TAXONOMIC AND GROSS ANATOMICAL INFLUENCES ON SPECIFIC GRAVITY–MECHANICAL PROPERTY RELATIONSHIPS[1]

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ABSTRACT

The relationship between specific gravity and modulus of elasticity, modulus of rupture, and maximum crushing strength in compression parallel to the grain was investigated for seven commercial timber genera. Exponential regressions were derived for each specific gravity–mechanical property relationship in the green and air-dried (12% moisture content) condition for each genus. The regressions were tested for significance and, if significant, compared by covariance analysis to determine if they were significantly different. The experiment was repeated, this time grouping commercial timber species according to their gross anatomical characteristics, i.e., ring porous, semi-ring porous, diffuse porous, and nonporous. Results of the covariance analyses indicate significant differences between most generic groupings and between most pore arrangement groupings. Data used in this study were obtained from the world literature.

Keywords: Specific gravity–mechanical property relationship, mechanical properties.

INTRODUCTION

The influence of specific gravity (G) upon mechanical properties is a fundamental relationship in wood that is understood but difficult to quantify. Specific gravity is considered a "good index" of the mechanical properties of clear, straight-grained, defect-free wood (U.S. Forest Products Laboratory 1974). Past studies have resulted in development of several empirical regressions for the specific gravity–mechanical property relationship based upon average specific gravity and mechanical property values for a number of timber species. The regression equations have been based upon worldwide data (Armstrong et al. 1984), groupings of species by geographic origin (Newlin and Wilson 1919; Markwardt 1930; Armstrong et al. 1984), and hardwood and softwood groupings (Armstrong et al. 1984). The *Wood Handbook* (U.S. Forest Products Laboratory 1974) contains the regression equations developed by Markwardt (1930), which are based upon average specific gravity and mechanical property values for commercial timber species of the United States. The results of the most recent study (Armstrong et al. 1984)

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suggest that grouping timbers by genera or by gross anatomical categories for developing specific gravity–mechanical property regressions may be preferable to grouping species on a geographical basis.

The objectives of the present study were to investigate the statistical validity of specific gravity–mechanical property regressions for timber species grouped by genera; to investigate the statistical validity of specific gravity–mechanical property regressions for timber species grouped by gross anatomical characteristics (ring porous, semi-ring porous, diffuse porous, and nonporous woods); and to assess whether any advantages may exist for using specific gravity–mechanical property regressions grouping timbers by these two categories when compared to global or geographic groupings. The specific gravity–mechanical property relationships were determined for three mechanical properties: modulus of elasticity (MOE) and modulus of rupture (MOR) from static bending tests; and maximum crushing strength (MCS) in compression parallel to the grain. Regressions were analyzed for all three properties at 12% moisture content (oven-dry basis) and in the green condition.

The specific gravity–mechanical property relationship is usually expressed as the exponential function:

$$S = aG^b$$

where "S" is the predicted value for a particular mechanical property and "a" and "b" are constants. This relationship is approximate due to variation in anatomical structure and chemical composition between and within species. The *Wood Handbook* (U.S. Forest Products Laboratory 1974) lists values of the constants for specific mechanical properties in the air-dry (12% moisture content) and green condition. The constants were first determined from average mechanical property data for domestic commercial species by Newlin and Wilson (1919) and subsequently updated by Markwardt (1930).

A recent study (Armstrong et al. 1984) reexamined the specific gravity–mechanical property relationship in order to determine if the regression equations listed in the *Wood Handbook* were also valid for timbers of worldwide origin. They revised Markwardt's equations slightly by applying linear regression analysis to current data and determined that significant differences existed in many cases between regressions based upon data on woods from different geographical sources. Their results supported the assertion that prediction of mechanical properties based upon specific gravity is best achieved on a species by species basis (U.S. Forest Products Laboratory 1974). In the course of the study, they also found significant differences between data for hardwood and softwood species from a given geographical area. This seems to suggest that specific gravity–mechanical property regression equations for species grouped by taxonomic classification or, perhaps, by gross anatomical characteristics such as pore arrangement may be preferable to groupings of all species from a specific geographical area. This study was undertaken to explore this contention.

MATERIALS AND METHODS

Data used in this study were obtained from literature from the United States (Kynoch and Norton 1938; Kukachka 1970; U.S. Forest Products Laboratory 1974), Great Britain (Lavers 1967), and Australia (Bolza and Kloot 1963). Data included 647 woods from six continents. These sources were chosen because they used ASTM or British standards for testing and provided a large number of species from different geographic origins. In cases where species were listed in more than one source, the data from the reference citing the largest sample size was used in the analysis.

Data were converted to a standard format according to procedures used by Armstrong et al. (1984). Standard International units were employed. Mechanical property and specific gravity data were adjusted to equivalent values for 12% moisture content (oven-dry basis) when air-dry data were given at other moisture contents close to 12%. Mechanical property data were also adjusted to equivalent values for 2- by 2-inch specimens.

The mechanical properties studied were MOE, MOR, and MCS. Each mechanical property was defined as a function of specific gravity using least squares regression analysis. Regression equations were developed for all three mechanical properties in both green and air-dry conditions for data grouped by genus and pore arrangement. Only regressions significant to a 95% level of confidence were used.

Genera and pore arrangement groupings were analyzed in separate phases of the study. The genera included in this study were *Abies, Acer, Carya, Eucalyptus, Picea, Pinus, Quercus,* and *Shorea.* The number of samples for each genera and each mechanical property studied is listed in Table 1. The pore arrangement groupings included were ring porous, semi-ring porous, diffuse porous, and nonporous (conifers). The number of samples for each group and each mechanical property studied is listed in Table 2. The pore arrangement groups included data for species from the genera listed above as well as from genera not included in the previous phase of the study.

Analysis of covariance was employed to compare the regression equations. Three characteristics of the regression lines were considered: slope, elevation, and variance. If any of these three were significantly different at a 95% level of confidence for two groups being compared, then the two groups were considered to have significantly different regression equations. All regressions and covariance analyses were done on computer using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS Institute Inc. 1982).

RESULTS AND DISCUSSION

Summaries of the results of the covariance analyses are contained in Figs. 1a, 1b, 2a, and 2b. Figures 1a and 1b contain comparisons of genera for wood in the green condition and at 12% moisture content. The letters in the body of the figure represent the mechanical properties evaluated (E = modulus of elasticity, R = modulus of rupture, and C = maximum crushing strength). If a particular letter occurs in the box adjoining two genera, these two genera do not have a significantly different regression equation as determined by covariance analysis for the property represented. For example, in Fig. 1a, the genera *Acer* and *Pinus* are indicated as sharing the letters "E" and "R." This indicates that *Acer* and *Pinus* do not have significantly different regression equations for the mechanical properties MOR and MOE but do have significantly different equations for MCS. Figures 2a and 2b are similarly organized. In Figs. 2a and 2b, pore arrangement comparisons are

TABLE 1. *Results of least-squares regression analysis for specific gravity–mechanical property relationships for genera in the air-dry and green condition.*[1]

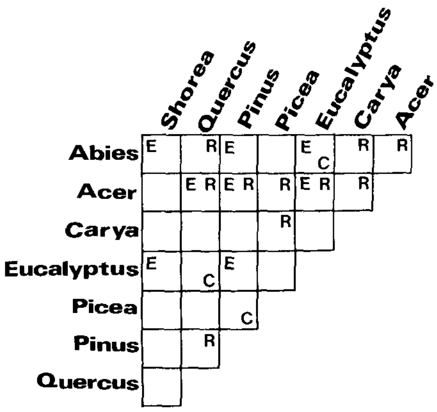
Genus	MC[2]	Specific gravity range	MOE = aG^b (mPa)				MOR = aG^b (kPa)				MCS = aG^b (kPa)			
			a	b	n	r^2	a	b	n	r^2	a	b	n	r^2
Abies	12	0.32–0.43	30,100	1.11	7	0.56	176,100	1.00	7	0.44	120,400	1.18	7	0.73
	G	0.30–0.40	31,100	1.31	7	0.49	134,100	1.19	7	0.81	78,300	1.18	7	0.73
Acer	12	0.48–0.63	23,700	1.30	4	0.78	257,000	1.75	4	0.91	92,300	1.18	4	0.92
	G	0.44–0.56	29,600	1.72	4	0.83	[3]	[3]	4	0.73	[3]	[3]	4	0.64
Carya	12	0.60–0.75	21,100	1.13	7	0.59	[3]	[3]	7	0.36	83,800	0.93	7	0.51
	G	0.56–0.66	20,900	1.50	7	0.70	148,000	1.48	7	0.93	[3]	[3]	7	0.31
Eucalyptus	12	0.58–1.10	17,100	0.39	55	0.15	148,000	0.58	56	0.39	73,700	0.43	56	0.05
	G	0.53–0.93	15,100	0.53	54	0.24	102,400	0.57	60	0.08	61,200	1.12	60	0.73
Picea	12	0.34–0.41	29,500	1.17	6	0.60	118,600	0.58	6	0.71	[3]	[3]	6	0.52
	G	0.33–0.38	[3]	[3]	6	0.56	134,100	1.19	6	0.87	50,100	1.04	6	0.85
Pinus	12	0.31–0.77	19,700	0.83	21	0.78	152,700	0.89	21	0.83	83,700	0.90	22	0.81
	G	0.29–0.68	16,000	0.75	22	0.56	110,100	1.06	22	0.74	54,800	1.15	23	0.92
Quercus	12	0.56–0.88	17,000	0.92	17	0.22	170,500	1.33	17	0.48	75,500	1.03	17	0.54
	G	0.52–0.91	13,800	0.79	18	0.35	97,400	0.96	18	0.66	54,100	1.44	17	0.73
Shorea	12	0.31–0.67	20,300	0.83	15	0.72	144,500	0.81	15	0.74	75,400	0.73	15	0.68
	G	0.30–0.67	19,200	0.86	16	0.74	144,800	1.11	16	0.86	68,900	1.02	16	0.71

[1] To convert to English units (1,000 p.s.i. for MOE and p.s.i. for MOR and MCS), multiply by 0.145.
[2] Moisture condition of test specimens (12 = 12% and G = above fiber saturation point).
[3] Regression is not significant at 95% confidence level.

TABLE 2. *Results of least-squares regression analysis for specific gravity-mechanical property relationships for pore arrangement groups in the air-dry and green condition.*[1]

Pore grouping	MC[2]	Specific gravity range	MOE = aG^b (mPa)				MOR = aG^b (kPa)				MCS = aG^b (kPa)			
			a	b	n	r^2	a	b	n	r^2	a	b	n	r^2
Ring porous	12	0.43–0.88	16,600	0.85	32	0.46	157,100	1.05	32	0.60	74,300	0.92	32	0.66
	G	0.40–0.91	14,800	0.89	33	0.54	107,100	1.04	33	0.62	54,900	1.32	32	0.58
Semi-ring	12	0.38–0.85	19,200	0.87	12	0.89	194,200	1.16	12	0.90	82,000	0.85	12	0.90
	G	0.34–0.64	14,100	0.63	13	0.68	122,100	1.03	13	0.88	46,000	0.84	12	0.86
Diffuse	12	0.26–1.09	18,300	0.83	79	0.72	160,300	1.04	81	0.87	79,800	0.92	82	0.55
	G	0.25–0.92	17,700	0.96	82	0.67	145,700	1.31	88	0.62	70,800	1.39	87	0.82
Conifers	12	0.30–0.77	19,700	0.81	54	0.53	158,600	0.93	55	0.77	83,400	0.85	56	0.77
	G	0.29–0.68	16,000	0.77	55	0.43	105,000	0.99	56	0.72	50,800	0.98	57	0.74

[1] To convert to English units (1,000 p.s.i. for MOE and p.s.i. for MOR and MCS), multiply by 0.145.
[2] Moisture condition of test specimens (12 = 12% and G = above fiber saturation point).



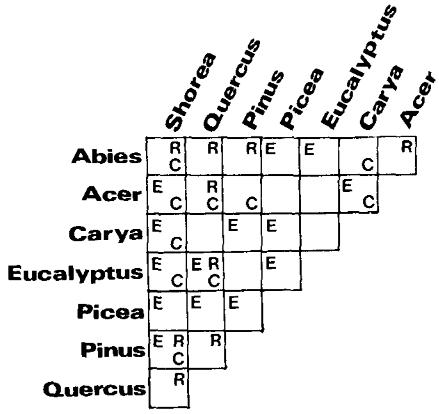


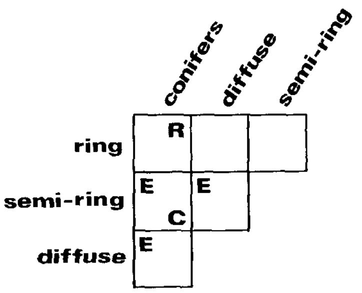
FIG. 1a. Results of covariance analysis for green wood grouped by genus. Letters indicate mechanical properties for which two groups did not have significantly different regression equations (E = MOE, R = MOR, C = MCS).

FIG. 1b. Results of covariance analysis for wood at 12% moisture content grouped by genus. Letters indicate mechanical properties for which two groups did not have significantly different regression equations (E = MOE, R = MOR, C = MCS).

indicated for wood in the green condition and at 12% moisture content, respectively.

Table 1 contains results from the regression analysis for genera in the green and air-dry conditions. The constants "a" and "b" for the equation ($S = aG^b$), the number of samples included in the analysis, and coefficients of determination (r^2) for the regression equations are given for each mechanical property examined. Also included is the range of specific gravities of the samples in each generic category. Table 2 contains similar data for pore arrangement regressions.

Of the 48 possible regression equations for timbers grouped by genus, 42 were determined to be significant at 95% confidence from the results of F-tests. Regressions found to be not significant are indicated in Table 1. Small sample size probably accounts for the six equations that were found to be not significant.



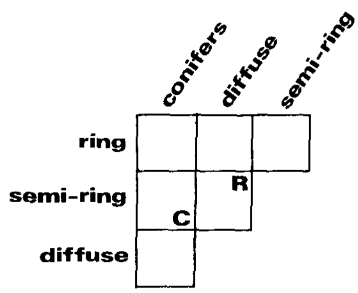


FIG. 2a. Results of covariance analysis for green wood grouped by pore arrangement. Letters indicate mechanical properties for which two groups did not have significantly different regression equations (E = MOE, R = MOR, C = MCS).

FIG. 2b. Results of covariance analysis for wood at 12% moisture content grouped by pore arrangement. Letters indicate mechanical properties for which two groups did not have significantly different regression equations (E = MOE, R = MOR, C = MCS).

However, for some groupings, *Eucalyptus* for example, the coefficients of determination indicate very poor correlation between the variables. Therefore, some caution must be exercised in using generic groupings for predictive purposes. All 24 possible regressions for timbers grouped by pore arrangement were significant at 95% confidence.

In both the study of genera and pore arrangement groups, several pairs of groups do not have significantly different regression equations for a particular mechanical property. However, a greater number significantly differ from each other. This indicates that grouping by genus and grouping by pore arrangement are justifiable in order to obtain more reliable regressions than might be obtained by grouping of timbers by geographic origin or by hardwoods and softwoods. The results also indicate that generic grouping, where significant, may be more desirable than grouping by pore arrangement. For example, Fig. 1a indicates that only 8 of 21 possible comparisons of MOE do not have significantly different regressions. For MOR, only 10 of 21 possible combinations do not have significantly different equations. For MCS, only 3 of 15 possible combinations do not have significantly different regressions. (The number of possible regressions was reduced from 28 to 21 for MOE and MOR and 15 for MCS by insignificant regressions for some genera as indicated in Table 1.)

CONCLUSIONS

Several conclusions may be made from the results of this study. The exponential function, $S = aG^b$, is significant when describing the specific gravity–mechanical property relationships for timbers grouped by genus. The validity of generic functions depends upon sample size. This function is also significant when describing timbers grouped by pore arrangement. Taxonomic (by genus) grouping for deriving the specific gravity–mechanical property relationship is preferable to grouping by geographic origin, taxonomic order, or pore arrangement group due to the significant differences between genera observed in the covariance analyses. Likewise, pore arrangement groupings are more desirable than grouping by geographic origin or taxonomic order.

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