NOTES AND CORRESPONDENCE

This section of the journal is available for wood scientists and technologists to publish technical notes and accounts of work in progress, as well as to discuss matters of education and professional development. In general, such material should be limited to no more than six double-spaced typewritten pages. Where applicable, contributions should appear in the approved style for technical articles in *Wood and Fiber*.

Readers are invited to submit discussions of articles that appear in *Wood and Fiber* for publication in this section. Any individual who wishes to discuss an article should submit his comments (in duplicate) soon after publication of the article. The paper being reviewed should be identified by title, author, and date of publication.

No discussion will be published unless the author of the original article has been provided with a copy of the discussion and has had an opportunity to submit a reply to the Editor, to be published with the discussion. Discussions and replies should not exceed the length suggested above. Where pertinent, references to the literature should be included.

It is anticipated that discussion and replies in *Wood and Fiber* can add, for both authors and readers, a dimension not normally found in technical journals.

Physical and Mechanical Properties of the Wood of Tree-of-Heaven[1]

The Tree-of-Heaven (*Ailanthus altissima* Mill.) is found in increasing quantities in central and Appalachian regions of the United States, particularly on strip mine land. Some of the pulp mills in these areas and as far south as Texas frequently receive shipments of this species as pulpwood. In the last two years, a number of inquiries have been made to the authors by various forest products firms regarding information which might be available on pulping as well as solid wood properties. However, no systematic attempts have been made in the United States to determine the wood properties. This is perhaps because of the scattered quantities available for industrial use and because this tree species is regarded as a "weed" by some foresters who believe that it overtakes the native species. The fact remains, however, that since its introduction in the early part of the nineteenth century, the Tree-of-Heaven has not taken over in

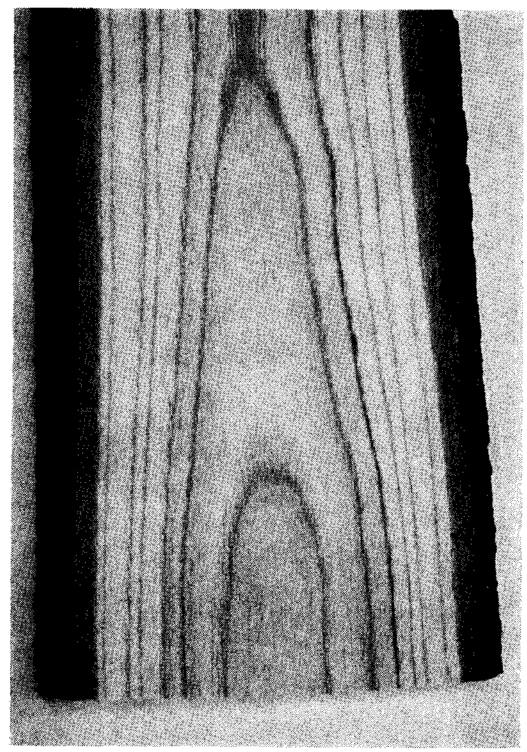

FIG. 1. A flat-sawn piece of the wood of Tree-of-Heaven.

[1] This study was financially supported by the North Central Forest Experiment Station, Forest Service, USDA. All mechanical tests were performed at the U. S. Forest Products Laboratory, Madison, Wisconsin.

TABLE 1. *Size and number of specimens for various tests*

Type of test	Specimen size (inches)	Number of specimens per bolt		Number of specimens per location		Total number of specimens	
		Green	12% M.C.	Green	12% M.C.	Green	12% M.C.
Specific gravity	$2 \times 2 \times 6$	–	4	–	20	–	60
Volume shrinkage	$1 \times 1 \times 6$	–	4	–	20	–	60
Static bending	$1 \times 1 \times 16$	4	4	20	20	60	60
Comp. parallel to grain	$1 \times 1 \times 4$	4	4	20	20	60	60
Comp. perpend. to grain	$2 \times 2 \times 6$	2	2	10	10	30	30
Impact bending	$2 \times 2 \times 30$	1	1	5	5	15	15
Shear parallel to grain	$2 \times 2 \times 2.5$	4	4	20	20	60	60
Toughness	$.79 \times .79 \times 11$	8	8	40	40	120	120
Hardness	$2 \times 2 \times 6$	2	2	10	10	30	30

TABLE 2. *Average values for the strength and dimensional properties of the wood of* Ailanthus altissima *Mill.*

Property		Moisture content: Green	Moisture content: 12% M.C.
Specific gravity		–	0.531
Volume shrinkage		–	10.81
Static bending (psi)	Modulus of elasticity	0.92×10^6	1.52×10^6
	Fiber stress at prop. limit	2124	5135
	Modulus of rupture	5997	11800
Compression parallel to grain (psi)	Modulus of elasticity	2.2×10^6	3.3×10^6
	Fiber stress at prop. limit	882.4	2834.8
	Maximum stress	2400.3	5265.8
Compression perpendicular to grain (psi)	Modulus of elasticity	0.60×10^6	1.61×10^6
	Fiber stress at prop. limit	381.0	1128.40
	Maximum stress	942.0	2201.9
Shear parallel to grain Maximum shear strength (psi)		1047.0	2241.6
Impact bending Maximum height of drop (inches)		30.4	38.6
Toughness (in–lb)		230.4	72.2
Hardness (lbs)	End	739.7	2165.5
	Tangential	723.4	1537.5
	Radial	701.4	1731.4

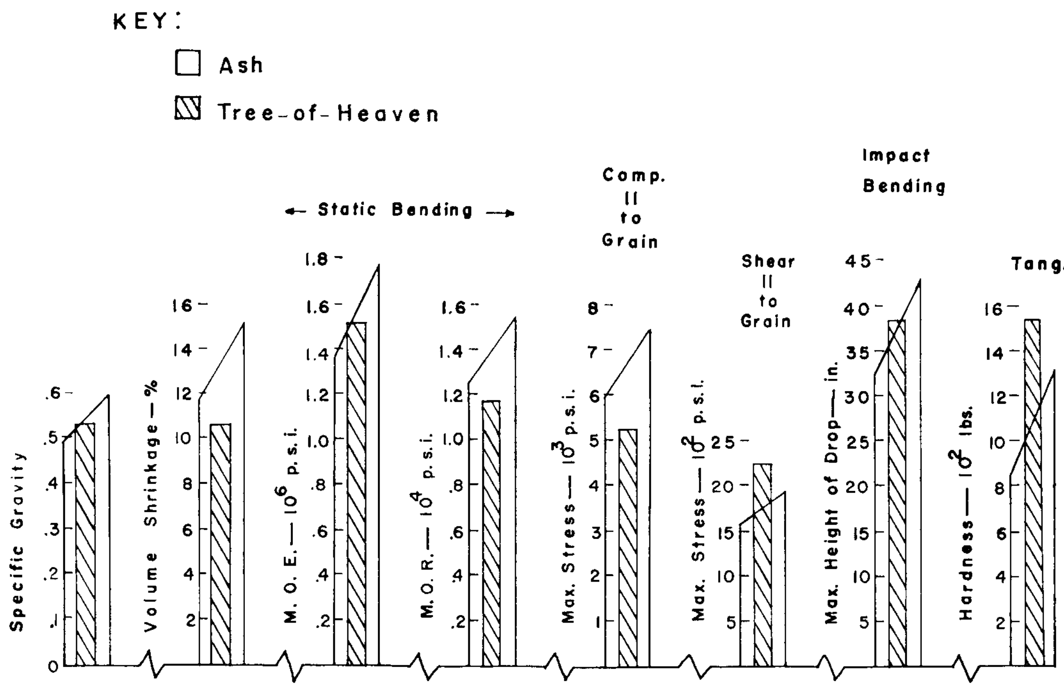

FIG. 2. A comparative bar diagram between the properties of the wood of Tree-of-Heaven and various species of ash.

any significant way in our hardwood forests.

The Tree-of-Heaven (also referred to as ailanthus) is a native of China and was reportedly brought to this county by a Pennsylvania nobleman around 1840 (Davies 1942; Rawling and Staidl 1924). It is a reasonably fast-growing species with trees reaching some 40 ft in height and a diameter of 6 inches in 10–15 years (Rawling and Staidl 1924). It can thrive under adverse conditions such as poor soil, minimal rainfall, and high air pollution (Adamik 1955; Adamik and Brauns 1957; Davies 1942; Narayanamurti and Singh 1962). The wood is ring-porous and displays attractive patterns when processed (Fig. 1). The natural color of the wood is very light yellow with occasional orange streaks.

The Tree-of-Heaven has received considerable attention around the world, particularly in arid regions. In the Far East, this species, as well as its close relatives such as *A. excelsa* Roxb. and *A. grandis* Roxb., is being used as a wood resource. Europeans as well as Asians have found the wood satisfactory for pulp production (Adamik 1955; Adamik and Brauns 1957; Guha and Madan 1965; Guha and Pant 1961). Particleboard and hardboard have been made successfully from it (Narayanamurti and Singh 1962).

As the demand for wood products continues to rise to the year 2000 (Timber Trends 1965; Zivnuska 1966) and perhaps beyond, and as wood-producing forests become more and more limited to subagricultural land, the need for fast-growing trees that thrive on poor soil becomes obvious.

PURPOSE OF STUDY

The purpose of this study was to provide basic information on wood properties of Tree-of-Heaven grown in the United States. This paper deals with the results of a series of physical and mechanical tests performed at two levels of moisture content (green and 12%). The physical properties included specific gravity and volumetric shrinkage, while the mechanical tests involved static bending, impact bending, compression parallel and perpendicular to the grain, shear parallel to the grain, toughness, and hardness.

PROCEDURE

Fifteen trees from three states (Missouri, Illinois, and Ohio) were secured, with each location providing five trees. The trees ranged from a DBH of 10 to 24 inches, with Illinois supplying most of the smaller logs and Missouri providing most of the larger logs. The Missouri trees were grown in the city of St. Louis, Illinois trees were cut in Williamson County, and Ohio trees came from Muskingum County.

The bolt selection within each tree followed a procedure set forth by Krahmer and Snodgrass (1967). Table 1 lists the size and the number of specimens cut for each test. ASTM standards (1966) were followed in all tests. The analysis of variance was performed on all data to determine the significance of variations due to moisture content, geographic locations, and the specimen location within the height of trees.

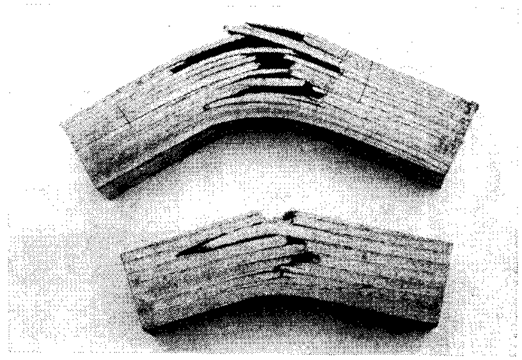

Fig. 3. Mode of failure in bending.

RESULTS

The results for all tests, regardless of geographic location and location within trees, are presented in Table 2. It is noted that the wood of ailanthus with a specific gravity of 0.531 can be considered a medium-density species whose properties are very similar to other wood species of this density range. Casual observers often compare the wood of Tree-of-Heaven with

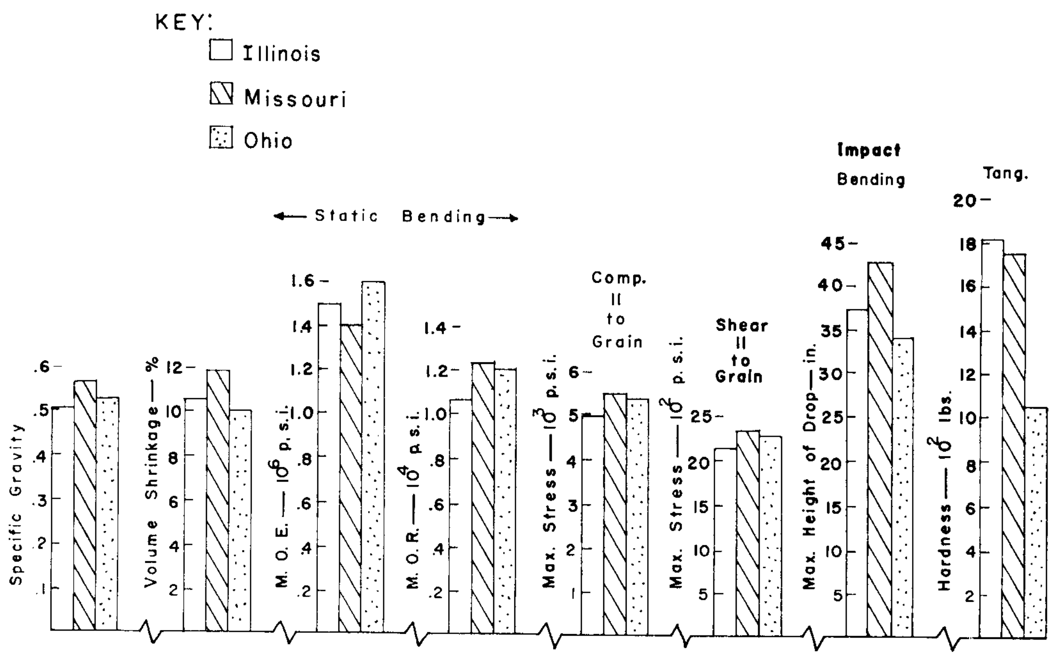

Fig. 4. The influence of location on some of the properties tested.

those of various species of ash (*Fraxinus* spp.). Figure 2 makes this comparison according to our data (for ailanthus) and other data (for ashes) published elsewhere (Wood Handbook 1955). It is noted that in many respects there is a basic similarity. However, in some properties (such as hardness or shear parallel to the grain) the wood of Tree-of-Heaven exhibits superior qualities while in others (such as modulus of rupture or in compression parallel to the grain), it yields somewhat lower values. This is probably due to the relatively large and numerous springwood pores in ailanthus, which essentially create layers of weakness within the wood (Fig. 3).

The influence of moisture content and geographic location upon the various wood properties determined was significant at 0.01 level, while no statistical significance was obtained for the location within trees. The effect of location on the data is presented in Fig. 4. Wood grown within the city of St. Louis yielded high bending strength, compression strength, shear impact bending, and toughness—presumably because of its higher specific gravity. No attempt will be made here to explain why the city-grown wood had higher specific gravity since no clear answer appears at the moment. Possibly this species responds significantly to certain environmental factors that are present within a city and are subsequently reflected in the quality of the wood.

CONCLUSIONS

From the evidence presented in this paper, clear, straight-grained wood of Tree-of-Heaven appears to be similar to many of our native medium-density hardwoods with respect to important physical and mechanical properties. Furthermore, increases in the mechanical strength values that take place upon drying are among the highest observed in woods grown in the United States. Both flat- and quarter-sawn boards display attractive grain patterns, making it possible to use this species for such applications as face veneers for furniture and paneling. In separate preliminary trials of industrial properties such as seasoning, machining, gluing, and finishing (not reported in this paper), ailanthus wood was satisfactory, with the possible exception of seasoning. This wood appears to have refractory tendencies because of a certain amount of tension wood present in the logs. Such industrial properties should be studied thoroughly before any firm statements regarding the commercial utility of the wood of Tree-of-Heaven can be made. Moreover, studies on the fiber morphology and the pulping properties of this naturalized wood species would be of benefit to the fiber and cellulose industries.

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Note on a Paper by Schniewind and Barrett "Cell Wall Model with Complete Shear Restraint"[1]

The basic concept of the determination of compliances for a cell wall in Schniewind and Barrett's paper (1969) is based on two assumptions: (1) Normal stresses cause no shear strains, and (2) shear stresses do not lead to normal strains. They made those assumptions without proof, which may leave some doubt in the minds of their readers. This note, however, proves that their assumptions are acceptable.

Consider an anisotropic plate subjected to uniform tension T_1, T_2. Then, the strains are

$$\begin{aligned} \epsilon_1 &= S_{11}T_1 + S_{12}T_2, \\ \epsilon_2 &= S_{12}T_1 + S_{22}T_2, \\ \gamma_{12} &= S_{16}T_1 + S_{26}T_2. \end{aligned} \quad (1)$$

According to Schniewind and Schniewind and Barrett (1969, 1969) there is no shear strain in a combined double cell wall under tension. Since T_1, T_2 are arbitrary, zero shear strain requires that

$$S_{16} = S_{26} = 0.$$

If this is true, it can be concluded that the double cell wall behaves orthotropically. Now consider the same plate subjected to a shear T_3 only. One has for this case

$$\begin{aligned} \epsilon_1 &= S_{16}T_3, \\ \epsilon_2 &= S_{26}T_3, \\ \gamma_{12} &= S_{66}T_3. \end{aligned} \quad (2)$$

Since the double cell wall is orthotropic (i.e., $S_{16} = S_{26} = 0$) when it is subjected to a shear T_3, one obtains:

$$\begin{aligned} \epsilon_1 &= 0, \\ \epsilon_2 &= 0, \\ \gamma_{12} &= S_{66}T_3. \end{aligned}$$

This must be true for all layers in the cell wall, since S_{16}, S_{26}, S_{12}, S_{11}, S_{22}, and S_{66} are all non-zero in each layer. The stress-strain relations are:

$$\begin{aligned} \epsilon^l_1 &= S^l_{11}\sigma^l_{11} + S^l_{12}\sigma^l_{22} + S^l_{16}\sigma^l_{12}, \\ \epsilon^l_2 &= S^l_{12}\sigma^l_{11} + S^l_{22}\sigma^l_{22} + S^l_{26}\sigma^l_{12}, \\ \gamma^l_{12} &= S^l_{16}\sigma^l_{11} + S^l_{26}\sigma^l_{22} + S^l_{66}\sigma^l_{12}, \end{aligned} \quad (3)$$

where the superscript l indicates a particular layer. The normal strains ϵ^l_1, ϵ^l_2 vanish if the normal stresses take the following form:

$$\begin{aligned} \sigma^l_{11} &= \frac{S^l_{16}S^l_{22} - S^l_{12}S^l_{26}}{S^l_{11}S^l_{22} - (S^l_{12})^2}\sigma^l_{12}, \\ \sigma^l_{22} &= \frac{S^l_{11}S^l_{26} - S^l_{12}S^l_{16}}{S^l_{11}S^l_{22} - (S^l_{12})^2}\sigma^l_{12}. \end{aligned} \quad (4)$$

Substitution of (4) into the third of (3) leads to:

$$\gamma^l_{12} = \{S^l_{16}\frac{S^l_{16}S^l_{22} - S^l_{12}S^l_{26}}{S^l_{11}S^l_{22} - (S^l_{12})^2} + S^l_{26}\frac{S^l_{11}S^l_{26} - S^l_{12}S^l_{16}}{S^l_{11}S^l_{22} - (S^l_{12})^2} + S^l_{66}\}\sigma^l_{12}. \quad (5)$$

This is equivalent to a cell wall subjected to a shear force only. As is known, for a two-dimensional layered elastic system, the stresses are additive and strains are identical; that is,

$$\begin{aligned} \sigma^c_{ij} &= \sum_{l=1}^{n} f_l\sigma^l_{ij} \\ \epsilon^c_i &= \epsilon^l_i \qquad (i, j = 1, 2) \\ \gamma^c_{ij} &= \gamma^l_{ij}, \end{aligned} \quad (6)$$

where f_l denotes the volume fractions of layers, and $\sum_{l=1}^{n} f_l = 1$; superscript c is used to denote average quantities of stress and strain for the cell wall. It follows from (5) and (6) that

$$S^c_{66} = \frac{A^l_{66}}{\sum_{l=1}^{n} f_l}, \quad (7)$$

[1] The author is indebted to the Kentucky Agricultural Experiment Station for support, and to Dr. R. E. Mark for encouragement in this study. The investigation reported in this paper (No. 69-8-115) is in connection with a project of the Kentucky Agricultural Experiment Station, and the paper is published with permission of the Director.

where

$$A^l_{66} = \frac{S^l_{22}(S^l_{16})^2 - 2S^l_{12}S^l_{16}S^l_{26} + S^l_{11}(S^l_{26})^2}{S^l_{11}S^l_{22} - (S^l_{12})^2} + S^l_{66}.$$

When a cell wall is subjected to tensile stresses σ_{11} and σ_{22}, then in this case one has

$$\begin{aligned} \epsilon^c_1 &= S^c_{11}\sigma^c_{11} + S^c_{12}\sigma^c_{22}, \\ \epsilon^c_2 &= S^c_{12}\sigma^c_{11} + S^c_{22}\sigma^c_{22}, \\ \gamma^c_{12} &= 0. \end{aligned} \quad (8)$$

Again, this must be true for all layers in the cell wall, since the elastic compliances S_{16}, S_{26}, S_{12}, S_{11}, S_{22} and S_{66} are all non-zero in each layer; then, the shear strain γ^l_{12} vanishes if the shear stress takes the following form:

$$\sigma^l_{12} = -(1/S^l_{66})(S^l_{16}\sigma^l_{11} + S^l_{26}\sigma^l_{22}). \quad (9)$$

Substitution of (9) into (3) leads to:

$$\begin{aligned} \epsilon^l_1 &= \{S^l_{11} - [(S^l_{16})^2/S^l_{66}]\}\sigma^l_{11} \\ &\quad + [S^l_{12} - (S^l_{16}S^l_{26}/S^l_{66})]\sigma^l_{22}, \\ \epsilon^l_2 &= [S^l_{12} - (S^l_{16}S^l_{26}/S^l_{66})]\sigma^l_{11} \\ &\quad + \{S^l_{22} - [(S^l_{26})^2/S^l_{66}]\}\sigma^l_{12}, \\ \gamma^l_{12} &= 0. \end{aligned} \quad (10)$$

This is equivalent to the system (8); by setting $\sigma_{22} = 0$ in (8) and (10), and using the relations (6), one obtains:

$$S^c_{11} = A^l_{11}/\sum_{l=1}^{n} f_l, \quad S^c_{12} = A^l_{12}/\sum_{l=1}^{n} f_l, \quad (11)$$

where

$$A^l_{11} = S^l_{11} - \frac{(S^l_{16})^2}{S^l_{66}}, \quad A^l_{12} = S^l_{12} - \frac{S^l_{16}S^l_{26}}{S^l_{66}}.$$

Similarly, setting $\sigma_{11} = 0$ in (8) and (10) gives

$$S^c_{22} = A^l_{22}/\sum_{l=1}^{n} f_l, \quad (12)$$

where

$$A^l_{22} = S^l_{22} - [(S^l_{26})^2/S^l_{66}].$$

From the above argument, one can conclude that Schniewind and Barrett's assumptions are acceptable.

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Schniewind, A. P., and J. D. Barrett. 1969. "Cell wall model with complete shear restraint." Wood and Fiber, **1**: 205–214.

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Authors' Reply to Comments by R. C. Tang on "Cell Wall Model with Complete Shear Restraint"

Contrary to R. C. Tang's suggestion, we did not "assume" orthotropic elasticity for the double cell wall with the principal directions parallel and perpendicular, respectively, to the cell axis, which then leads to absence of shear strains due to normal stresses and to absence of normal strains due to shear stresses. This relationship is rather a direct consequence of the assumption that the double cell wall deforms as a unit, with the further provision that specific layers of the double cell wall occur in pairs of equal thickness and microfibrillar angles of equal magnitude but opposite sign. The same assumption regarding deformation was stated as fact by R. C. Tang and is commonly made in dealing with layered systems.

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