STRENGTH PROPERTIES OF WOOD RELATED TO TRUNK INJECTION OF TREE GROWTH REGULATORS

by Therese A. Wasniewski, William R. Chaney, Harvey A. Holt and John F. Senft

Abstract. The strength properties of wood discolored by trunk injection of tree growth regulators (TGRs) were investigated. Sections of trunk 60 cm in length were removed from the boles of yellow poplar (*Liriodendron tulipifera*) trees 12 months after injection with *Clipper* or *Cutless* and from blue gum (*Eucalyptus globulus*) 44 months after trunk injection with *Atrinal*. Miniboards (2.5 x 2.5 x 40.6 cm) were cut with a band saw from one trunk section below and two trunk sections above injection sites in yellow poplar. Miniboards were taken only from one trunk section above injection sites in blue gum. Miniboards containing discolored and nondiscolored wood were cut from adjacent areas of the trunk sections of treated trees. Boards also were cut from untreated yellow poplar trees. The miniboards were planed to uniform dimensions and were tested in a Universal Testing Machine configured for beam bending stress on a 35.6 cm span. The stiffness (modulus of elasticity) and the breaking strength (modulus of rupture) of each of 216 samples of yellow poplar and 14 samples of blue gum were determined. Discoloration of yellow poplar and blue gum wood associated with injection of TGRs did not reduce wood strength or elasticity.

The visible disadvantages of trunk injection of tree growth regulators (TGRs) are stains on bark from exudation and holes drilled into the bark. Potentially more critical than these cosmetic problems is the possibility that injection of TGRs may weaken the wood and result in a hazardous tree. Columns of discolored wood that extended both below and above injection sites to a height of 20 ft have been reported in yellow poplar (25, 26), indicating the possibility of detrimental changes in wood properties around injection sites.

The objective in using TGRs is to reduce shoot elongation while minimizing damage to trees and tree related hazards. This study was established to determine if trunk injection of yellow poplar (*Liriodendron tulipifera*) with *Clipper* or *Cutless* and blue gum (*Eucalyptus globulus*) with *Atrinal* would affect the stiffness and breaking strength of the wood.

Two variables commonly used to compare strength properties of wood are modulus of rupture (MOR) and modulus of elasticity (MOE). MOR is the maximum bending strength of the wood. MOE indicates the ability of the wood to recover its original shape and size after stress is removed. The typical relationship between the bending (strain) and the force (stress) applied to the middle of a wooden beam is shown in Figure 1. If the stress applied does not exceed the proportional limit, the relationship of stress to strain is

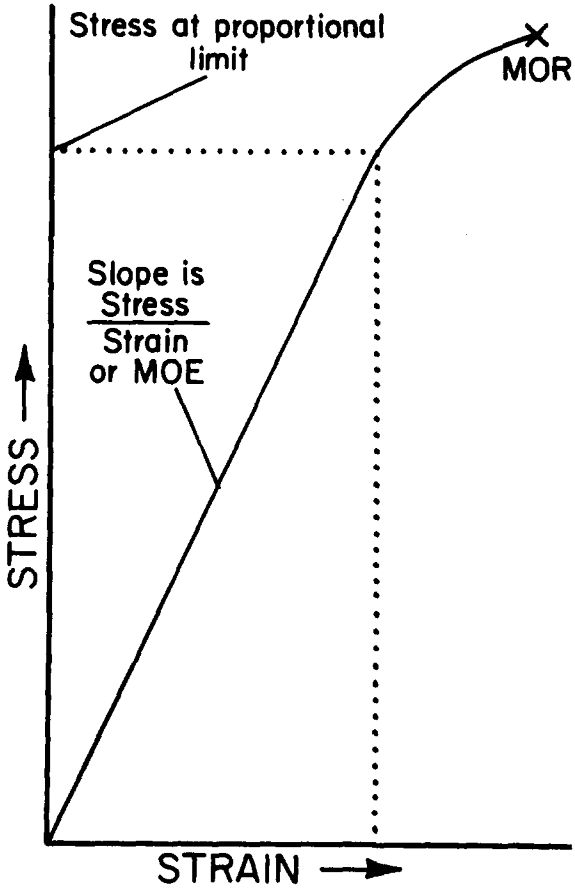

Figure 1. Typical stress-strain curve for wood.

linear and is a constant value, the MOE, expressed in *psi*. Eventually the stress-strain curve levels off and a maximum load occurs followed by beam fracture. It is from this maximum load point that the MOR, expressed in *psi*, is calculated (9).

Materials and Methods

Treatment and harvest. Twelve plantation grown yellow poplar trees in Tippecanoe County, Indiana, ranging from 15 -18 cm (6-7 inches) dbh and 16 - 20 m (45-55 feet) tall were randomly selected for the study. Six of the trees were untreated and six were injected with TGRs on July 1, 1990. Four holes were drilled into each of the six treated trees at the four cardinal directions 0.9 m (3 feet) above ground line. Two of the holes in each tree were injected with 40 ml of Cutless and two were injected with 40 ml of *Clipper* at 60 psi with an Arborchem injector. One year after treatment 6 treated and 6 untreated trees were cut down. The trunks were cut into three 60-cm-long (24 inch) bolts, one below the injection height and two above.

Four blue gums, ranging from 15 - 25 cm (6 - 10 inches) dbh, were cut along a street in Santa Rosa, California with the assistance of a Davey Tree crew in June, 1991. The trees had been trunk injected with *Atrinal* about 15 cm (6 inches) above ground line 44 months earlier on October 24, 1987. Sixty-cm-long (24 inch) trunk sections immediately above the injection sites were collected and shipped to Purdue University.

Miniboard preparation and testing. Miniboards 2.5 x 2.5 x 40.6 cm (1 x 1 x 16 inches) were cut from the sapwood of trunk sections using a band saw and squared to uniform dimensions on a planer. Eight miniboards were cut from each of the three trunk sections of treated yellow poplar. Four of the miniboards contained discolored wood caused by the injection treatment and four contained nondiscolored wood cut from areas adjacent to the discolored zones. Only four miniboards were cut from the three trunk sections of each untreated yellow poplar. A total of 216 miniboards of yellow poplar were prepared for testing. A total of 14 miniboards of nondiscolored wood and wood discolored by *Atrinal* treatment were cut from the four blue gum trees.

All miniboards were tested while green. Percent moisture content was determined after testing by oven drying sections 2.5 x 2.5 x 7.6 cm (1 x 1 x 3 inches) cut from each board near the center at the load site. If moisture content is <25%, a correction factor must be added for calculation of MOE and MOR values. Since moisture content of both species averaged about 70% at the time of testing, no correction factor was necessary.

The bending strength and elasticity of each board were determined. Miniboards were freely supported at both ends and loaded in the center of a 35.6 cm (14 inch) span (Figure 2) with a crosshead speed of 0.127 cm (0.05 inches) per minute. For each board tested, a computer printout was generated at 20 second intervals that listed the amount of load in pounds and the corresponding mid-span deflection in thousandths of an inch as measured with a transducer. From these data MOE and MOR were calculated for each of the 216 samples of yellow poplar and 14 samples of blue gum. Data were analyzed by an analysis of variance using the General Linear Model (GLM) with a 3 x 2 x 2 factorial design for the yellow poplar study and a complete block design for the blue gum study. Mean differences were separated using Student-Newman-Keuls.

MOE and MOR were calculated as follows:

$$MOE = PL^3/48\ ID$$

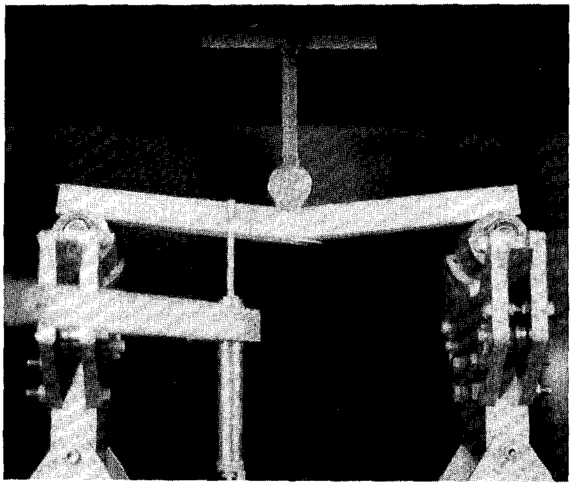

Figure 2. Miniboard in a Universal Testing Machine supported at both ends and loaded in the center of a 35.6 cm span at the point of rupture.

where:
P = the load in pounds (below the proportional limit)
L = the distance between supports (span) in inches
I = *moment of inertia, a function of beam size* ((Width x depth ^{3})/12 for beams with a rectangular cross section; units are inches^4)
D = the deflection at midspan in inches resulting from P

$$MOR = 1.5PL/bd^2$$

where:
P = the breaking (maximum) load in pounds
L = the distance between supports (span) in inches
b = the width of the beam in inches
d = the depth of the beam in inches

Results

Data for the miniboards taken from untreated yellow poplar trees were used as a baseline for differences in MOE and MOR. No statistical difference in strength properties was found associated with the north, south, east or west directional orientation of the wood within the tree, but a difference was found associated with height above the ground. Boards taken from the section closest to the ground were less stiff than boards from the two sections above it as indicated by the lower average MOE value (Table 1). Average MOR for boards from the trunk sections closest to the ground was higher than that for those from the sections furthest from the ground (Table 1).

When nondiscolored boards from trunk injected yellow poplar trees were tested, a difference due to height was found for MOE that was the same as that found for untreated trees. No differences in MOR occurred (Table 2).

No differences in strength properties of yellow poplar wood discolored in response to injections of *Cutless* or *Clipper* were found (Table 3). Consequently, these values were combined in subsequent analyses.

Average MOE for yellow poplar wood discolored by injection with TGRs was lower below the injection sites than above (Table 4). The same pattern was found for wood of untreated trees (Table 1) and for nondiscolored wood taken from treated trees (Table 2). Average MOR of discolored yellow poplar wood did not vary with height (Table 4) just as was found for nondiscolored wood in TGR treated trees (Table 2).

When the results for the three heights were combined and the three types of boards cut from yellow poplar were compared, there was no difference in MOE or MOR between wood from untreated trees, nondiscolored wood from trees injected with TGRs, and wood discolored by injection treatment (Table 5).

No significant differences in MOE or MOR

Table 1. Effect of height in the trunk on modulus of elasticity (MOE) and modulus of rupture (MOR) of miniboards taken from untreated yellow poplar trees.

Height above ground (cm)	MOE (x 10^6 psi)	MOR (psi)
0-60	0.86 a*	7,268 a
75-135	0.96 b	7,016 ab
135-195	0.95 b	6,764 b

* Values in columns followed by the same letter are not significantly different at 5%.

Table 2. Effect of height in the trunk on modulus of elasticity (MOE) and modulus of rupture (MOR) of nondiscolored miniboards taken from trunk injected yellow poplar trees.

Height above ground (cm)	MOE (x 10^6 psi)	MOR (psi)
0-60	0.79 a*	7,061 a
75-135	0.87 b	6,887 a
135-195	0.86 b	6,534 a

*Values in columns followed by the same letter are not significantly different at 5%.

Table 3. Modulus of elasticity (MOE) and modulus of rupture (MOR) of miniboards containing discolored wood taken from yellow poplar trunks injected with Cutless and Clipper.

Injection treatment	MOE (x 10^6 psi)	MOR (psi)
Cutless	0.81 a*	6,148 a
Clipper	0.80 a	6,467 a

*Values in columns followed by the same letter are not significantly different at 5%.

Table 4. Effect of height in the trunk on modulus of elasticity (MOE) and modulus of rupture (MOR) of miniboards containing discolored wood taken from yellow poplar trunk injected with Cutless and Clipper.

Height above ground (cm)	MOE (x 10^6 psi)	MOR (psi)
0-60	0.73 a*	6,429 a
75-135	0.86 b	6,217 a
135-195	0.82 b	6,263 a

*Values in columns followed by the same letter are not significantly different at 5%.

Table 5. Modulus of elasticity (MOE) and modulus of rupture (MOR) of miniboards from untreated yellow poplar trees, nondiscolored wood from growth regulator treated trees, and discolored wood from growth regulator treated trees.

Miniboard type	MOE (x 10^6 psi)	MOR (psi)
Untreated	0.92 a*	7,016 a
Nondiscolored/Treated	0.84 a	6,851 a
Discolored/Treated	0.80 a	6,307 a

*Values in columns followed by the same letter are not significantly different at 5%.

Table 6. Modulus of elasticity (MOE) and modulus of rupture (MOR) of miniboards cut from blue gum containing nondiscolored wood and wood discolored by trunk injection with *Atrinal*.

Miniboard type	MOE (x 10^6 psi)	MOR (psi)
Nondiscolored wood	0.63 a*	6,142 a
Discolored wood	0.56 a	5,807 a

*Values in columns followed by the same letter are not significantly different at 5%.

were found between nondiscolored wood and discolored wood of blue gum (Table 6).

Discussion

Discoloration and decay of wood in trees is of interest to urban foresters for reasons different from those for foresters interested in the use of products derived from wood. The wood-using industry is concerned about the quality of their product, whereas urban/utility foresters are concerned about the strength of standing trees and the potential hazards they pose.

Wood discoloration occurs in response to wounds caused by injection of TGRs, fungicides, insecticides, pruning, maple tapping, increment boring, and sapsucker damage (2,4,8,11,12,16,18, 19,20,21,24). Shigo (20) emphasized that all discolored wood does not develop into decomposed wood, but decomposing wood in living trees develops within the boundaries of discolored wood. Similar populations of fungi, bacteria, or both have been found in discolored and clear wood of yellow poplar, sweetgum, nuttall oak, green ash, sugarberry, and eastern cottonwood (15,21,23). Even though microorganisms have been found in discolored wood, it is generally agreed that discolored wood is primarily physiological in origin.

There are three categories of stains in wood (14): 1) mineral stains, 2) oxidative stains, and 3) chemical stains. The olive to greenish-black discolorations known as mineral stain that may occur in wood of hardwoods are traceable to crystalline inclusions in the lumen of the xylem cells. They are composed of various minerals in association with carbonates dispersed among noncrystalline phenolic substances. Mia (13) found no damage to the cells walls in cells containing these inclusions.

Sapwood of all trees contains organic compounds as well as oxidizing enzymes. When temperature and moisture conditions are favorable, action of enzymes may produce substances causing discolorations in the wood. These discolorations are oxidative stains and may vary in color from shades of yellow, grey, green, and orange to brown. This type of stain develops in both softwoods and hardwoods, and does not affect the strength of wood (14). In response to tapping wounds in sugar maple, phenolics are released from cells. Oxidation causes discoloration of woody tissue, and the compounds formed, quinones, inhibit the growth of invading microorganisms (1).

The most common of the chemical stains is produced by a reaction between wood containing tannins and iron. The result is a blue-black compound resembling ink stain. It has been suggested that formation of iron tannates may reduce decay resistance of wood by removing some fungitoxic chemical protection.

The majority of strength testing on discolored wood was done in the late 1930's and early 1940's with a small amount performed in the late 1970's. Most of this research dealt with "blue stain" related to beetle killed southern pines. Overall, most discolored wood showed a decrease in strength but not enough to be of practical significance (3,6,7,10,12,14,22).

There also has been some research on strength of wood discolored by increment boring. Lorenz (12) found no difference in static bending and compression tests between clear and discolored wood caused by increment boring in birch trees. Hepting et al. (10) found mineral stained yellow poplar veneer to be just as strong as normal colored heartwood and sapwood. However, Scheffer (17) found that during seasoning of hardwoods, stained wood had a pronounced tendency to crack open along areas where the discoloration was deepest.

Although discolored wood does not always lead to decay, the question arises whether discolored wood is more susceptible to decay. Findlay (5) found that stained sapwood of Scotch pine was slightly more susceptible to decay by *Merulius lacrymoans, Poria vailliatii,* and *Coniophora cerebella* but not significantly enough to be of practical importance. Contrary to widespread notion, there is no conclusive evidence that discolored wood is more susceptible to decay than unstained wood (14).

Although there was no statistical difference between MOE and MOR values of the three types of boards tested in this study, there was a trend in both values for the untreated and nondiscolored boards to have the highest values and the discolored boards to have the lowest in both yellow poplar and blue gum (Tables 5 and 6). Whether these results represent random variation or a trend that would eventually result in significant differenes in strength properties of discolored and nondiscolored wood over a longer period of time is unknown and impossible to predict from results of this study. Long-term investigation of the relationship of trunk injection to discoloration and physical properties of wood is needed.

Although the only boards to have a difference in MOR due to height were the boards from untreated yellow poplar trees (Table 1), this difference occurs naturally and was expected. Long fiber cells result in stronger wood than short fibers. Long fiber cells exist in older wood which occurs in a greater proportion lower on a tree trunk making the wood nearest the ground naturally stronger (5).

A difference in MOE values due to height that was opposite to that for MOR was found in all three types of yellow poplar boards (Tables 1, 2, and 4), i.e., elasticity increased with height. This difference does not follow the naturally occurring pattern described above. We have no explanation for this result.

Conclusions

The following conclusions can be drawn from this investigation:

1) Strength properties of wood of yellow poplar discolored by trunk injection of TGRs were not significantly different than those of wood from untreated trees and nondiscolored wood of treated trees one year after injection treatment.

2) No difference was found in wood strength or elasticity between yellow poplar wood discolored by injection with *Clipper* or *Clipper.*

3) Strength properties of wood of blue gum discolored by trunk injection of *Atrinal* were not significantly different than those of nondiscolored wood 3.7 years after treatment.

4) No difference was found in wood strength or elasticity associated with the north, south, east, or west orientation in the tree trunk.

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Department of Forestry and Natural Resources
Purdue University
West Lafayette, IN 47907

Résumé. Les propriétés de résistance du bois décoloré par l'injection dans le tronc de régulateurs de croissance ont été étudiées. Des sections de bois ont été prélevées du tronc de tulipiers (*Liriodendron tulipifera*) et d'eucalyptus globuleux (*Eucalyptus globulus*) un an ou plus après l'injection avec le Clipper et/ou le Cutless. Des planchettes de bois décoloré et de bois non décoloré ont été découpées des zones adjacentes de sections de troncs d'arbres traités et d'arbres non traités. Les planchettes ont été planées afin d'uniformiser les dimensions et ont été ensuite testées dans une machine à tester universelle. La rigidité (module d'élasticité) et la résistance à la cassure (module de rupture) de chacun des 216 échantillons de tulipier et des 14 d'eucalyptus ont été évaluées et comparées. Les différences n'ayant pas été significatives, cela indique alors que, sous les conditions de cette étude, l'injection de régulateur de croissance n'affecte pas la résistance ou l'élasticité du bois et ne rehausse donc pas le potentiel de danger associé à rupture du tronc.

Zusammenfassung. Die Krafteigenschaften von Holz, welches durch Stamminjektionen mit Wachstums-regulatoren verfäbt wurde, wurden untersucht. Es wurden nach einer Behandlung mit Clipper u./o. Cutless ein bis mehrere Jahre anschließend Stammabschnitte von Tulpenbaum (*Liriodendron tulipifera*) und Eukalyptus (*Eucalyptus globulus*) entfernt. Kleine Bretter wurden aus dem verfärbten und dem benachbarten unverfärbten Holz der behandelten und von unbehandelten Bäumen geschnitten. Die Bretter wurden auf gleiche Form gehobelt und anschließend in einer 'Universal Testing Machine' getestet. Die Steifheit (Modul der Elastizität) und die Brechstärke (Modul der Brüchigkeit) aller 216 Holzproben vom Tulpenbaum und von 14 Eukalyptusproben wurden bestimmt und verglichen. Die Unterschiede waren nicht signifikant. Daraus wird geschloßen, daß, unter den Bedingungen dieser Studie, die Injektionen mit Baumwach-stumsregulatoren weder die Stärke noch die Elastizität des Holzes reduziert und auch die mit der Brüchigkeit des Stammes verbundene Gefährdung nicht erhöht wird.