Properties and grading of Danto and Ramon 2 by 4's

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Abstract

Physical and mechanical properties were obtained for approximately 600 2 by 4's of Ramon *(Brosimun alicastrum)* and 600 2 by 4's of Danto (*Vatairea Iundellii*), from Guatemala. The lumber was visually graded according to U.S. grading rules. Full-sized tests were conducted in bending and in tension and compression parallel to the grain. Clearwood tests were conducted in bending and shear. Little relationship was found between the flexural properties of 2 by 4's and those of knot-free specimens cut from the lumber. Visual grading rules satisfactorily sorted lumber into grades with distinct strength values. However, modulus ofelasticity varied little by visual grades. The relationship between tensile strength and bending strength for both species was similar to that ofdomestic softwoodand hardwood species. The relationship between compression strength and bending strength was similar to domestic species for Ramon, which did not contain interlocked grain, but not for Danto, which contained interlocked grain. The conservative relationship of ASTM D 1990 could be used to estimate the compressive strength of these two species from bending strength. However, it is cautioned that compression-bending relationships assumed in ASTM standard D 6570 for mechanically graded lumber should not be used with either tropical or temperate hardwood species that typically contain interlocked grain without further verification of the inherent relationship.

There are some 300 species of trees in the tropical forests of northern Guatemala and southern Mexico. Of these, only two groups, mahogany and cedar, are widely used in local and international markets. Neither species can regenerate naturally unless their seedlings find sufficient light to survive. Thus, harvesting other species, which occur more frequently but are less utilized, is key to a balanced regeneration. Increased harvest of other species will also be needed if these lowland tropical forests are to be managed sustainably and profitably. Without commercial value; there is little incentive to maintain the forest cover. Ramon (*Brosimun alicastrum*) and Danto (*Vatairea Lundellii*) are two species that occur frequently in these forests but are not well known in timber markets. (In Mexico, trees of *Vatairea* spp. may be called Amargoso.)

There also is increased interest in the United States in using natural durable tropical hardwoods in structural applications such as for building restoration and transportation structures. Although there is information on the application of visual and mechanical grading procedures to U.S. domestic hardwoods, these have not been applied to tropical hardwoods. None of the U.S. studies included species with interlocked grain. The objectives of this report are to summarize physical and mechanical property data collected on Danto and Ramon when visually graded by U.S. procedures and to evaluate the property relationships assumed in U.S. property standards for both visually graded and mechanically graded structural lumber.

Background

General description

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 120 feet (36.6 m), with straight cylindrical boles clear to 75 feet (22.9 m). Diameters may reach 40 inches (102 cm). 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. The 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 as tool handles.

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Table 1. — *Effect of interlocked grain on the static bending properties of utile and greenheart 2 by 6's (Weddell 1961).*[a]

Species	Acute spiral angle	No. of specimens	Mean MOR	Mean MOE
	(degrees)		(psi)	($\times 10^6$ psi)
Utile	0 to 6	9	12,659	1.79
	6 to 12	15	11,280	1.80
	12 to 18	13	9,685	1.62
	18 and over	9	7,609	1.49
Greenheart	0 to 6	48	20,127	3.502
	6 and over	25	16,495	3.149

[a]MOR = modulus of rupture; MOE = modulus of elasticity; 1 psi = 6.89 kPa.

The growing region of Danto stretches 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 125 feet (38.1 m) in height, with trunk diameters commonly growing to 3 feet (91.4 cm). Boles have narrow high buttresses and may be clear to 70 feet (21.3 m). The heartwood is yellow, but becomes orange-brown upon exposure. Sapwood may be whitish, grayish, or yellow-brown. The wood is course textured. The grain may be straight hut can also he strongly interlocked. The heartwood is moderately to very durable and is very difficult to treat with preservatives. Treatability of the sapwood is reported as good. Locally, the wood is used in construction, flooring, and for railroad crossties.

Influence of interlocked grain on wood properties

Interlocked grain (also called double spiral grain) is a characteristic feature of a great number of tropical species and a few domestic hardwoods such as tupelo, blackgum, sweetgum, sycamore, cottonwood, and elm (Davis 1962, Webb 1969, Chudnoff 1984). It is formed when the grain inclination changes from a right- or lefthand helix to the opposite slope during the life of a tree (Panshin and deZeeuw 1970). Boards cut from such trees show a characteristic ribbon or stripped figure on the radial surface and cross-grain on the tangential surface.

Weddell (1961) evaluated the effect ofinterlocked gain on the flexural properties of utile (*Entandrophragma utile*) and greenheart (*Ocotea rodiaei*) 2 by 6's in static bending. The lumber was tested on edge in third-point bending. Because the spiral growth layers were not easily discernable on the cross section of the pieces. the angle the rays made with the wide face was used to determine grain angle. In addition, two grain angles were determined for each piece:

a. the average angle of the bands following the more acute spiral direction (termed acute spiral angle);

b. the average angle of all the spiral bands (termed the average spiral angle).

Both modulus of rupture (MOR) and modulus of elasticity (MOE) decreased with increasing slope angle. Mean trends for the properties of utile and greenheart 2 by 6's grouped according to the acute angle between the rays and the wide face are given in **Table 1.** Weddell concludes that the effect of ray angle was more marked on MOR than on MOE. He also notes that the effects arc slightly less than those of simple cross-grain. Weddell suggests that pieces with steeply interlocked grain should not be graded for structural use. This latter suggestion apparently is related to the tendency of such pieces to fail suddenly without warning.

Marsoem and Kikata (1987) investigated the effect of interlocked grain on strength using small specimens of white meranti (*Shorea* spp.) in impact bending. While they found reductions in strength with increasing grain slope, the reductions were less than those assumed for static strength in ASTM D 245 (ASTM 2000).

Hernandez and Almeida (2003) evaluated the effect of density and interlocked grain on the shear strength of three species from the Amazon: ishpingo (*Amburana cearensis*), pumaquiro (*Aspidosperma macrocarpon*), and tulpay (*Clarisia racemosa).* Using a method described by Webb (1969), they characterized the interlocked grain in each piece by measuring the maximum right spiral and maximum left spiral of individual grain bands after the piece had been split along a radial line. The sum of the maximum left and right spiral measurements was defined as the maximum angular deviation (MAD). Shear strength was determined using the block shear specimen of ASTM D 245. Two different shear strengths were calculated. The nominal shear strength was obtained by dividing the maximum load by the assumed nominal failure area of 2 in^2 (2500 mm^2). However, the failure surface for specimens with interlocked grain was a wavy surface that was influenced by the grain direction within each growth hand. The area of this wavy surface was estimated. The actual shear strength was calculated by dividing the maximum load by the estimated actual failure surface. As would be expected because of the smaller assumed surface area, the nominal shear strength is consistently higher than the actual shear strength **(Table 2).** Although the ratio of the nominal to the actual value ranges from 1.18 to 1.34, because of the high variability of the test results this difference is only significant for Tulpay. The effect of density and MAD on actual and nominal shear strength is shown in **Table 3.** Shear strength increases with increasing density for both methods of calculating shear. For shear values calculated using the actual (wavy) shear area, shear strength decreases with increasing degrees of slope (increasing MAD). With shear strength calculated on the basis of the assumed nominal shear area, shear values increased with increasing MAD for tulpay and ishpingo, hut decreased with increasing MAD for pumaquiro. Thus; the use of an assumed nominal shear area for species with interlocked grain can mask real reductions in shear strength that could affect field performance.

Table 2. — *Shear strength of three tropical species containing interlocked grain (adapted from Hernandez and Almeida 2003).*

Species	No. of specimens	Density[a]	Moisture content	MAD[b]	Shear strength		
					Nominal	Actual	Ratio[c]
		(kg/m^3)	(%)	(degrees)	(MPa)		
Ishpingo	62	552	10.5	16.2	11.1	8.3	1.34
Pumaquiro	48	659	12.4	15.4	13.4	10.8	1.24
Tulpay	44	664	10.9	12.3	13.6	11.5	1.18

[a]Basic density based on ovendry weight and green volume.
[b]MAD = maximum angular deviation.
[c]Ratio = nominal strength divided by actual strength.

Table 3. — Relationship between shear strength parallel to the grain, basic density, and maximum angular deviation for three Amazonian hardwoods (adapted from Hernandez and Almeida 2003).[a]

		$P = A_1 + A_2(BD) - A_3 MAD_x$			
Property	Species	A_1	A_2	A_3	r^2
$\tau_{TLactual}$	Ishpingo	3	0.012	-0.09	0.34
	Pumaquiro	-6	0.03	-0.17	0.42
	Tulpay	–4	0.024	-0.07	-0.70
$\tau_{TLnominal}$	Ishpingo	7	0.06	0.006	0.25
	Pumaquiro	–2	0.021	-0.05	0.34
	Tulpay	0.6	0.017	0.16	0.53

[a]MAD = maximum angular deviation (sum of maximum left and right spiral grain deviations); BD = basic density (calculated from ovendry weight and green volume).

Materials and methods

The 2 by 4 lumber used in this study was cut from 12-foot- (3.6-m-) long logs obtained from a sawmill in north central Guatemala. To avoid shipping material of very low quality to the United States, the lumber was first graded in the rough, green state according to the standard grading rules ofthe southern pine Inspection Bureau (SPIB 1977). As would he normal practice for southem pine, the top grade (No. 1 and better, or No.1+) in this study was really a combination of Select Structural and No. I. For these species, the No. 1+ grade is predominately Select Structural. Two-hundred specimens of each grade (No. 1+, No. 2, and No. 3) for each species were obtained from the mill. To ensure that standard sizes would be available for testing, the lumber was sawn oversized and predried to approximately 25 percent moisture content (MC). Upon arrival at the USDA Forest Service, Forest Products Laboratory, the lumber was dried to approximately 12 percent MC using the T5-C2 modified schedule with a maximum dry-bulb temperature of 160°F (Boone et al. 1988) and then planed to 1.5 by 3.5 inches (38 by 89 mm). The lumber was then graded by a quality supervisor of the Southern Pine Inspection Bureau. To establish a uniform MC, the lumber was equilibrated in a humidity room maintained at 68°F (20°C) and 65 percent relative humidity (nominal 12% MC).

Prior to destructive testing, every piece of lumber was identified with a unique numerical code for both species. Physical measurements and records included length, width. thickness, MC using a moisture meter (Simpson 1994), slope of grain using both a slope of grain meter and a scribe, and size and code of significant knots. A full-span dynamic MOE (E_{tv}) value was obtained on each piece using transverse vibration techniques with the lumber oriented flatwise.

The design ofthe experiment is shown in **Tables 4** and **5.** To assign lumber to three groups for testing full sire in bending, and in tension and compression parallel to the grain, the lumher was ranked by E_{tv} values (highest to lowest). The four pieces that had the highest E_{tv} values were randomly assigned as follows: two pieces to he tested in bending. one to he tested in compression, and one to he tested in tension. Previous to the lumber testing, an approximately 4-foot- (1.2-m-) long section was cut from the ends of the 12-foot- (3.6-m-) long bending specimens. These sections provided samples for the clearwood tests in static bending. shear parallel to the grain, and compression perpendicular to the grain.

Full-size testing was conducted following procedures in ASTM D 4761. Edgewise bending tests were conducted using third-point loading and 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 he stressed in tension. The clear span between grips for the tensile tests was

Table 4 — Properties of Ramon 2 by 4's at 11 percent moisture content [a]

					Percentiles			
Property	Grade	Sample size	Mean value	COV	5th	10th	25th	50th
				(%)				
Moisture content (%)	1+	I13	11.00	5.4	--	--	--	--
	2	78	10.90	6.3	--	--	--	--
	3	61	10.50	5.3	--	--	--	--
	Econ	33	11.10	5.3	--	--	--	--
Specific gravity	1+	93	0.67	6.8	--	--	--	--
	2	99	0.68	6.5	--	--	--	--
	3	93	0.69	7.6	--	--	--	--
	Econ	33	0.69	7.7	--	--	--	--
MOE (static) ($\times 10^6$ psi)	1+	113	2.44	13.7	1.84	1.94	2.25	2.45
	2	78	2.41	20.1	1.52	1.88	2.20	2.37
	3	61	2.40	22.0	1.39	1.62	2.10	2.37
	4	33	2.19	26.7	0.89	1.24	1.85	2.28
E_{tv}[c] ($\times 10^6$ psi)	1+	211	2.40	11.2	1.93	2.09	2.22	2.42
	2	166	2.39	11.4	1.89	2.09	2.22	2.39
	3	125	2.37	11.5	1.89	2.03	2.19	2.36
	Econ	70	2.26	14.3	1.63	1.84	2.02	2.30
MOR ($\times 10^3$ psi)	1+	113	13.65	26.9	5.50	8.47	11.66	14.10
	2	78	11.38	27.7	4.71	7.66	9.24	1I.49
	3	61	11.10	36.7	2.9'1	5.75	7.48	11.80
	Econ	33	8.33	50.3	1.78	2.63	5.10	8.97
UTS ($\times 10^3$ psi)	1+	49	8.96	36.3	3.79	4.86	6.98	8.26
	2	40	7.53	39.7	2.57	3.07	5.59	7.32
	3	30	5.34	56.8	1.51	1.64	2.74	5.02
	Econ	17	6.86	41.3	1.66	2.08	2.63	3.51
UCS ($\times 10^3$ psi)	1+	19	7.81	10.7	5.79	6.89	7.35	7.89
	2	41	6.88	19.2	4.22	4.74	6.23	7.13
	3	34	6.42	19.11	3.59	4.50	5.82	6.01
	Econ	19	5.15	31.8	1.91	2.36	4.38	5.63

[a]1+ = No. I and better; COV = coefficient of variation; MOE = modulus of elasticity: MOR = modulus of rupture; UTS = ultimate tensile stress; UCS = ultimate compressive stress; 1 psi = 6.89 kPa.

[b]Specific gravity based on ovendry weight and ovendry volume.

[c]E_{tv} MOE obtained using transverse vibration technique.

Table 5. — Properties of Danto 2 by 4's at 11 percent moisture content. [a]

Property	Grade	Sample size	Mean value	COV	Percentiles 5th	10th	25th	50th
				(%)				
Moisture content (%)	1+	92	10.3	5.5	--	--	--	--
	2	92	10.0	5.9	--	--	--	--
	3	63	10.5	5.5	--	--	--	--
	4	38	10.6	5.4	--	--	--	--
Specific gravity	1+	94	0.63	6.0	--	--	--	--
	2	93	0.64	6.2	--	--	--	--
	3	98	0.64	6.6	--	--	--	--
	4	38	0.65	6.8	--	--	--	--
MOE (static) ($\times 10^6$ psi)	1+	92	2.75	12.9	2.24	2.31	2.48	2.71
	2	92	2.71	16.9	2.06	2.23	2.42	2.65
	3	63	2.69	18.0	1.81	2.09	2.41	2.62
	4	38	2.65	21.1	1.63	1.70	2.34	2.67
E_{tv} [c] ($\times 10^6$ psi)	1+	185	2.49	12.1	2.06	2.16	2.29	2.45
	2	173	2.44	12.4	2.02	2.10	2.23	2.41
	3	131	2.40	11.4	1.99	2.09	2.21	2.38
	4	80	2.20	13.7	1.66	1.85	1.99	2.22
MOR ($\times 10^3$ psi)	1+	92	12.02	21.6	7.24	8.39	10.12	12.25
	2	92	11.22	28.2	5.16	6.71	9.05	11.74
	3	63	10.12	28.6	3.83	6.18	8.22	10.48
	4	38	7.96	27.3	1.95	2.95	4.75	7.86
UTS ($\times 10^3$ psi)	1+	47	8.59	23.2	4.49	6.09	7.21	8.22
	2	43	7.56	35.5	2.82	4.14	5.62	7.40
	3	32	6.56	46.3	2.02	2.51	3.67	6.56
	4	19	4.53	59.1	1.02	1.12	2.13	5.18
UCS ($\times 10^3$ psi)	1+	46	7.09	15.7	5.38	5.80	6.29	7.11
	2	38	6.70	20.4	4.47	4.96	5.36	6.86
	3	36	5.62	32.6	2.04	3.39	4.03	5.84
	4	22	4.65	36.7	1.23	2.32	3.16	4.86

[a] 1+ = No. 1 and better; COV = coefficient of variation; MOE – modulus of elasticity: MOR = modulus of rupture; UTS = ultimate tensile stress: UCS – ultimate compressive stress; 1 psi = 6.89 kPa.
[b] Specific gravity based on ovendry weight and ovendry volume.
[c] E_{tv} MOE obtained using transverse vibration technique.

6.5 feet (2 m). Compression testing was conducted on full-length specimens supported according to provisions in ASTM D 198. After testing, samples were cut from each specimen to determine the MC by D 4442 and specific gravity by Method A of D 2395.

Clearwood testing was conducted following procedures in ASTM D 143 (secondary methods). Clear, straight-grained specimens 1 by 1 by 16 inches (25.4 by 25.4 by 406.4 mm) were tested in static bending. Alternative 2- by 1.5-inch (50.8- by 38.1-mm) block specimens were used for the shear parallel to the grain tests (Bendtsen and Porter 1978).

Results and discussion

Properties of 2 by 4's

The mechanical properties of Ramon and Danto 2 by 4 lumber tested in this study are summarized in **Tables 4** and **5,** respectively. Only about 11 percent of the failures occurred at knots, whereas about 36 percent of the failures were attributed toslopeofgrain. Despite the relative lack of knots in these two species, the visual grading rules do a reasonable job of separating property estimates by grade for MOR, ultimate tensile stress (UTS), and ultimate compressive stress (UCS), especially at the fifth percentile level. However, there is little difference in mean MOE between grades. For the major U.S. softwood species, there is generally a 10 to 20 percent difference between mean MOE values of Select Structural and No. 2 grade lumber.

In the United States, property relationships are used for a variety of purposes (Green and Kretschmann 1991). The MOR-MOE relationship is used to help establish mechanical grades. Relationships between MOR and other strength properties, such as with UTS and UCS, are also used to estimate properties of mechanically graded lumber (ASTM D 6570). With visually graded lumber, the ability to estimate other properties from MOR reduces the amount of testing that must he conducted in an in-grade testing program (ASTM D 1990). Knowing and utilizing these relationships could he very valuable in Guatemala because of the many species to be tested, the difficulty of species identification, and the limited facilities available for conducting tests other than bending.

MOE-property relationships.– Although statistically significant, the correlation between strength properties and MOE appears generally lower than expected **(Table 6).** For example, the coefficients of determination (r^2) between MOR and MOE are only 0.24 and 0.23 for Danto and Ramon, respectively. These low r^2 values appear similar to values obtained for some tropical hardwood species **(Table 7).** They are also lower than coefficients for southern pine (0.52 for 2,161 2 by 4's) and Douglas-fir (0.56 for 2,781 2 by 4's) determined in the in-grade testing program (Green et al. 1989). As might be expected, however, the narrower range of densities often found when testing a single species from one geographic area may contribute to the low correlation. The coefficient of determination obtained by Senft and Della-Lucia (1979) improved considerably when the range of MOE was increased by combining their data for three species **(Table 7).** Firmanti et al. (2005) found that mechanical grading based on MOE was feasible on a species-independent basis for tropical species, provided that tropical softwoods were not included in the sample.

UCS-MOR relationship. — **Figure 1** shows the UCS/MOR ratio as a function of MOR for the 2 by 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

Table 6. — Modulus of elasticity and strength relationships for Danto and Ramon 2 by 4 lumber.

Property relationship[a]	Species	Sample size	Property A B(E) A	B	Coefficient of determination, r^2
			----((×10³ psi)[b] ----		(%)
MOR to MOE	Danto	285	1.070	3.590	0.24
	Ramon	285	1.721	4.242	0.23
MOE to E_{tv}[c]	Danto	285	0.00063	0.00086	11.37
	Ramon	285	−0.00018	0.00108	0.43
UTS to E_{tv}	Danto	141	−3.049	4.270	0.20
	Ramon	143	6.468	5.724	0.22
UCS to E_{tv}	Danto	142	−0.233	2.778	0.23
	Ramon	143	5.196	0.010	0.32

[a]MOR = modulus of rupture; MOE = modulus of elasticity; UTS = ultimate tensile stress: UCS = ultimate compressive stress.
[b]1 psi = 6.89 kPa.
[c]E_{tv} = dynamic modulus of elasticity obtained by transverse vibration

Table 7. — Relationship between modulus of elasticity and modulus of rupture for dry lumber.

Species or group	Sample size	r^2	Reference
Banak	60	0.44	Senft and Della-Lucia (1979)
Tuchi	80	0.26	Senft and Della-Lucia (1979)
Pagnia	69	0.17	Senft and Della-Lucia (1979)
All three	209	0.75	Senft and Della-Lucia (1979)
Yvryapyta	80	0.57	Aplin and Pastor (1988)
Kurapay ra	80	0.27	Aplin and Pastor (1988)
Kurapa'y	80	0.24	Aplin and Pastor (1988)
Guatamba	80	0.16	Aplin and Pastor (1988)
Kupay	80	0.16	Aplin and Pastor (l988)
From natural forest	566	0.56	Firmanti et al. 2005
Borneo timber	314	0.53	Firmanti et al. 2005
Shorea sp.	192	0.64	Firmanti et al. 2005
Kapur	60	0.71	Firmanti et al. 2005
Planted hardwood	300	0.57	Firmanti et al. 2005
Acacia mangium	I20	0.71	Firmanti et al. 2005
Falcata	60	0.63	Firmanti et al. 2005
Rubber wood	60	0.61	Firmanti et al. 2005

1993a, 1993b). However, the UCS/MOR-MOR relationship for Danto appears to he flatter than those of the other species. We believe that this could be a result of the presence of extensive interlocked grain in virtually all the Danto samples. The conservative relationship assumed in ASTM D 1990 for visually graded lumber could be used to estimate UCS from MOR. However, the relationship assumed in ASTM D 6570 for mechanically graded lumber could produce nonconservative estimates of UCS for MOR values less than about 9,000 psi (62 MPa). Until additional data are available, we caution that the D 6570 relationship between UCS and MOR should not be used with either tropical or domestic hardwood species that typically contain interlocked grain.

UTS-MOR relationship.— **Figure 2** shows the relationship between UTS/MOR and MOR obtained for Danto and Ramon. The minimum data points for these two species are slightly lower than found with temperate hardwoods but are similar to the data for temperate softwoods (Green and Kretschmann 1991, ASTM D 6570). The results are generally higher than the conservative ratio of 0.45 given in ASTM D 1990.

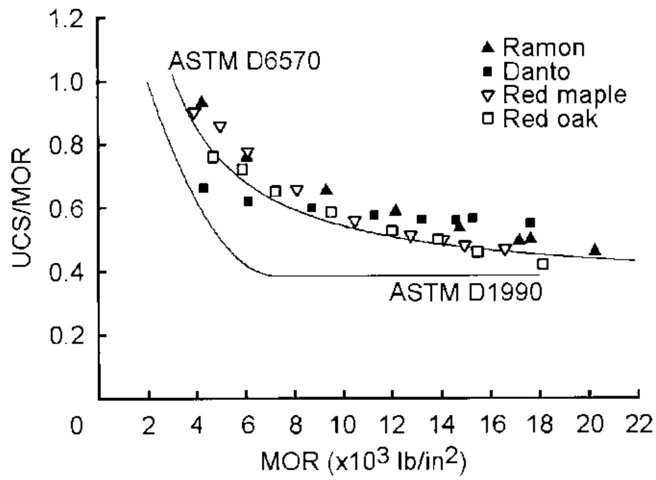

Figure 1. — Relationship between ultimate compression strength (UCS) and bending strength (MOR) for tropical hardwoods (1 psi = 6.89 kPa).

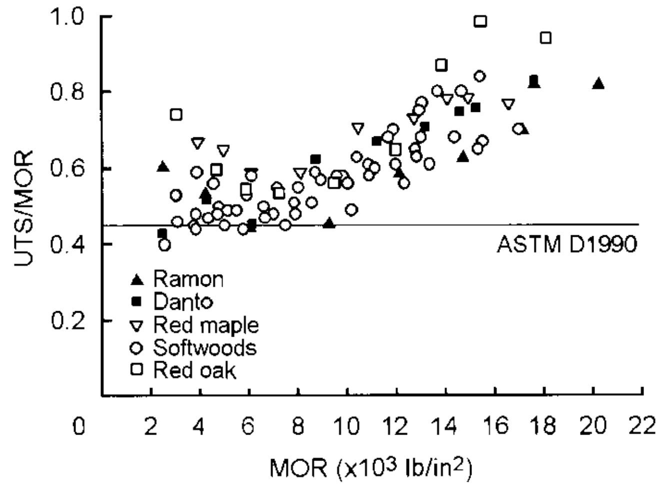

Figure 2. — Relationship between ultimate tensile strength (UTS) and bending strength (MOR) for tropical hardwoods (1 psi = 6.89 kPa).

Clearwood properties

Bending.— Tests were also conducted on 285 small; clear specimens cut from 4-foot- (1.22-m-) long sections from the ends of the original 12-foot (3.6-m) bending specimens for each species. For Danto. the mean MOR value of 16.44 × 10³ psi (113.4 MPa) and MOE of 2.18 × 10⁶ psi (15.0 GPa) found in this study are only slightly less than the values of 17.20 × 10³ psi (118.6 MPa) for MOR and 2.34 × 10⁶ psi (16.1 GPa) for MOE reported by Chudnoff (1984). However, flexural properties for Ramon found in this study are much higher than the MOR of 16.05 × 10³ psi (1 10.7 MPa) and MOE of 1.85 × 10⁶ psi (1 2.8 GPa) reported by Chudnoff. Because these small specimens had no knots but still contained the same grain deviations present in the 2 by 4's, it might be assumed that there would he a good correlation between the properties of the 2 by 4's and those of the small specimens cut from them. However, pairwise regressions between the MOE obtained from the 2 by 4's and from the small specimens had an r^2 value of 0.128 for Ramon and 0.188 for Danto. For MOR. the r^2 value between large and small specimen values was about 0.06 for both Danto and Ramon. Thus, we conclude that the flexural properties determined from small, clear specimens arc not adequate predictors of the properties of lumber from tropical species.

Shear.— Mean shear strength for the 285 Danto specimens was 2,110 psi, with a non-parametric fifth percentile of 1,790 psi. For Ramon, the equivalent values were 2,540 and 1,780 psi. For both species, these values were calculated using the nominal shear area of 3 in^2 (19.4 cm^2). Fifth percentile values could be used to establish allowable properties for each species. The shear values for both species could also be conservatively estimated by a relationship between shear strength and specific gravity that is an alternative approach for machine stress rated (Green et al. 1994). Unfortunately, the recent work of Hernandez and Almeida (2003) was unknown to the authors at the completion of this study. and the specimens are no longer available for determination of actual shear area. It would he anticipated that the shear strength of Danto would be less had the actual shear area been used. The laser profiling procedure recently developed by Scott et al. (2005) could easily be adapted for estimating failure surfaces for specimens having interlocked grain.

Conclusions

1. Both Ramon and Danto have properties that are higher than most U.S. domestic species and are therefore suitable for structural applications.

2. Slope of grain, not knots, is the predominant strength-controlling growth feature with both species.

3. With both species, the National Grading Rule for visually graded structural lumber sorts grades into groupings with strength properties that decrease with decreasing grade.

4. The MOE of both species varied little with visual grade.

5. The correlation between MOR and MOE is lower for these two species than might be expected. However, we believe that this is primarily due to the limited range in MOE values that arc often observed when a single species is tested. Available literature suggests that mechanical grading of tropical hardwoods on a species-independent basis is feasible.

6. The relationship between UTS and MOR for both species is within the range expected for domestic species. The UTS/MOR ratio of 0.45 given in ASTM D 1990 would seem appropriate for estimating allowable tensile stress parallel to the grain when only bending tests are conducted.

7. The relationship between USC and MOR of Ramon is similar to that assumed for domestic hardwood and softwood species. Thus, it appears that the procedures ofASTM D 1990 and ASTM D 6570 may be used for tropical species to estimate allowable compression strength parallel to the grain from the allowable bending strength if interlocked grain is not present.

8. The relationship between UCS and MOR of Danto does not appear to be the same as that assumed for domestic softwood and hardwood species. We believe that the virtually constant UCS/MOR ratio may be due to the presence of extensive interlocked grain in our Danto 2 by 4's. Thus, we caution that the relationships of ASTM D 6570 may not he appropriate for estimating allowable compressive strength from allowable bending strength. The more conservative relationship prescribed in ASTM D 1990 could be used with Danto.

9. The procedures adopted in the western United States for predicting the shear strength of machine stress rated lumber from specific gravity would appear to give a conservative estimate for Ramon and Danto.

10. Little correlation was found between the flexural properties of Danto and Ramon 2 by 4's and those obtained from small knot-free specimens cut from the 2 by 4's.

Literature cited

Aplin, E.N. and A. Pastor. 1988. Evaluation of strength properties of 5 tropical hardwoods of Paraguay. In: Proc. 1988 Inter. Conf. on Timber Engineering. Forest Prod. Soc., Madison, WI.

American Society for Testing and Materials (ASTM). 2000. D 143: Standard methods of testing small. clear specimens of timber. D 245: Standard practice for establishing structural grades and related allowable properties for visually graded lumber. D 198: Standard test methods of static tests of timbers in structural sizes. D 1990: Standard practice for establishing allowable propertics for visually graded dimension lumber from in-grade tests of full-size specimens. D 2395: Standard test methods for specific gravity of wood and wood-based materials. D 4442: Standard test methods for use and calibration of hand-held moisture meters. D 4761: Standard test methods for mechanical properties of lumber and wood-base structural material. D 6570: Standard practice for assigning allowable properties for mechanically graded lumber. In: Annual Book of Standards. Vol. 04.09, Wood. ASTM, West Conshohocken, PA.

Bendtsen, B.A. and S. Porter. 1978. Comparison of results from standard 2-inch with 1-1/2-inch shear block tests. Forest Prod. J. 28(7):54-56.

Boone, R.S., C.J. Kozlik, P.J. Bois, and E.M. Wengert. 1988. Dry kiln schedules far commercial woods: Temperate and tropical. Gen. Tech. Rept. FPL-GTR-57. USDA Forest Sen-.. Forest Products Lab., Madson, WI.

Chudnoff, M. 1984. Tropical Timbers of the World. Agri. Handbook 607. USDA Forest Serv., Washington, DC.

Davis, E.M. 1962. Machining and related characteristics of United States hardwoods. Tech. Bull. 1267. USDA Forest Serv., Washington, DC.

Echenique-Manrique, R. and R. Plumptre. 1990. A guide to the use of Mexican and Belizean timbers. Tropical Forestry Pap. 20. Oxford Forestry Inst., Dept. of Plant Sciences, Univ. of Oxford, Oxford, UK.

Firmanti, A., E.T. Bachtair, S. Surjokusumo, K. Komatsu, and S. Kawai. 2005. Mechanical stress grading of tropical timbers without regard to species. J. of the Japanese Wood Res. Soc. 51(4):339-347.

Green, D.W., B.E. Shelley, and H.P. Vokey. 1989. Proc. In-grade testing of structural lumber. Proc. 47363. Forest Products Soc., Madison, WI.

__________ and D.E. Kretschmann. 1991. Lumber property relationships for engineering design standards. Wood and Fiber Sci. 23(3):436-456.

__________ and K.A. McDonald. 1993a. Mechanical properties of red maple structural lumber. Wood and Fiber Sci. 25(4):365-374.

__________ and __________, 1993b. Investigation of the mechanical properties of red oak 2 by 4's. Wood and Fiber Sci. 25(1):35-45.

__________, D.E. Kretschmann, and J.A. Fantozzi. 1994. Shear and compression perpendicular to grain property estimation for 2400f MSR Iumber. Forest Prod. J. 44(11/12):75-81.

Hernandez, R.E. and G. Almeida. 2003. Effect of wood density and interlocked grain on the shear strength of three Amazonian tropical hardmoods. Wood and Fiber Sci. 35(2):154-166.

Marsoem, S.N. and Y. Kikata. 1987. The effect of interlocked grain on the mechanical properties of white meranti. Bulletin of Nagoya Univ., Nagoya. Japan 9:51-77.

Panshin, A.J. and C. deZeeuw. 1970. Textbook of Wood Technology, Vol. 1. McGraw-Hill Book Company, New York.

Scott, C.T., R. Hernandez, C. Frihart, R. Gleisner, and T. Tice. 2005. Methods for quantifying percentage wood failure in black-shear specimens by a laser scanning profilometer. Pap. ID JA112957. J. of Testing and Eval. 2(8). www.astm.org.

Senft, J.F. and R.M. Della-Lucia 1979. Increased utilization of tropical hardwoods through species-independent structural grading. Forest Prod. J. 29(6):22-28.

Simpson, W.T. 1994. Resistance moisture meter correction factors for four tropical wood species. Res. Note FPL-RN-0260. USDA Forest Serv., Forest Products Lab., Madison, WI.

Southern Pine Inspection Bureau (SPIB). 1977. Standard grading rules far southern pine lumber. SPIB. Pensacola, FL.

Webb. C.D. 1969. Variation of interlocked grain in sweetgum. Forest Prod. J. 19(8):45-48.

Weddell, E. 1961. Influence of interlocked grain on the bending strength of timber with particular reference to utile and greenheart. J. of the Inst. of Wood Sci. 2(7):56-72.