Property Relationships for Tropical Hardwoods

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Abstract

Physical and mechanical properties were obtained for two species of lumber–Ramon *(Brosimum alicastrum)* and Danto *(Vatairea lundellii)* –obtained from northern Guatemala. Full-sized tests were conducted in bending and in tension and compression parallel to grain following procedures of the American Society for Testing and Materials (ASTM). With one exception, property relationships were found to follow the same trends obtained in previous studies for temperate softwoods and hardwoods. However, the compression strength parallel to grain of the Danto lumber did not follow the expected relationship with modulus of rupture because of extensive interlocked grain. Recommendations are given for estimating compression and tensile strength from bending strength in the absence of test data. A significant relationship was found between bending strength and stiffness, but the coefficient of determination was less than might be anticipated.

Keywords : *Brosimum alicastrum, Vatairea lundellii,* 2×4, bending, tension parallel to grain, compression parallel to grain.

During the last few years the Forest Products Laboratory has been involved in a project to study the properties and grading of lumber for species growing in Guatemala. This research initially focused on the properties of pines (Rosales et al. 1995; Resales et al. in preparation). We are currently studying tropical hardwood species (Resales and Green, in preparation). Neither Guatemala nor the United States has procedures to assign allowable engineering properties to tropical hardwoods. The objective of the current research is to establish the technical background needed to grade and assign allowable properties to tropical hardwood species for possible application in either country.

The objective of this paper is to present information on the relationships between modulus of elasticity (MOE) in bending and modulus of rupture (MOR) in bending, and between strength in bending and compression or tension parallel to grain. A general discussion of grading options will be addressed in a later paper.

Background

Property Relationships

Relationships between lumber properties are used extensively in deriving allowable engineering design properties for lumber (Green and Kretschmann 1991). For example, the relationship between MOE and MOR forms the basis for sorting most machine-stress-rated (MSR) lumber. These relationships are also used to estimate untested properties when it is not possible, or economically justified, to conduct tests in all failure modes. In the United States, the ultimate compression stress (UCS) parallel to grain of MSR lumber is estimated from MOR using the following formula (Green et al. 1995):

$$UCS/MOR = 2.061(1/MOR) + 0.3376 \quad \text{if } MOR \geq 2.835 \times 10^3 \text{ in}^2 \ (\geq 19.55 \text{ MPa}) \qquad (1)$$

or

$$UCS/MOR = 1.06 \quad \text{if } MOR < 2.835 \times 10^3 \text{ in}^2 \ (< 19.55 \text{ MPa})$$

The UCS value is divided by the appropriate general adjustment factor to convert it into an allowable property (ASTM D 245; ASTM 1991).

For visually graded lumber tested full size, ASTM D 1990 (ASTM 1991) uses a more conservative procedure

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to estimate UCS for species not tested in compression parallel to grain:

$$UCS/MOR = 1.55 - 0.32\ MOR + (0.022 \times MOR^2) \quad (2)$$
$$\text{if } MOR \leq 7.2 \times 10^3\ in^2\ (\leq 49.6\ MPa)$$

$$UCS/MOR = 0.40$$
$$\text{if } MOR > 7.2 \times 10^3\ in^2\ (> 49.6\ MPa)$$

For visually graded lumber it is also possible to make a conservative estimate of ultimate tensile strength (UTS) parallel to grain if the species is only tested in bending (ASTM D 1990; ASTM 1991):

$$UTS/MOR = 0.45 \quad (3)$$

Similar relationships are extensively used in other countries to derive allowable properties for structural lumber (Green and Kretschmann 1989). Thus, understanding the relationships between lumber properties is essential when applying existing engineering design standards to new species.

General Description of Hardwoods Tested

Approximately 300 species of trees grow in the tropical forests of northern Guatemala and southern Mexico. With the exception of two groups, mahogany and cedar, these species have little commercial value. Without commercial value there is little incentive to maintaining the land as forests. In addition, Guatemala has a need for materials for housing that could be partly satisfied by using its native species. These concerns led to an effort to evaluate structural grading procedures for these hardwood species. Using information provided by USAID, we selected two species that were among the top 15 species in terms of standing timber volume and that were either naturally durable or treatable with preservatives. The selected species were Ramon *(Brosimum alicastrum)* and Danto *(Vatairea lundellii).*

Ramon and related species of *Brosimum* are found in southern Mexico, through Central America, and southward into the Peruvian Amazon (Chudnoff 1984). Individual trees reach a height of 36.6 m (120 ft), with straight cylindrical boles clear to 22.9 m (75 ft). Diameters may reach 1,000 mm (40 in.). Both heartwood and sapwood are a uniform yellowish white. The wood texture is fine to medium. The grain is often straight, but occasionally irregular to shallowly interlocked. Durability is low and the wood is reported to be moderately resistant to treatment (Echenique–Manrique and Plumptre 1990). Locally, the wood is used in general construction, flooring, furniture, veneers, and tool handles.

Danto is distributed from southern Mexico, southward along the Atlantic region of Central America and Venezuela to the Rio de Janeiro region of Brazil (Chudnoff 1984). Trees may reach 38 m (125 ft) in height, with trunk diameters commonly to 900 mm (36 in.). Boles may be clear to 21 m (70 ft). The heartwood is yellow, but becomes orange-brown upon exposure. Sapwood may be whitish, grayish, or yellow–brown. The wood is coarse textured. A silica content of 0.2 percent is reported. The heartwood is moderately to very durable and is very difficult to treat with preservatives. Treatability of the sapwood is reported as good. The grain of Danto may be straight, but it can also be strongly interlocked. Interlocked grain is a form of spiral grain that usually occurs in hardwood species and is found occasionally in coniferous species (Webb 1969). If occurrence is severe, interlocked grain may cause serious problems such as twisting, grain tear-out in machining, and reduction of mechanical properties. It may also provide a ribbon figure in quartersawn lumber and veneer that is desirable in furniture. Locally, the wood is used in construction, flooring, and railroad crossties.

Materials and Methods

The 2×4 lumber used in this study was cut from 3.6-m-(12-ft-) long logs obtained from a sawmill in northern Guatemala (Rosales and Green, in preparation). (Note: 2x4 refers to nominal 2- by 4-in. (standard 38- by 89-mm) lumber.) The general appearance of the lumber was quite good, relative to growth characteristics that usually limit properties for U.S. softwood species. Although the pieces of lumber had some knots, slope of grain was more often the most serious grade-limiting defect. Upon arrival at the Forest Products Laboratory, the lumber was kiln dried to approximately 12-percent moisture content and then planed to 38 by 89 mm (1.5 by 3.5 in.). The lumber was graded by a quality supervisor of the Southern Pine Inspection Bureau and equilibrated in a humidity room maintained at 20°C (68°F) and 65 percent relative humidity (nominal 12-percent moisture content).

Approximately 600 pieces each of Danto and Ramon 2×4 lumber was used for the study. Prior to destructive testing, each piece of lumber was identified with a unique numerical code and physical measurements were taken. The MOE of each specimen was taken by vibration techniques (MOE_d). To assign lumber to three groups for testing full size in bending and in tension and compression parallel to grain, the lumber was ranked by MOE_d values (highest to lowest). Using groups of four pieces within the ranked MOE_d values, specimens were

randomly assigned to the tests as follows: two pieces for testing bending, one piece for compression, and one piece for tension.

Full-size testing was conducted following procedures in ASTM D 4761 (ASTM 1991). Edgewise bending tests were conducted using third-point loading at a span-to depth ratio of 17:1. The grade-controlling defect was placed between the load heads and randomly located with respect to the edge to be stressed in tension. The clear span between grips for the tension tests was 2 m (6.5 ft). Compression testing was conducted on full-length specimens supported according to provisions in ASTM D 198 (ASTM 1991). After testing, samples were cut from each specimen to determine moisture content by ASTM D 4442 and specific gravity by Method A of D 2395 (ASTM 1991).

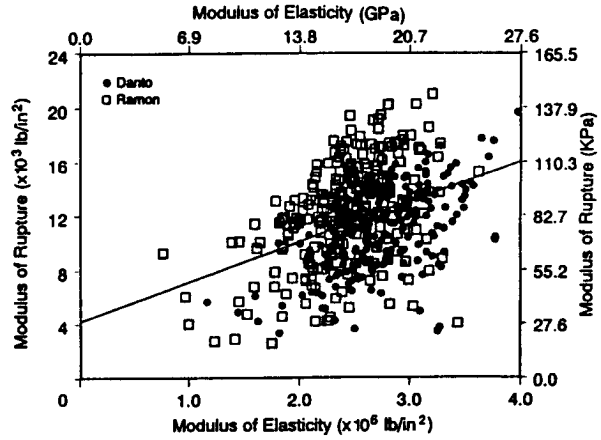

Figure 1—MOE–MOR relationship for Danto and Ramon 2x4 lumber.

Results and Discussion

The properties of Danto and Ramon lumber used in this study are described in Table 1. Both species were conditioned in the same chamber for about 6 months prior to testing. The difference in equilibrium moisture content was probably a result of the slightly higher extractive content of Danto.

The relationship between MOE and MOR for Danto and Ramon 2×4 lumber is shown in Figure 1. Generally, the correlation between strength properties and MOE was significant (0.95 level) but lower than might be expected for lumber containing defects (Table 2). The r^2 values appear similar to values obtained for many other tropical and temperate hardwood species. They also appear lower than coefficients for temperate softwoods. However, the r^2 value is sensitive to the range of values for MOE. When only a few logs are taken in one geographic area, the range of MOE values may be reduced. It should also be noted that Douglas Fir–Larch, Southern Pine, and Hem–Fir are groupings of several species. Further, these samples were taken from the entire geographic range over which the species grow. Thus, the low correlation for an individual species need not imply that the MOR–MOE relationship is not useful when considering species-independent grading. If valid, however, a low correlation would make the sorting less efficient. Comparison of grading alternatives for tropical species will be addressed in a later report.

Table 1—Properties of Ramon and Danto 2x4 lumber[a]

Ramon lumber			Danto lumber		
Sample		Property	Sample		Property
285	MC	11.3% (4.0)	285	MC	10.0% (4.4)
285	SG	0.64 (6.7)	285	SG	0.61 (6.0)
285	MOE	16.5 GPa (19.2)	285	MOE	18.7 GPa (16.5)
285	MOR	81.8 MPa (34.1)	285	MOR	74.5 MPa (30.4)
143	UCS	47.3 MPa (21.4)	142	UCS	43.0 MPa (27.5)
143	UTS	49.1 MPa (48.2)	141	UTS	50.1 MPa (39.3)

[a]Values in parentheses are coefficients of variation. 1 lb/in² = 6.894 kPa.
MC is moisture content, SG specific gravity, MOE modulus of elasticity, MOR modulus of rupture, UCS ultimate compression stress, UTS ultimate tensile stress.

Table 2—Relationship between MOE and MOR for dry lumber

Species or group	Sample (n)	r^2	Reference
Danto	285	0.26	This report
Ramon	285	0.21	This report
Danto, Ramon	570	0.15	This report
Banak	60	0.44	Senft and Della Lucia 1979
Tachi	80	0.26	Senft and Della Lucia 1979
Pequia	69	0.17	Senft and Della Lucia 1979
Banak, Tachi, Pequia	209	0.75	Senft and Della Lucia 1979
Yvrya pyta	80	0.57	Aplin and Pastor 1988
Kurupay'ra	80	0.27	Aplin and Pastor 1988
Kurupa'y	80	0.24	Aplin and Pastor 1988
Guatambu	80	0.16	Aplin and Pastor 1988
Kupay	80	0.16	Aplin and Pastor 1988
Red Maple	260	0.31	Green and McDonald 1993
Northern Red Oak	215	0.46	Green and McDonald 1993
Yellow-Poplar	126	0.25	Green and McDonald 1993
Aspen–Cottonwood	85	0.30	Green and McDonald 1993
Southern Pine	2,161	0.52	Green and McDonald 1993
Douglas Fir–Larch	2,781	0.56	Green and McDonald 1993
Hem–Fir	903	0.53	Green and McDonald 1993

Relationship of UCS to MOR

Figure 2 shows the UCS/MOR ratio as a function of MOR for the 2 ×4 lumber tested in this study. The relationship for Ramon compares favorably with the average trend determined for temperate softwood species (Green and Kretschmann 1991) and with those obtained for two temperate hardwood species (Green and McDonald 1993). However, the relationship for Danto is much different. We believe that this was a result of extensive interlocked grain in virtually all the Danto samples. Other research showed that interlocked grain has a marked effect on strength properties and, to a lesser extent, the MOE of wood (e.g., Weddell 1961). We therefore caution that the general relationship used to relate UCS/MOR and MOR for most temperate species should not be used for species likely to contain severe interlocked grain.

Relationship of UTS to MOR

Figure 3 shows the relationship between UTS/MOR and MOR obtained for Danto and Ramon. The minimum points for these two species were slightly lower than those found for temperate hardwoods but similar to data for temperate softwoods, on which most design standards are based. The results were generally higher than the conservative ratio of 0.45 given in D 1990 (ASTM 1991).

Conclusions

The results of this study on the mechanical properties of Danto and Ramon 2×4 lumber led to the following conclusions:

1. There is a significant correlation between MOE and MOR for Danto and Ramon lumber. However, the r^2 values appear lower than the expected value of 0.5 for temperate softwoods. This may be inherent to the species or the result of sampling logs from a limited geographic range.

2. The relationship between UTS and MOR of both species appears to be within the range expected from tests on temperate species. The UTS/MOR ratio of 0.45 given in ASTM D1990 would seem appropriate for estimating allowable tensile strength in the absence of tension test data.

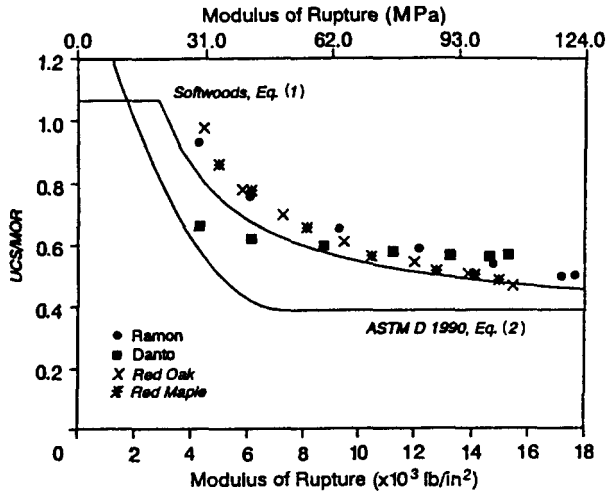

Figure 2—Relationship of compression strength parallel to grain to bending strength.

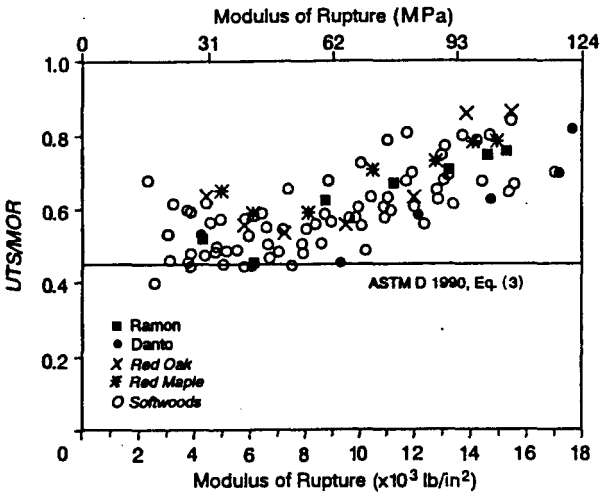

Figure 3—Relationship of tensile strength parallel to grain to bending strength.

3. The relationship between UCS and MOR of Ramon appears to be within the range expected from tests on temperate species. Thus, standardized relationships, such as those given in Equations (1) and (2) of this paper, would seem appropriate for estimating allowable compression strength parallel to grain in the absence of compression test data.

4. The relationship between UCS and MOR of Danto appears to be different than that typically found for temperate species. We believe this to be a result of extensive interlocked grain in the test specimens. In the absence of compression test data, we suggest application of the conservative relationship of ASTM D1990 (Eq. (2) of this paper).

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