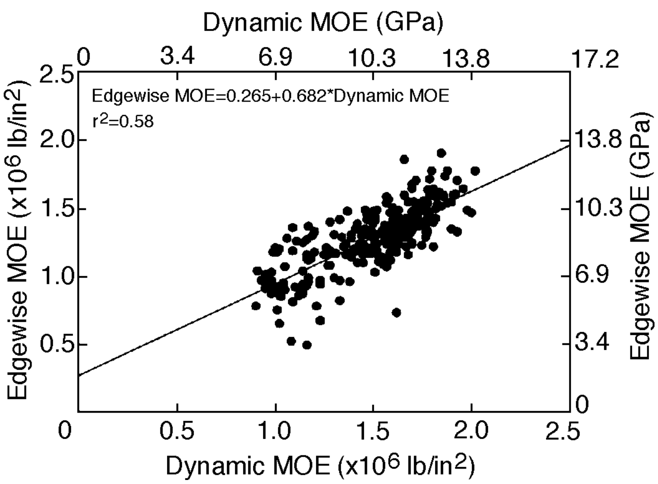


**Figure 3—Relationship between dynamic MOE and edgewise static MOE.**

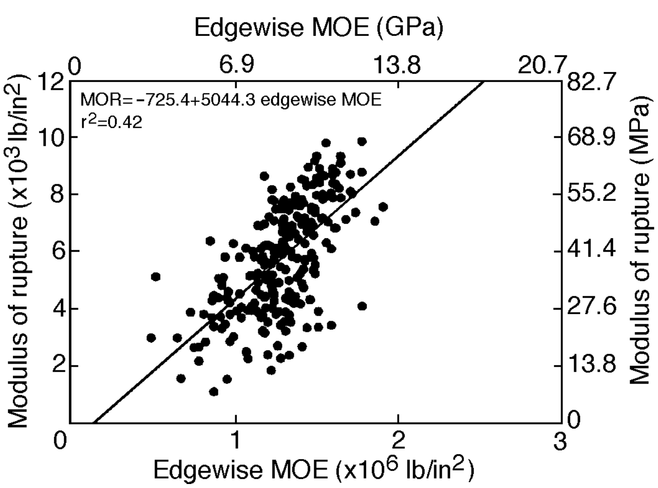


**Figure 4—Relationship of edgewise MOE to MOR.**

satisfactory for the development of machine-stress-rated (MSR) lumber.

## Machine Stress Rating

Machine stress rating (MSR) is a type of machine-graded lumber. Such lumber is evaluated by a machine using a non-destructive test followed by visual grading to limit certain characteristics that the machine cannot detect or may not properly evaluate. This material is often used in demanding engineering applications that require reduced variability and assurance of a particular minimum bending strength level.

The following procedure was used to simulate possible MSR grades. All material that did not meet the No. 2 warp and wane requirements was eliminated. The remaining pieces were ranked by static edgewise MOE. Boundaries were then selected based on 0.82 times the average target MOE. This boundary was shifted upward in cases where, based on this boundary, the average MOE for the remaining test data would have been too low for the target average MOE of the selected grade until the average MOE for the remaining test data was obtained. After the MOE level was established, the pieces that failed to make targeted bending strength values were counted to ensure that the criteria for 5$^{th}$ percentile estimation with 75% tolerance outlined in D2915 (ASTM 1996) were met.

The highest grade possible would most likely be a 1800f–1.5E grade. With this grade, slightly more than 33% of pieces would make a grade of 1800f–1.5E (81 of 243 pieces). Decreasing the strength level to 1650f would not improve the yield because this particular sort was controlled by MOE, not MOR. Visually, this material had a high percentage of small knots. However, the stiffness of this material would probably support only an MSR grade with an associated MOE level of 1.0 GPa ($1.5 \times 10^6$ lb/in$^2$). A second sort indicated that 60% of the material could be placed in a lower grade of 1450f–1.3E (147 of 243 pieces).

# Discussion

The objective of this study was to investigate the structural potential of a hybrid poplar, Wisconsin-5. Results suggest that the material is suitable for construction lumber with properties similar to those of aspen and cottonwood. The use of this material in trusses would most likely be limited to web members because only a small portion of the material had high levels of strength and stiffness. However, the material could be used for light framing applications; in particular, studs of walls. The sample that we obtained came from a relatively open-grown stand and had several large knots. Therefore, there is the potential that even higher grade yields could be obtained from each log if different management techniques were used.

Although the objective of this study was not to conduct a yield study, there were substantial yield differences, nearly 20% between the actual and simulated lumber recoveries. Differences between actual and Best Open Face simulated lumber recovery suggest the potential increases that can be made with more efficient handling of the material. Although there were problems with proper log trim allowances (over and under length), the majority of the lower actual lumber recovery was due to the fact that the study logs in group A were sawn to a 44- by 102-mm (1.75- by 4-in.) size. Better control of log-over-length and lumber width and thickness would increase lumber recovery substantially.

Another observed characteristic of the material harvested was a significant dark brown discoloration of the heartwood (Fig. 5). The drying process moderated this discoloration. This mottled look could be an attractive character mark in paneling or cabinetry.

The wood was very easy to process in the sawmill. Drying was the most difficult aspect of producing the structural lumber. However, when the wood is dried in flitch form, significant improvements can be made in the warp characteristic of the final lumber produced.

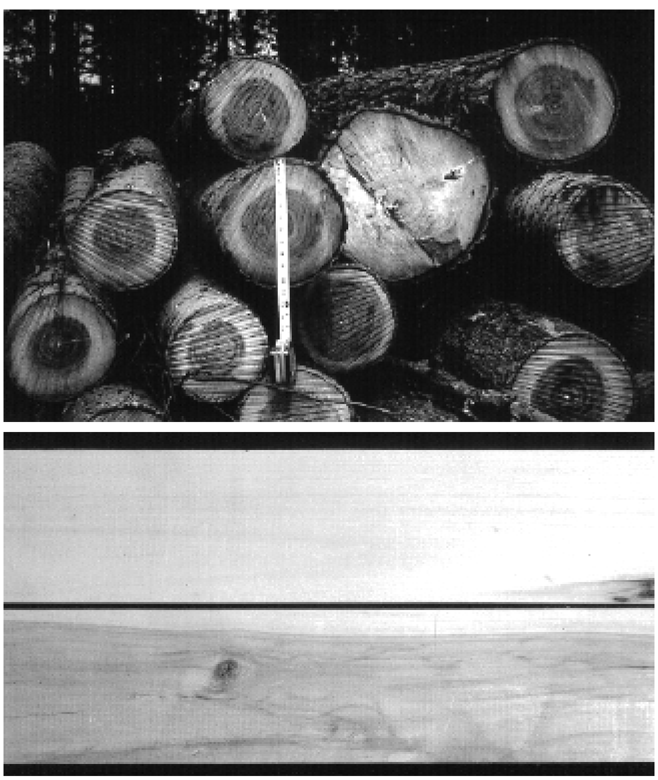

**Figure 5— Discoloration observed in logs (top) and boards (bottom).**

# Conclusions

The following conclusions about Wisconsin-5 hybrid poplar were drawn as a result of this study:

- 65% of this type of sawn material will fall in the visual grades of either Standard and better or No. 2 and better.
- This poplar clone produces visually graded material that is similar in properties and characteristics to current visually graded native aspen and cottonwood.
- 60% of this sawn material will fall in an MSR grade of 1450f–1.3E.
- To avoid excessive degrade as a result of warping during drying, this material should be dried in flitch form.

The application of this type of material for furniture, millwork, and paneling will be investigated. Additional work is needed to determine if some hybrids have less of a discolored core than do other hybrids. In addition, it would be good to test other hybrids and planting density.

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