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Properties of Medium-Density Fiberboard Related to Hardwood Specific Gravity

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Abstract

Boards of acceptable quality were made from barky material, pressure-refined from 14 species of southern hardwoods. Static bending and tensile properties (parallel to surface) of specimens were negatively correlated to stem specific gravity (wood plus bark), chip bulk density, and fiber bulk density. Bending and tensile properties increased with increasing densification ratio, but the rate of increase was much less than published information for flakeboard from 9 of the 14 species. Results for internal bond strength were inconclusive. By regression analysis, internal bond was independent of stem specific gravity, chip bulk density, and fiber bulk density. Measurements of fiber pH and Bauer–McNett screen classification also failed to explain the wide variation in internal bond.

Introduction

Most strength properties of flakeboards and particleboards are negatively correlated with the wood's specific gravity. Particleboards made from high-density species are therefore weaker than boards of equal weight made from low-density species. Admittedly, more resin is spread per unit of surface area on dense particles than on less dense particles, but the close contact that occurs when lighter particles are pressed promotes better resin efficiency and is the controlling factor affecting strength properties (4).

In fiberboards, i.e., boards made from fibers produced from chips processed through a steam-pressurized disc refiner, strength properties and wood specific gravity are not closely correlated as in particleboards and flakeboards. For this reason, wood of dense species is being utilized for medium-density fiberboard (2). However, the exact nature of the relationship between fiberboard strength and wood density is not comprehensively reported in the literature. The present study was designed to investigate how species density affects bending and tensile properties of fiberboards produced from pressure-refined fibers. Fourteen species of southern hardwoods were selected for their range of specific gravities and their abundance on southern pine sites (Table 1). These 14 species represent about 87% of the total hardwood volume on southern pine sites.

Table 1. Approximate Volume[1] of 14 Southern Hardwoods Growing on Pine Sites.

Species	Species Code	Approximate Volume on Pine Sites (%)
Sweetgum (*Liquidambar styraciflua* L.)	SG	21
Hickory, true (*Carya* spp.)	Hi	10
Black tupelo (*Nyssa sylvatica* Marsh.)	BT	9
Post oak (*Quercus stellata* Wangenh.)	PO	9
Southern red oak (*Q. falcata* Michx.)	SRO	9
Water oak (*Q. nigra* L.)	WaO	8
White oak (*Q. alba* L.)	WO	8
Yellow-poplar (*Liriodendron tulipifera* L.)	YP	4
Sweetbay (*Magnolia virginiana* L.)	SB	3
White ash (*Fraxinus americana* L.)	WA	2
Red maple (*Acer rubrum* L.)	RM	1
Winged elm (*Ulmus alata* Michx.)	WE	1
Hackberry (*Celtis occidentalis* L.)	Ha	1
Blackjack oak (*Q. marilandica* Muenchh.)	BjO	1
		87

[1] Percentages of all hardwood volume growing on southern pine sites; data based on Forest Survey data for Alabama, Louisiana, Texas, Oklahoma, 1963-1965.

Experimental Procedure

The study had only two major variables: (1) hardwood species with stem specific gravity (wood plus bark) ranging from 0.396 to 0.655 (Table 1) and (2) fiberboard densities of 38.7 lb/ft^3 ($0.62\ g/cm^3$) and 51.2 lb/ft^3 ($0.82\ g/cm^3$). Four fiberboard panels of each density were pressed from each species.

Collection and Preparation of Material

For each species, three 6-in. (152.4 mm) trees were selected from different sites in central Louisiana. All material to a 2-in. (50.8 mm) top diameter was chipped with bark intact at a local sawmill. Green chips were transported to the Bauer Bros. Company laboratory in Springfield, Ohio, for refining in a Bauer 418 pressurized-refiner.[1] An attempt was made to maintain refiner conditions at a steam pressure of 95 psi (6.6 MPa), retention time of 5 minutes, and plate clearance of 0.050 in. (1.27 mm). Because of a temporary reduction in steam pressure, three species (winged elm, water oak, and red maple) were refined at 82 psi (5.7 MPa).

Analysis of chips entering and of fibers leaving the refiner indicated that moisture content (MC) was increased substantially in the refiner. Averaged over all species, moisture content was 71% for chips entering the refiner and 109% for fibers coming out. As expected, dry chip bulk density was positively related (significant at 0.01 level) to stem specific gravity; i.e., chip bulk density increased with increasing stem specific gravity (Table 2). Although fiber bulk density was generally greater for species of high specific gravity, the relationship was significant only at the 0.05 level. Other factors, such as species reaction to steam-pressure and inability to control the steam pressure at desired levels, no doubt contributed to the variability in quality of fiber leaving the refiner.

Wet fibers were dried to about 3% MC at a temperature of approximately 220° F (104° C). The fibers were then blended with 10% resin solids (Allied Chemical Fiberbond Binder) in a rotating drum-type blender.

Mat and Board Formation

Resin-spread fibers sufficient for a single board [3/8-in. (9.5 mm) thick] were passed through a 12-in. (305 mm), single-disc, laboratory refiner equipped with spiked teeth. This

[1]Mention of trade names is solely for identification of material and equipment used and does not imply endorsement by the U.S. Department of Agriculture.

Table 2. Properties of 14 Hardwood Species Before and After Refining.

Species Code	Stem[1] Specific Gravity	Stem[1] Bark Percent	Chip Moisture Content (%)	Dry Bulk Density lb/ft^3 (Specific Gravity) Chips	Fibers
	0.655	.6	55	13.55 (0.217)	1.78 (0.028)
BjO	0.639	23.0	79	13.24 (0.212)	2.11 (0.034)
PO	0.627	16.5	56	14.10 (0.226)	2.28 (0.036)
SRO	0.607	20.0	72	12.24 (0.196)	1.39 (0.022)
Hi	0.597	18.6	54	13.31 (0.213)	2.51 (0.040)
WE[2]	0.578	9.5	62	12.22 (0.196)	2.13 (0.034)
WaO[2]	0.562	15.6	70	12.18 (0.195)	1.92 (0.031)
WA	0.543	14.7	48	10.81 (0.173)	1.88 (0.030)
Ha	0.532	10.9	64	10.55 (0.169)	1.84 (0.029)
RM[2]	0.500	12.2	62	11.11 (0.178)	1.53 (0.024)
BT	0.491	14.2	84	10.71 (0.171)	1.29 (0.021)
SG	0.439	13.4	105	9.52 (0.152)	1.48 (0.024)
SB	0.437	13.5	98	9.09 (0.145)	1.56 (0.025)
YP	0.396	15.2	88	7.61 (0.122)	1.55 (0.025)

[1] Based on species averages for 10 trees [6 in. (154 mm) dbh] collected from sampling locations in each species range within an 11-state area. Specific gravity is based on ovendry weight and green volume (wood plus bark); percent of bark is based on ovendry weight (F. G. Manwiller, Southern Forest Experiment Station, unpublished data).

[2] Steam pressure, 82 psi (5.7 MPa) in refiner; all others, 95 psi (6.6 MPa).

procedure was shown previously (5) to increase internal bond strength substantially in sweetgum fiberboards. The milled fibers were then blown into a cyclone and allowed to drop about 4 ft (1.22 m) into a forming box (16.5 by 20 in. or 419 by 508 mm). Mat moisture content entering the hot press averaged 8.5% with a standard deviation of 0.70%.

Low-density mats were pre-pressed at 100 psi (6.99 MPa); and high-density mats, at 300 psi (21 MPa). Mats were then placed in an oil-heated hot press maintained at 330° F (166° C) and were compressed under 485 psi (33.9 MPa) specific pressure. Closing time to thickness stops averaged 10 seconds for low-density and 89 seconds for high-density mats.

Tests

All laboratory boards were conditioned at 50% relative humidity and 72° F (22° C) for 2 weeks before they were tested for bending and tensile properties. One bending, one tension-parallel-to-surface, and five tension-perpendicular-to-surface (internal bond) specimens were prepared from adjoining strips in the center of each laboratory board. All tests were conducted according to ASTM D 1037-72a except that bending specimens were 2 in. (50.8 mm) wide (1). Average moisture content at time of test for all specimens ranged from 5.4 to 6.3%. All fiberboard densities, therefore, are based on this moisture content.

Results and Discussion

Properties of fiberboards were somewhat low (Table 3), probably because of the inclusion of bark. In a previous study (6), including bark in fiberboards made of sweetgum, hickory, and southern red oak decreased tensile and bending strengths by 16 to 18%, modulus of elasticity (MOE) by 10 to 14%, and internal bond (IB) by 8%. The decrease was attributed to the greater percentage of fines passing a 48-mesh screen in the barky fibers.

Static Bending

Fiberboards made at both densities showed similar trends. Average modulus of rupture (MOR) and MOE were lowest in fiberboards prepared from winged elm and greatest in those prepared from yellow-poplar and sweetgum (Table 3). Wide variation in stem specific gravity is a

Table 3. Mechanical Properties of Fiberboards from 14 Species of Southern Hardwoods Prepared at Densities of 0.62 and 0.82 g/cm^3.[1] (English Units)

	Static Bending		Tension Parallel		
Species Code	MOR (psi)	MOE (10^3 psi)	σ_{max} (psi)	E (10^3 psi)	IB (psi)
WO	2,606	254	1,613	225	66
	4,886	435	3,462	490	149
BjO	2,968	283	1,560	216	80
	4,615	416	3,250	417	126
PO	3,006	310	1,795	300	107
	4,713	446	2,771	492	199
SRO	3,706	376	2,259	316	91
	5,409	511	3,710	566	177
Hi	3,138	249	1,748	260	68
	4,750	365	3,330	484	211
WE	2,537	222	1,226	203	87
	4,063	353	3,029	423	157
WaO	3,371	305	1,996	276	79
	5,242	458	3,922	522	180
WA	3,642	328	2,421	321	109
	6,595	524	4,153	560	230
Ha	3,221	322	1,808	318	78
	4,930	440	3,398	485	192
RM	3,344	328	2,165	302	91
	5,546	505	4,125	509	211
BT	3,939	354	2,092	278	80
	6,781	534	4,296	496	197
SG	4,554	432	2,700	374	83
	6,398	561	4,292	579	155
SB	3,817	371	2,157	301	61
	6,330	528	3,969	539	165
YP	4,524	438	2,502	351	68
	6,802	576	4,481	573	125

[1]The first line for each species gives values for low-density specimens; the second line gives values for high-density specimens.

Table 3. Mechanical Properties of Fiberboards from 14 Species of Southern Hardwoods Prepared at Densities of 0.62 and 0.82 g/cm^3.[1] (SI Units)

Species Code	Static Bending MOR (MPa)	Static Bending MOE (MPa)	Tension Parallel σ_{max} (MPa)	Tension Parallel E (MPa)	IB (MPa)
WO	17.97 33.69	1750 3000	11.12 23.87	1550 3380	0.46 1.03
BjO	20.46 31.82	1950 2870	10.76 22.41	1490 2880	0.55 0.87
PO	20.73 32.50	2140 3080	12.38 19.11	2070 3390	0.74 1.37
SRO	25.55 37.30	2590 3520	15.58 25.58	2180 3900	0.63 1.22
Hi	21.64 32.75	1720 2520	12.05 22.96	1790 3340	0.47 1.46
WE	17.49 28.01	1530 2430	8.45 20.89	1400 2920	0.60 1.08
WaO	23.24 36.14	2100 3160	13.76 27.04	1900 3600	0.55 1.24
WA	25.11 45.47	2260 3610	16.69 28.64	2210 3860	0.75 1.59
Ha	22.21 33.99	2220 3030	12.47 23.43	2190 3340	0.54 1.32
RM	23.06 38.24	2260 3480	14.93 28.44	2080 3510	0.63 1.46
BT	27.16 46.76	2440 3680	14.42 29.62	1920 3420	0.55 1.36
SG	31.40 44.11	2980 3870	18.62 29.59	2580 3990	0.57 1.07
SB	26.32 43.65	2560 3640	14.87 27.37	2080 3720	0.42 1.14
YP	31.19 46.90	3020 3970	17.25 30.90	2420 3950	0.47 0.86

[1] The first line for each species gives values for low-density specimens; the second line gives values for high-density specimens.

major contributor to the species effects. By regression analysis, MOR and MOE were negatively correlated to stem specific gravity (Figure 1), dry chip bulk density (Figure 2), and dry fiber bulk density (Figure 3). All regressions were significant at the 0.01 level.

Bending MOR and MOE were best described by the densification ratio (ratio of metric fiberboard density to stem specific gravity). Regression analysis showed that MOR and MOE increased as densification ratio increased (Figure 4). However, the reaction to changes in densification ratio is apparently less pronounced in fiberboard than in flakeboard. Hse (3) prepared flakeboards from nine species (all common to this study) with flakes 3 in. (76.2 mm) long, 3/8 in. (9.5 mm) wide, and 0.015 in. (0.38 mm) thick and established regressions of bending properties on compaction (densification) ratio. Over a comparable range of ratios, increases in MOR and MOE for flakeboard were almost double the increases for fiberboard.

Figure 5 illustrates a very close correlation between MOR and MOE ($r^2 = 0.93$). Thus, nondestructive testing methods could be used to indirectly establish a value for MOR by determining MOE.

Tension Parallel to Surface

As in bending, average values for tensile strength were lowest in fiberboards prepared from winged elm and greatest in those prepared from yellow-poplar and sweetgum (Table 3). Tensile strength was negatively correlated to stem specific gravity (Figure 6), dry bulk chip density (Figure 7), and dry fiber bulk density (Figure 8). Tensile strength increased with increasing densification ratio (Figure 9). Similar results were found for tensile MOE, but the regressions generally explained less of the total variation.

Internal Bond

Internal bond strength is very responsive to board density (Figure 10). However, attempts to relate IB to stem specific gravity, chip bulk density, or fiber bulk density proved futile. Variation among species was so widespread that trends could not be established. High-density species did not necessarily produce fiberboard with better or worse IB strength than did low-density species. Specific gravity alone, therefore, was not enough to predict IB strength. Further attempts to correlate the percent of bark or the fiber pH to IB strength also proved inconclusive. A significant relationship was obtained between IB and core densification ratio, but 60% of the total variation was unexplained.

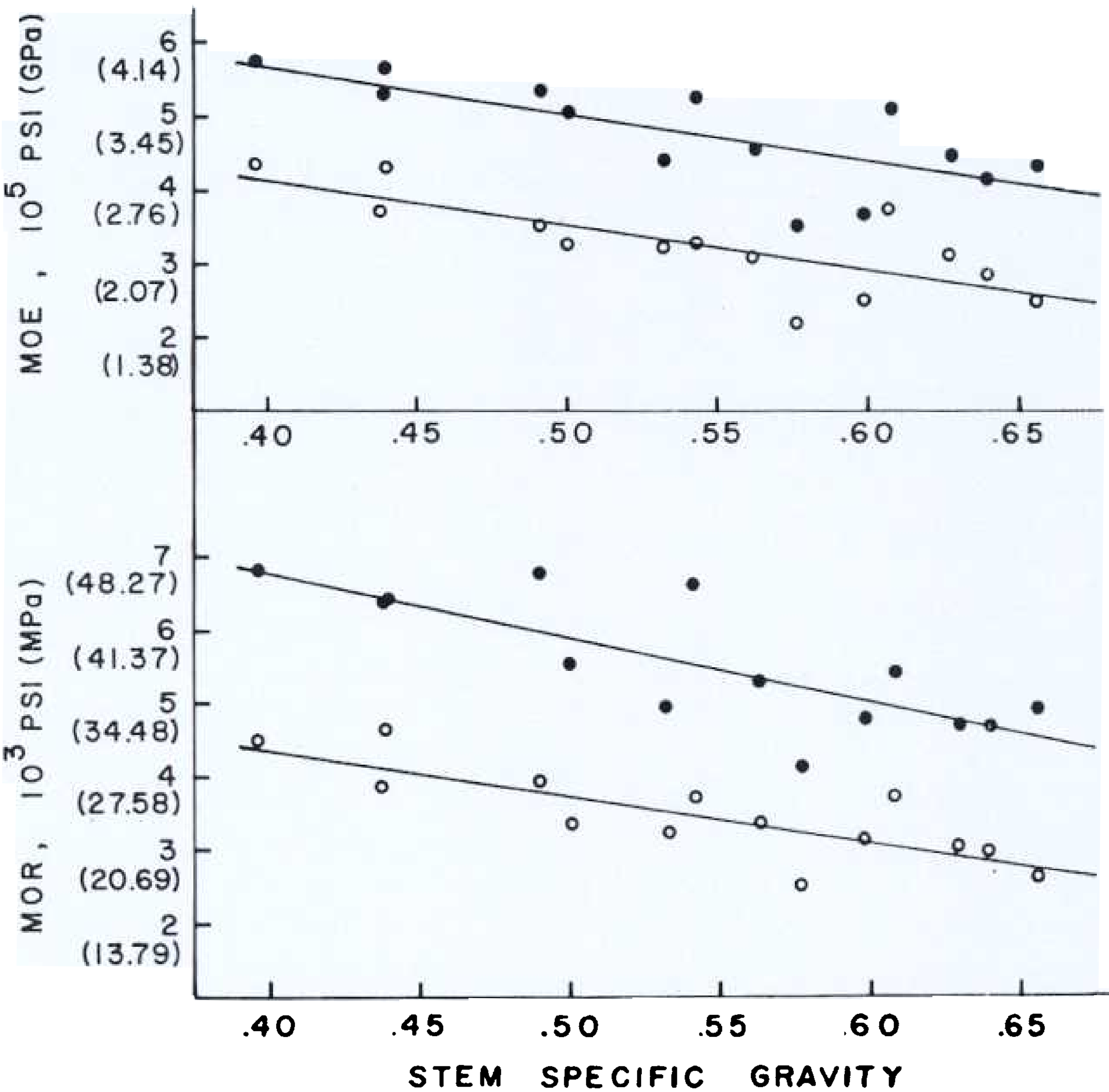

Figure 1. Correlation of Bending Properties to Stem Specific Gravity for High-Density (Solid Dots) and Low-Density (Open Circles) Fiberboards. In Figures 1 through 9, Each Data Point Represents an Average of Four Replications for Each of 14 Southern Hardwood Species.

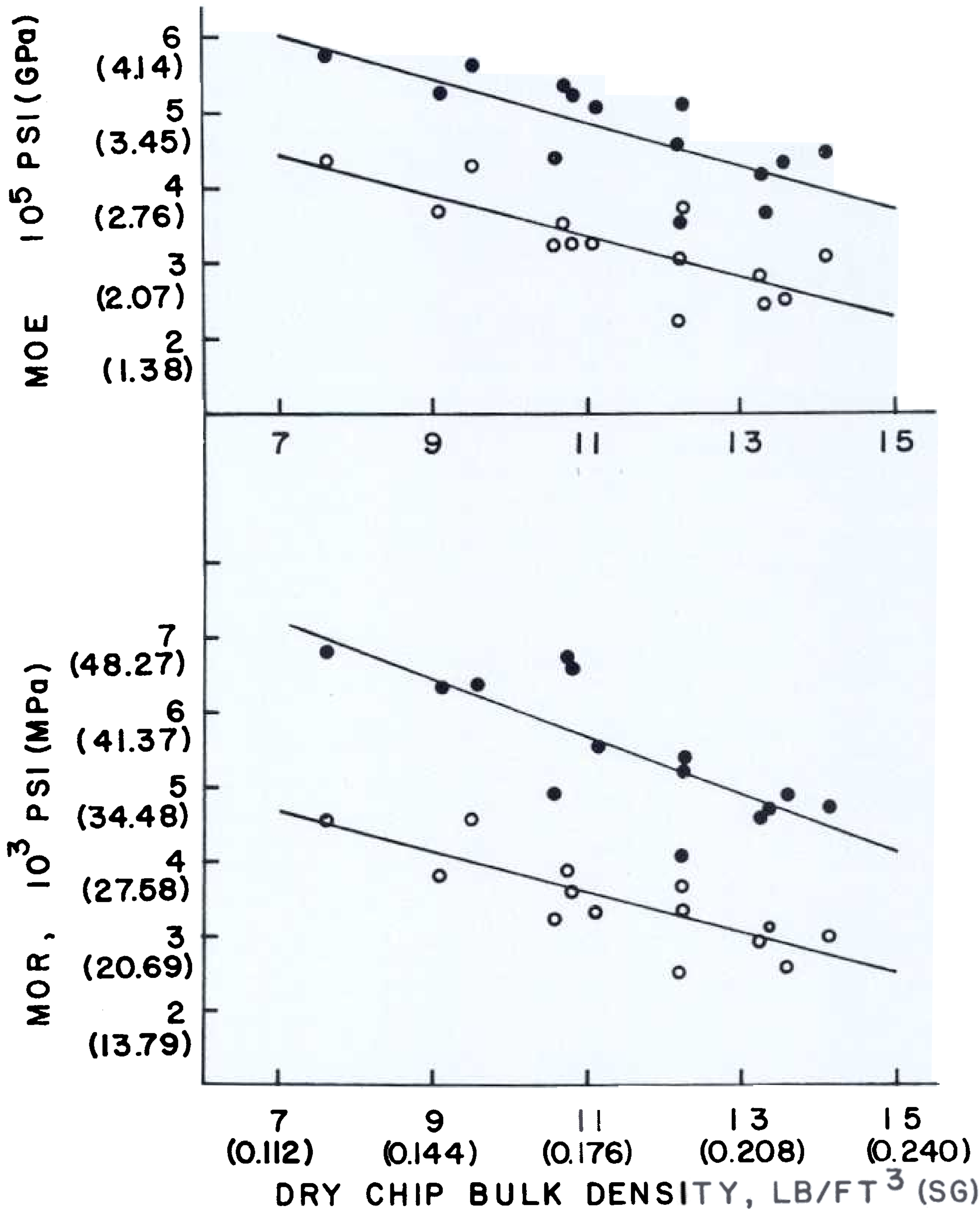

Figure 2. Correlation of Bending Properties to Dry Chip Bulk Density for High-Density (Solid Dots) and Low-Density (Open Circles) Fiberboards.

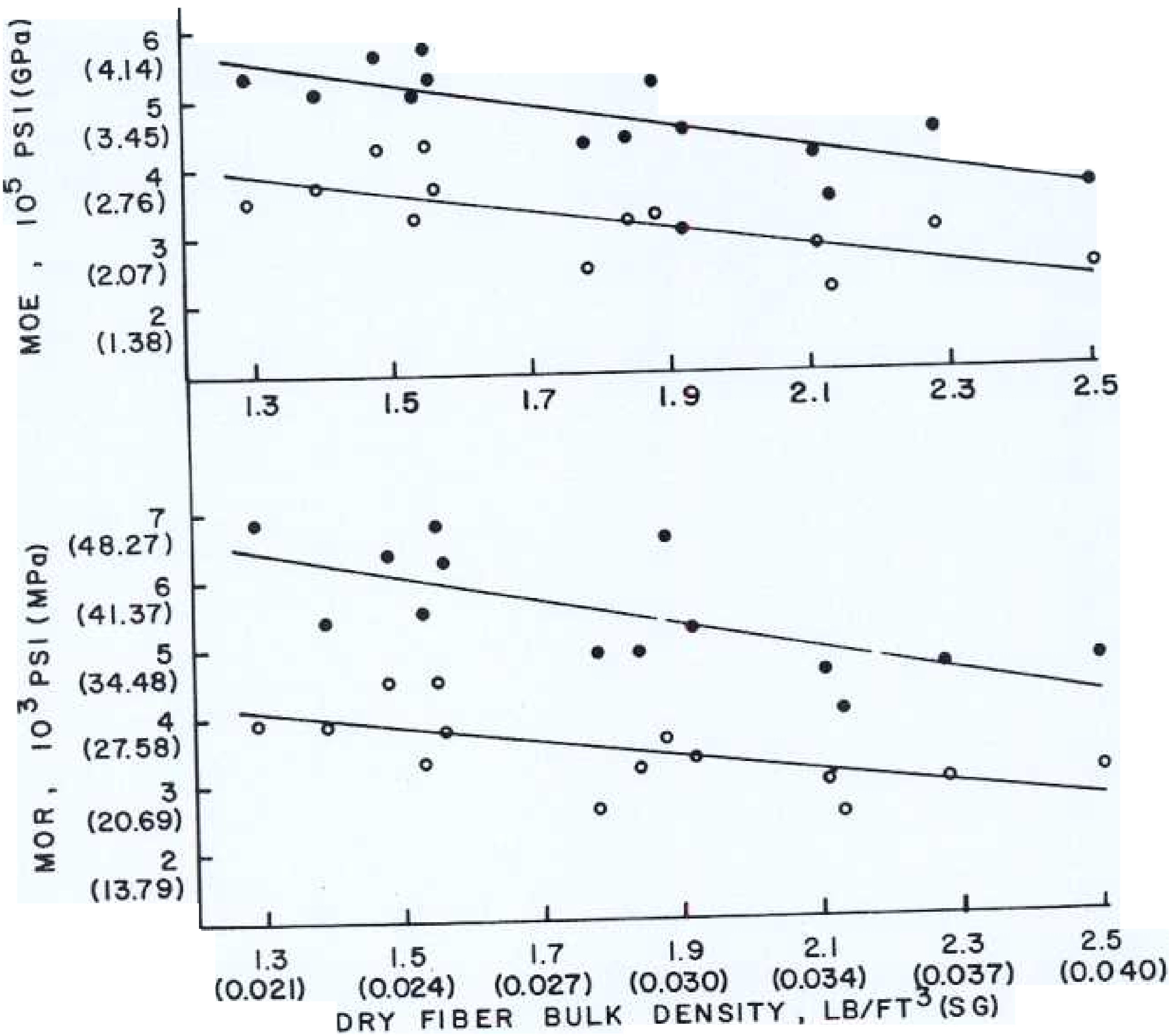

Figure 3. Correlation of Bending Properties to Dry Fiber Bulk Density for High-Density (Solid Dots) and Low-Density (Open Circles) Fiberboards.

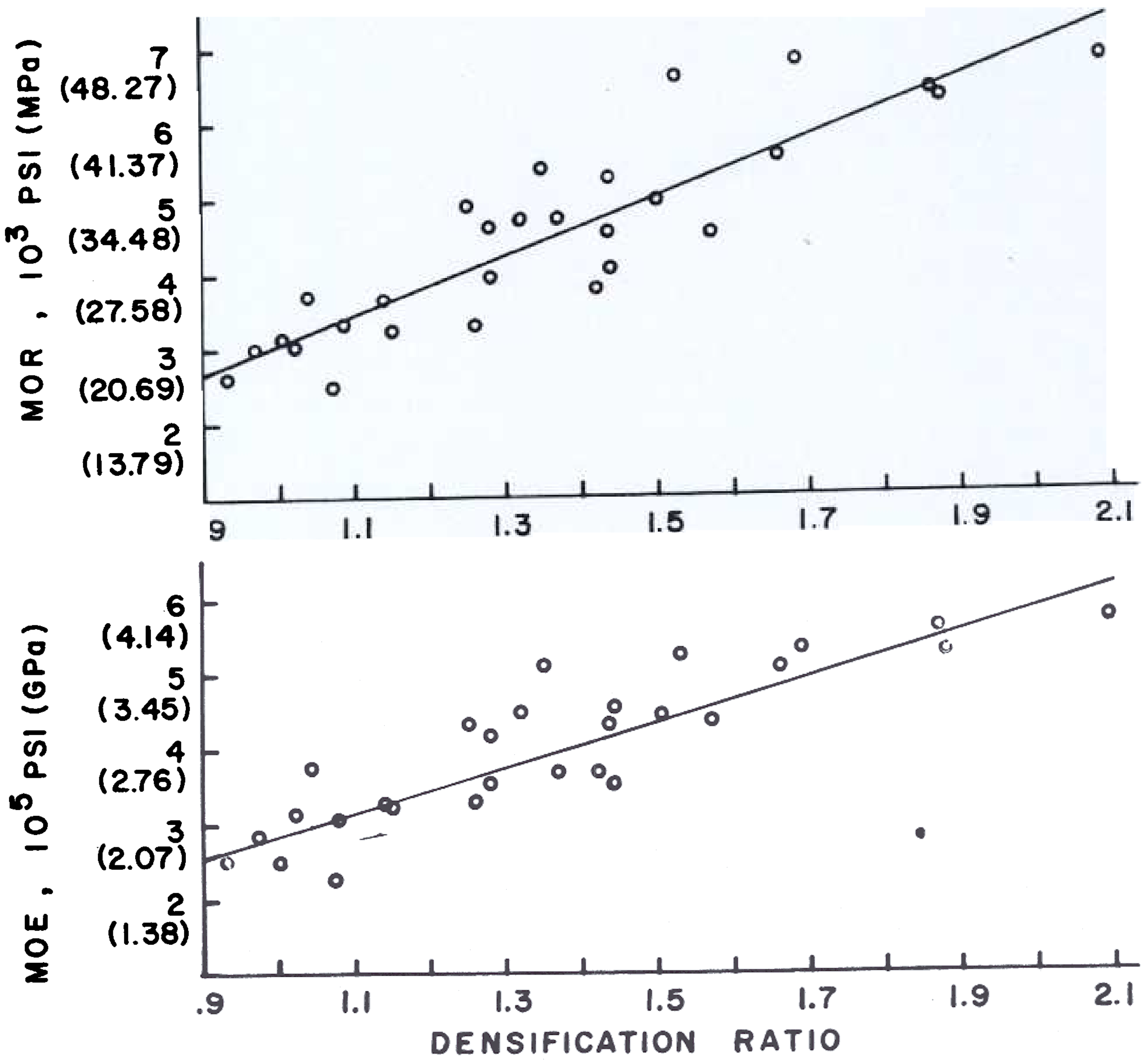

Figure 4. Correlation of Bending Properties to Densification Ratio for Both Low- and High-Density Fiberboards Made from 14 Species of Hardwoods.

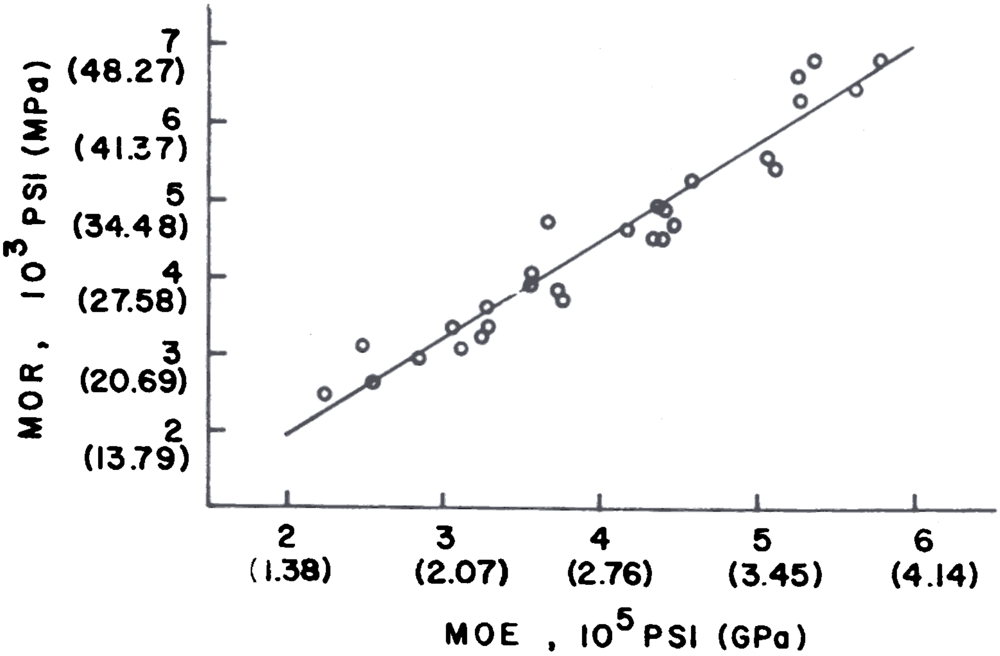

Figure 5. Correlation of Bending Strength (MOR) to Bending Modulus of Elasticity (MOE) for Fiberboards from 14 Species of Southern Hardwoods.

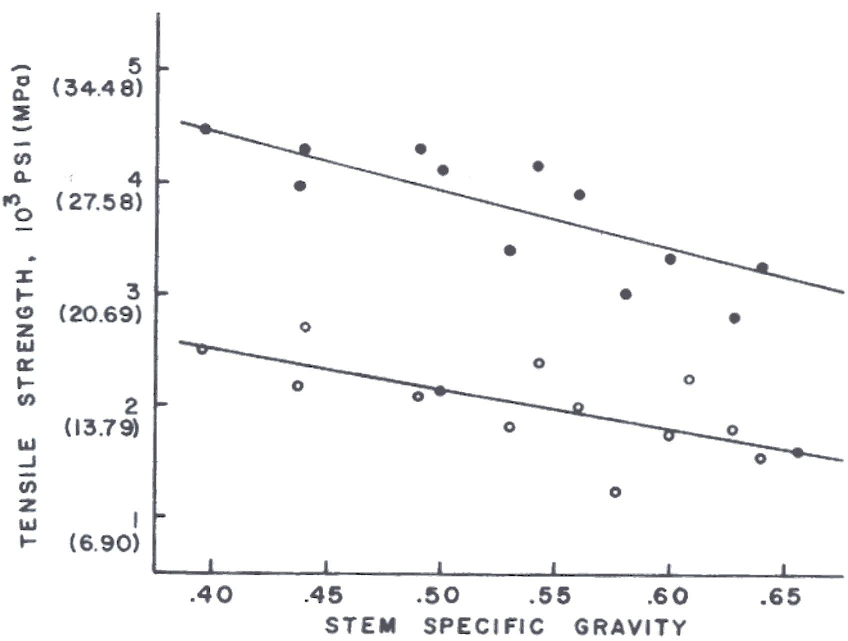

Figure 6. Correlation of Tensile Strength to Stem Specific Gravity for High-Density (Solid Dots) and Low-Density (Open Circles) Fiberboards

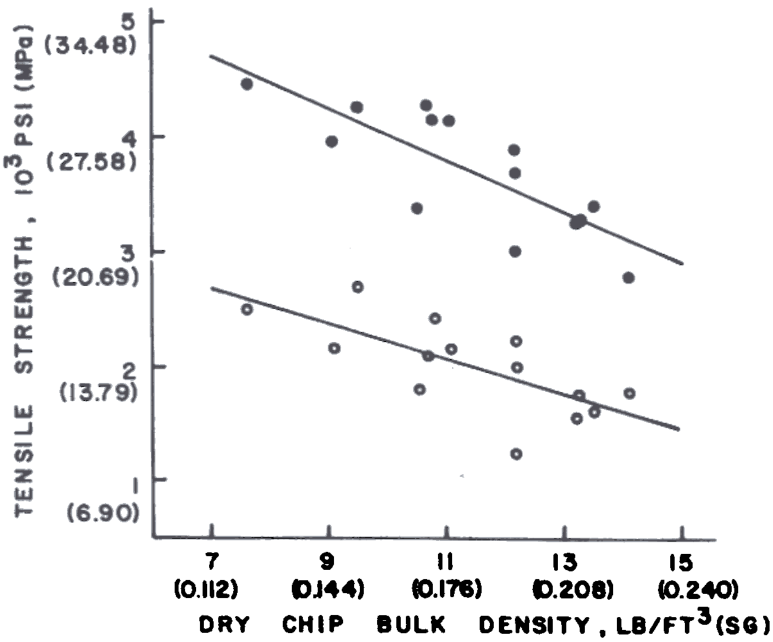

Figure 7. Correlation of Tensile Strength to Dry Chip Bulk Density for High-Density (Solid Dots) and Low-Density (Open Circles) Fiberboards.

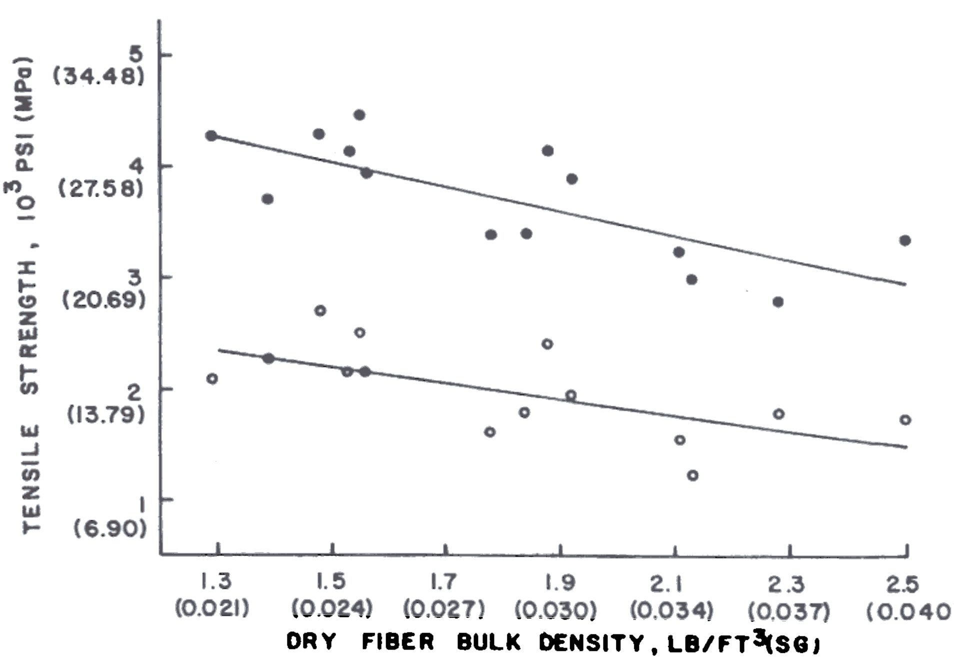

Figure 8. Correlation of Tensile Strength to Dry Fiber Bulk Density for High-Density (Solid Dots) and Low-Density (Open Circles) Fiberboards.

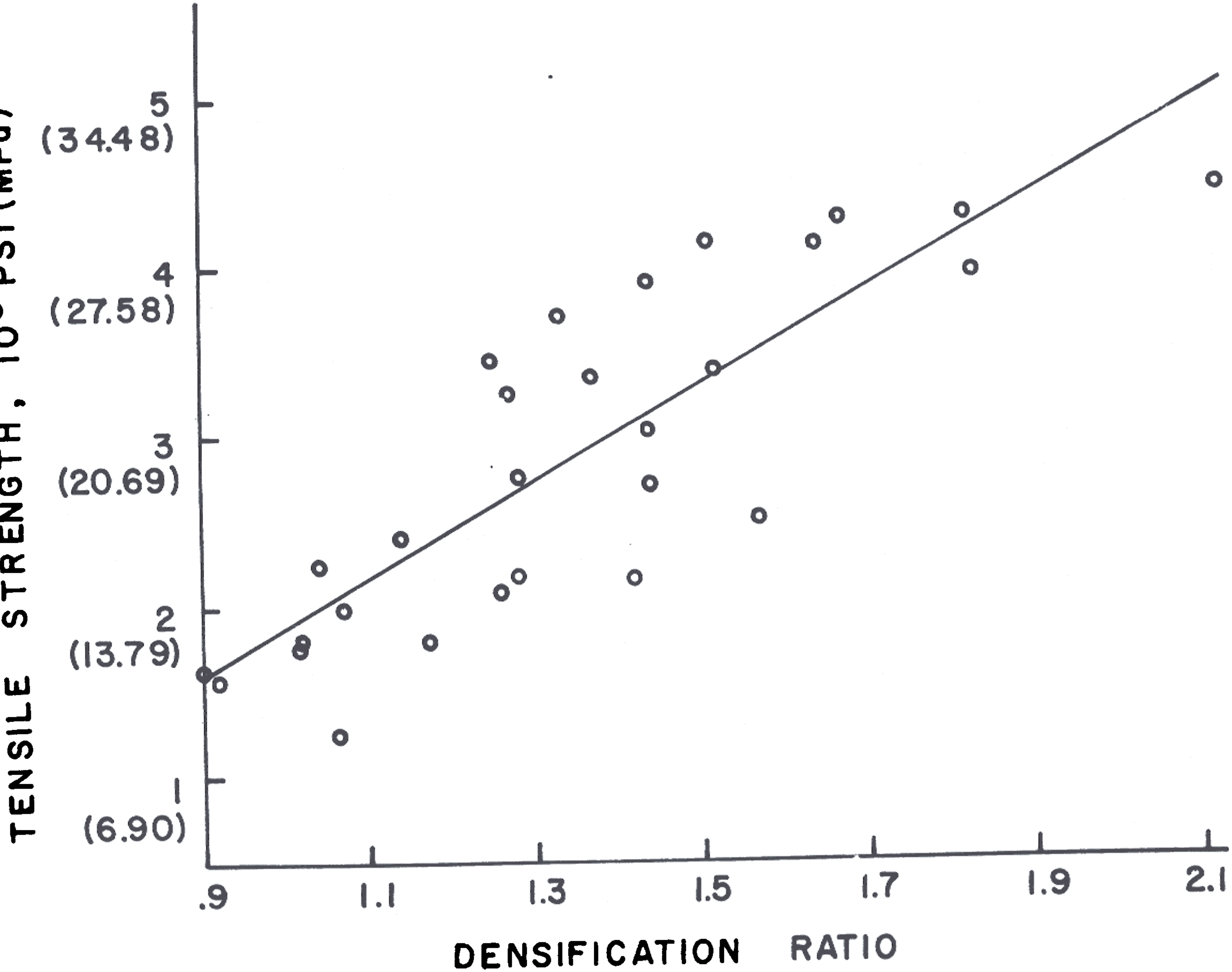

Figure 9. Correlation of Tensile Strength to Densification Ratio for Fiberboards from 4 Species of Southern Hardwoods.

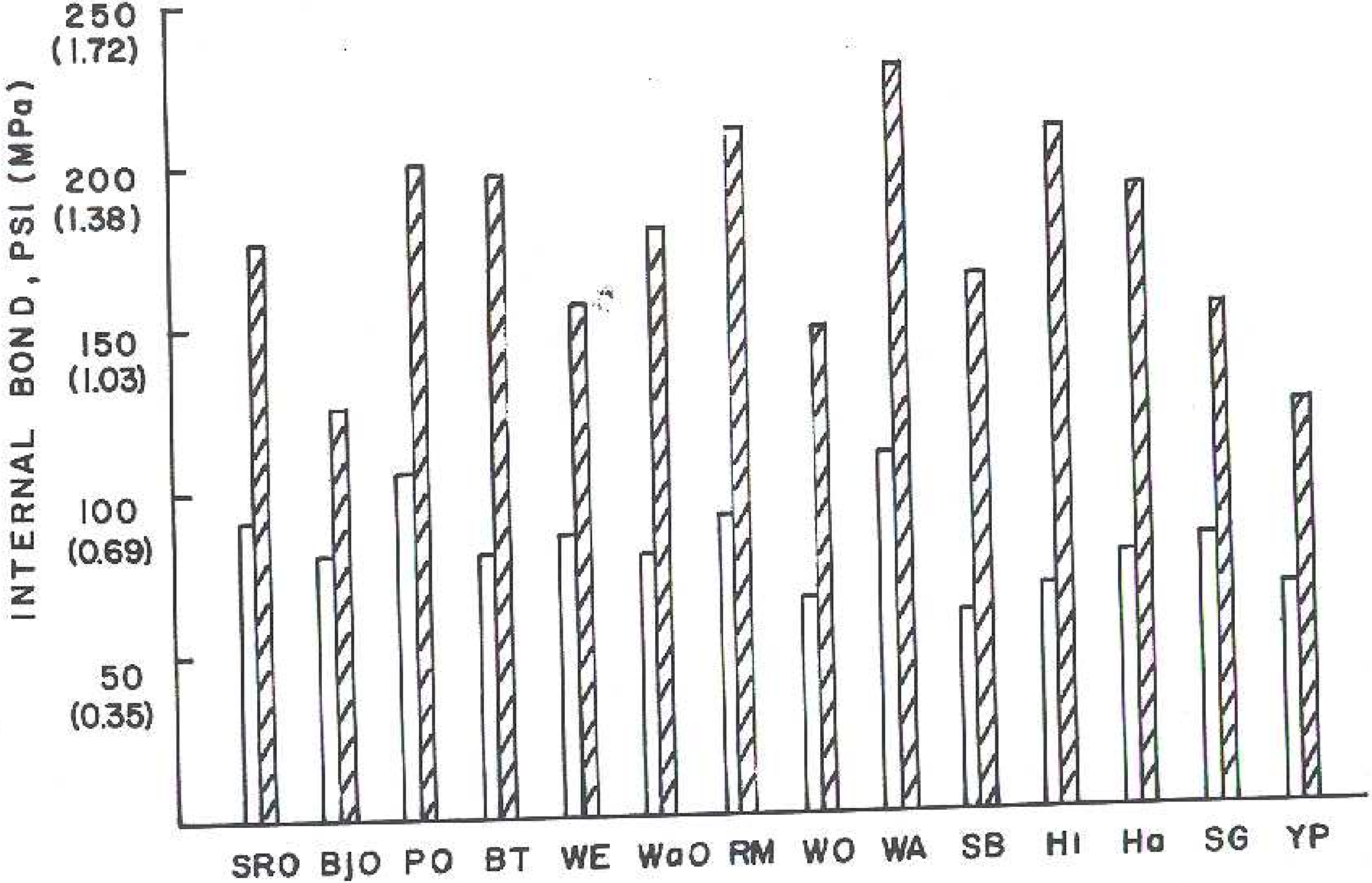

Figure 10. Internal Bond Strength for 14 Species of Southern Hardwoods. Shaded Areas Indicate High-Density Specimens (0.82 g/cm^3), and Clear Areas Indicate Low-Density Specimens (0.62 g/cm^3).

Table 4. Bauer-McNett Fiber Classification of Pressure-Refined Fibers from 14 Southern Hardwood Species.

Species Code	Bauer–McNett Classification +8	-8/+14	-14/+28 %	-28/+48	-48
WO	55.1	14.5	10.4	7.1	12.9
BjO	30.1	19.5	16.2	14.1	20.1
PO	33.5	19.3	15.0	12.7	19.5
SRO	32.5	15.6	16.7	18.2	17.0
Hi	52.7	14.5	10.3	7.9	14.6
WE[1]	61.8	13.7	7.2	4.5	12.8
WaO[1]	57.2	12.6	11.0	7.5	11.7
WA	32.7	21.4	14.8	12.7	18.4
Ha	44.4	12.4	11.7	10.5	21.0
RM[1]	45.9	13.5	15.1	10.6	14.9
BT	57.4	13.2	11.0	7.1	11.3
SG	22.8	26.8	23.9	14.0	12.5
SB	49.1	19.5	13.7	6.8	10.9
YP	26.1	17.6	19.3	16.6	20.4

[1]Steam pressure, 82 psi (5.7 MPa) in refiner; all others, 95 psi (6.6 MPa).

To determine if IB was related to the proportion of fines (material passing a 48-mesh screen), three replications of fiber samples for each species were fractionated in a Bauer-McNett classifier. The results (Table 4) indicated a wide variation in fiber sizes. However, regression analysis failed to indicate any significant relationships between percent fines and IB. Internal bond strength is apparently controlled by complicated interactions of factors too numerous to isolate in this study.

Conclusions

Increasing stem specific gravity, chip bulk density, and fiber bulk density decreased MOE, MOR, and tensile strength of medium-density fiberboard. Bending and tensile properties increased with increasing densification ratio, but the rate of increase was much less pronounced than in comparable published information for flakeboard. These relationships were significant over the broad range of specific gravities studied but may not have been apparent if only a narrow range of specific gravities had been considered. Even though specific gravity is a significant factor, other species characteristics may also contribute: for example, winged elm was not the species with the highest density, but it had the lowest properties.

Internal bond strength was independent of stem specific gravity, chip bulk density, and fiber bulk density. Fiber pH and screen classification of fibers also failed to explain the wide variation in IB. Internal bond results were inconclusive and were complicated by interactions too numerous to isolate in this study.

References

1 American Society for Testing and Materials. 1974. Standard Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials. *ASTM D 1037-72a*, Part 22, p. 275-316.

2. Anonymous. 1974. Summary of the Discussion Period at the Pressure-Refined Fiber Session. *Seventh Particleboard Proceedings* [1973], WSU, p. 69-79.

3. Hse, C.-Y. 1975. Properties of Flakeboards from Hardwoods Growing on Southern Pine Sites. *For. Prod. J.* 25(3): 48-53.

4. Moslemi, A. A. 1974. *Particleboard, Vol. 1: Materials*. South. Ill. Univ. Press: Carbondale. 244 p.

5. Suchsland, O., and G. E. Woodson. 1976. Properties of Medium-Density Fiberboard Produced in an Oil-Heated Press. *USDA For. Serv. Res. Paper SO-116*, 10 p. South. For. Exp. Stn., New Orleans, La.

6. Woodson, G. E. 1976. Effects of Bark, Density Profile and Resin Content on Medium-Density Fiberboards from Southern Hardwoods. *For. Prod. J.* 26(2): 39-42.