DATA BASIC TO THE ENGINEERING DESIGN OF RECONSTITUTED FLAKEBOARD

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ABSTRACT

Flakeboards made with uniform densities throughout their thickness and different degrees of flake alignment were used to establish relationships between bending, tension, and compression values of modulus of elasticity or modulus of rupture (or stress to maximum load) and the variables of specific gravity and flake alignment.

An equation using sonic velocity as an indicator of alignment was developed that describes the relations over a broad range with a high degree of confidence.

Bending stiffness of boards having a density gradient were predicted within approximately ±20% using the derived relationships.

INTRODUCTION

Hot-pressed particleboards or flakeboards are characterized by a density gradient through the thickness plane [4,6]. The gradient is a result of progressive plasticization of the wood. Moisture in the board is converted to steam and the heat is transferred from the faces of the board to the core in pressing. The final form of the density gradient is determined by such factors as press temperature, press closing rate, average moisture content, distribution of moisture within the mat, particle geometry, and species.

Because the mechanical properties of reconstituted wood increase substantially with an increase in density, the "effective" bending strength and stiffness of a flakeboard depend largely on the properties of its outermost layers; in this respect it can be compared to an I-beam (Figure 1).

The design of flakeboards for applications with specific flexural properties requires a knowledge of the relationship between density, strength and stiffness. Unfortunately, most available data have been derived from boards of varying levels of average density, themselves containing a density gradient. Few attempts have been made to establish the relationship between physical properties and layer densities [1,2,5,7]. This research establishes the relationship betwen specific gravity (density) and the physical and mechanical properties of reconstituted wood flakes. The scope includes the evaluation of several flake types, two species, and several degrees of flake alignment.

EXPERIMENTAL DESIGN AND PROCEDURE

Homogeneous boards, 0.5 by 24 by 28 in. (13 by 610 by 711 mm), were constructed using three types of Douglas-fir flakes and three types of oak flakes. Duplicate boards were made at each of four density levels (30, 40, 50 and 60 lbs/ft^3) (480, 641, 801 and 961 kg/m^3) and at each of four degrees of alignment with the Douglas-fir flakes. Target alignment levels varied with the flake type used (see Table 1).

The experiment was expanded to include several types of oak flakes to provide data for a concurrent study. No replicate boards were constructed using oak flakes. Target density and alignments varied with the flake type and are shown in Table 1.

All boards except those made with the 0.045 in. (1.143 mm) thick oak flake contained 5% phenolic resin and 1% wax. The boards made from 0.045 in. oak flakes contained 6% phenolic resin and 1% wax to conform to board specifications in the concurrent study. All mats contained 10% moisture prior to pressing. Closure time was not considered as a variable since all boards were pressed to stops between initially cold platens. Time to raise the core temperature to 235°F (113°C) varied between 9 and 11 minutes depending on board specific gravity, the denser boards taking longer to heat up. The boards were held in the press for 17 to 19 minutes, and were cooled in the press.

Some problems were encountered in cold pressing the 60 lb/ft^3 (961 kg/m^3) boards. Even with the 1,500 psi (10.34 MPa) pressure on the mat, heat was necessary to close the last 0.015 in. (0.318 mm). Consequently, these 60 lb/ft^3 (961 kg/m^3) boards had a slight density gradient. Sanding the 0.5 in. (12.7 mm) boards to a 0.4375 in. (1 1.1 mm) thickness eliminated most of the density gradient and all of the face precure.

The main objective in heating the boards was to bring the core up to resin-curing

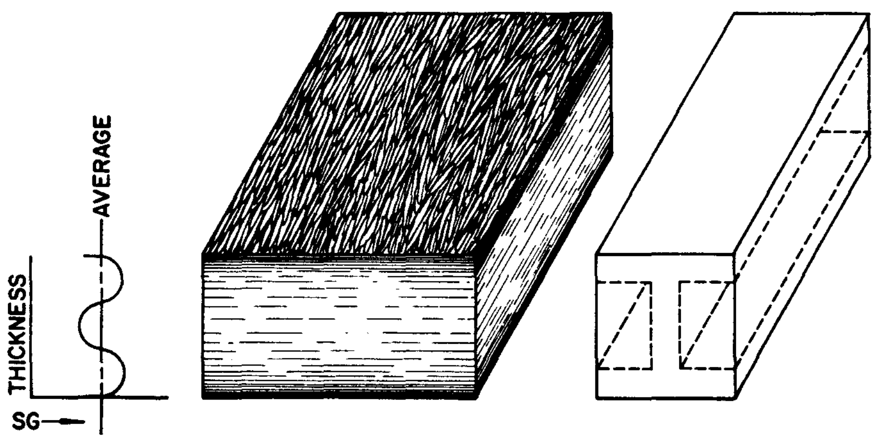

Figure 1. *"I-beam" effect of hot pressed flakeboard having a density gradient through the thickness plane.*

Table 1
Experimental Design

Flake Type[a]				
Thickness inches (mm)	*Length inches (mm)*	*Machine*	*Target Density lbs/ft³ (kg/m³)*	*Target Alignment %*
		Douglas-fir [b,c]		
0.020 (0.508)	3 (76)	Disk	30, 40, 50, 60 (480, 641, 801, 961)	0, 40, 60, 80
0.020 (0.508)	1.5 (38)	Disk	30, 40, 50, 60 (480, 641, 801, 961)	0, 35, 50, 65
0.020 (0.508)	0.75 (19)	Ring	30, 40, 50, 60 (480, 641, 801, 961	0, 15, 20, 30
		Oak [c,d]		
0.010 (0.254)	3 (76)	Disk	40, 50, 60 (641, 801, 961)	0, 30, 50, 70
0.020 (0.508)	3 (76)	Disk	40, 60 (641, 961)	0, 30, 50, 70
0.045 (1.143)	2 (51)	Ring	30, 40, 50 (480, 641, 801)	0, 50

[a]All flakes were random width.
[b] Two replications per density and alignment condition, or 32 boards for each flake size.
[c] Two samples were cut from each board in both the parallel and the perpendicular to alignment direction for bending, tensile, and compression tests. Two density gradients were samples from each board.
board for each density and alignment condition for each flake size.

temperatures in as short a period as possible, while still maintaining a minimum temperature differential between the face and core layers. Previous exploratory work showed long heat-up periods (30 minutes) to be detrimental to the glue bond. Use of 180 psi (1241 kPa) steam pressure in the press platens allowed the centerline temperature to reach 235°F (113°C) in 9-11 minutes with a maximum face-to-core temperature differential of 90°F (32°C) (Figure 2).

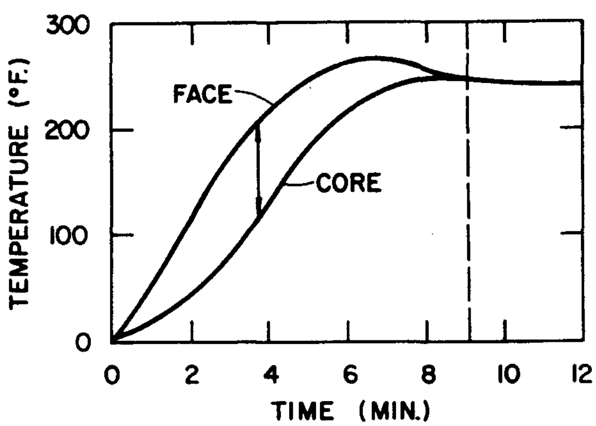

Figure 2. *Temperature curve for heating uniform density boards showing a maximum 90°F (32°C) temperature differential between face and core.*

TESTS AND MEASUREMENTS

All boards were conditioned at 65% relative humidity prior to testing. Density gradients were measured using a planer to remove layers 0.030 in. (0.762 mm) thick. Mechanical properties of bending, tension, compression, interlaminar shear, and rail shear were obtained both parallel and perpendicular to the cardinal direction of alignment, following ASTM D 1037 test procedures. Internal bond and the dimensional stability properties of thickness swelling, linear expansion, and water absorption were also measured.

Two methods were used to measure flake alignment. The first method involved measuring the angles which 200 individual flakes made with the cardinal alignment direction on the surface of each board. The second method measured the velocity of a sonic wave produced by a James V-meter through a 3 by 9 in. (76 by 229 mm) section of the bending specimens. The V-meter produced a 50 kHz sound at intervals of 0.1 second with a 1-to-100 on:off ratio. The sound was transmitted by a sending head held against one edge of the board and received by another sensor held against the opposite edge of the board. The time it took for the sound wave to travel from the sending head to the receiver was measured in microseconds. Measurements were taken in the direction parallel to alignment and also in the direction perpendicular to alignment.

The sonic method for measuring alignment proved very convenient and had such a high correlation with the physical properties of bending that it was used throughout the course of data analysis.

The following discussion deals only with results of the flexure, tension, and compression tests and their relationship to specific gravity and flake alignment. The remainder of the data will be analyzed and published later.

RESULTS AND DISCUSSION

Specific Gravity

Analysis of density profile data showed a slight gradient in the 60 lb/ft^3 (961 kg/m^3) boards. Face layers were approximately 8-9% higher in specific gravity than the average board value. Deviation of the gradient in the other boards was generally within ±5% of the average.

Flake Alignment

A typical histogram of the distribution of 200 flake alignment angles as measured around the cardinal direction of alignment is shown in Figure 3. The average alignment angle, θ, is computed as the summation of the measured angles without regard to sign divided by the summation of the frequencies [3]. The percent of alignment is then defined as $(45 - \theta)/45$, implying that a board with random distribution of flakes has a 0% alignment. When board properties are tested in a direction perpendicular to the cardinal direction of alignment, the alignment is designated as being negative. The standard deviation of the flake angles, σ_{180}, as shown in the histograms, is a measure of the dispersion of the flake angles. Earlier work [3] indicated that the relationship between 8 and the standard deviation was somewhat different from a normal distribution. The present study, however, showed only a slight bow in the data and indicated the relationship could be described very well by a straight line (Figure 4).

An easy method used in the past to measure flake alignment involved determining the percent of flake angles which fall within ±20° of the cardinal direction of alignment. The relationship found in this study, comparing percent of angles within ±20° of the cardinal direction of alignment to θ, was almost identical to that determined in past work [3] (Figure 5).

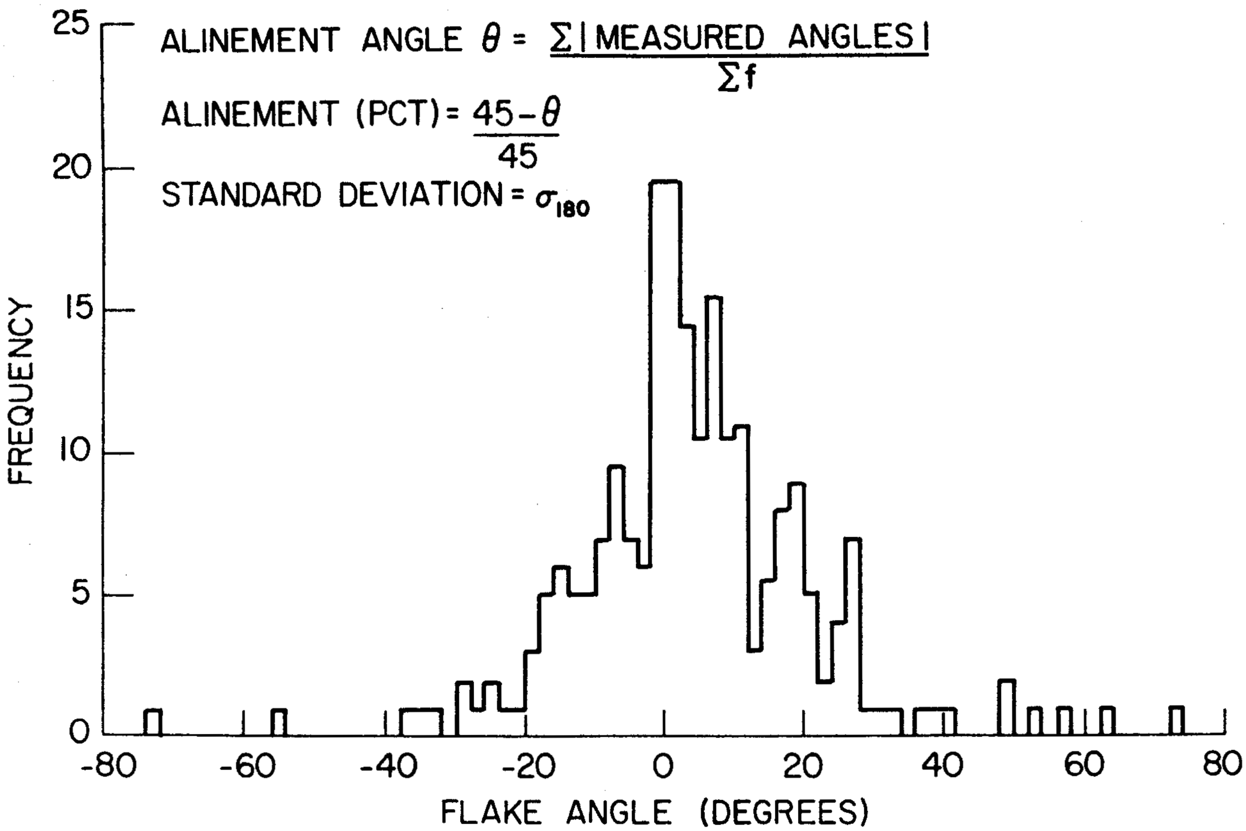

Figure 3. *Flake alignment angles as measured for a 0.020 × 3 in. (0.508 × 76 mm) Douglas-fir flakeboard with 72% alignment.*

Since bending stiffness is closely related to alignment, the ratio of the bending modulus of elasticity (MOE) in the parallel direction to that of the bending MOE in the perpendicular direction is sometimes used to express degree of flake alignment. A very strong correlation was found between the bending MOE ratio and the sonic velocity ratio (Figure 6). The shaded area in the graph does not represent any mathematical confidence limits but does include at least 95% of all data. Because of this strong correlation and the ease of obtaining the measurements, the sonic velocity was used as a measurement of alignment throughout the data analysis.

The relationship between the sonic velocity ratio and the percent of alignment as measured on the faces of each board is shown in Figure 7. Each flake type and species has its own relationship, which appears to be critical in determining the correlation between specific gravity, flake alignment, and flexural properties. A regression analysis combining all data without regard to flake type shows that the sonic velocity ratio approaches 3.741 at 100% alignment (Figure 7). The sonic velocity ratio is plotted on a logarithmic scale. This is necessary since the sonic velocity ratio approaches 1 as alignment approaches 0. The relationship between the sonic velocity ratio, MOE ratio (plotted on a logarithmic scale), and the percent of alignment for the compression, tension, and bending MOE properties of all flake types as a group is described in Figure 8. Compression and tension MOE have nearly the same slope, which is somewhat greater than the slope of the bending MOE curve.

Sonic velocity is compared to percent of alignment for each flake type in Figure 9.

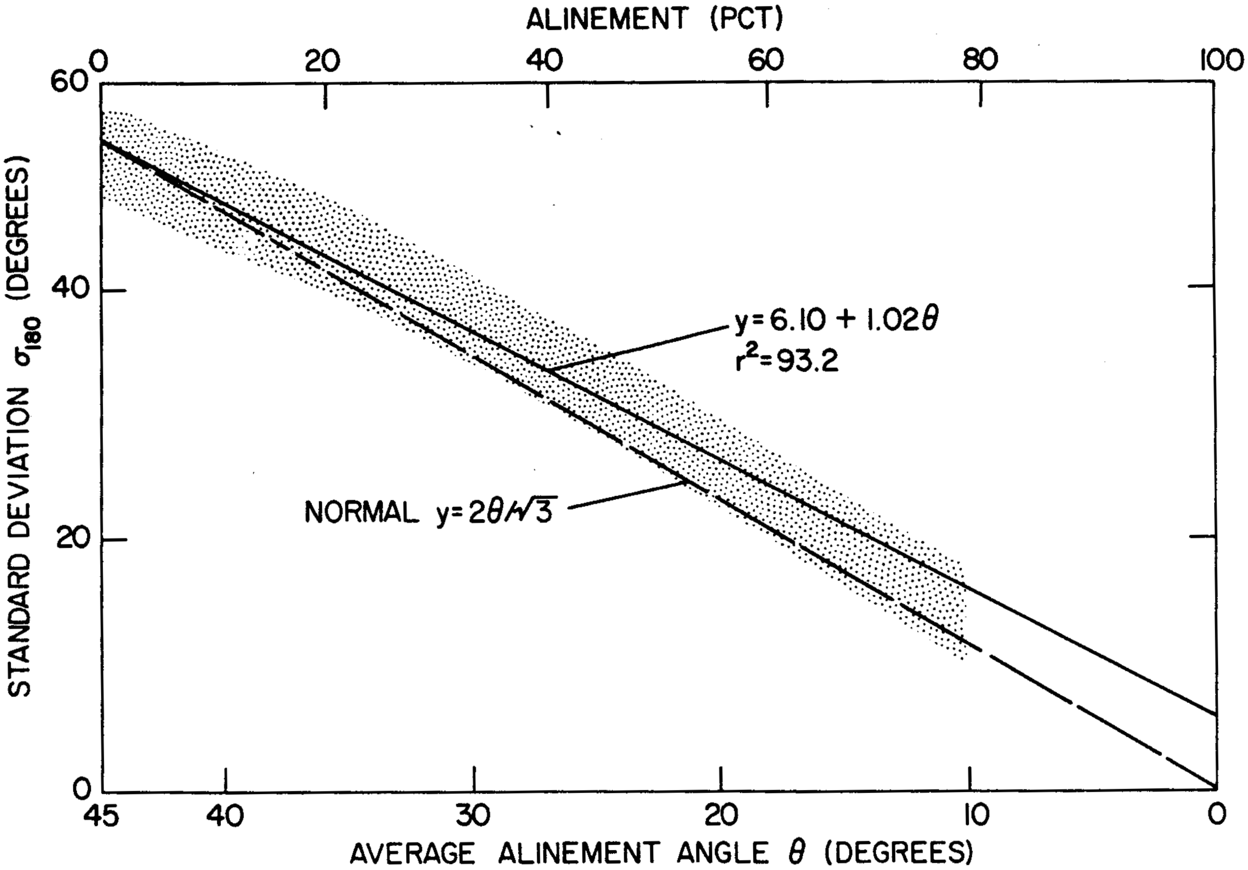

Figure 4. *Flake angular dispersion versus average alignment angle θ. (Shaded area includes approximately 95% of all data).*

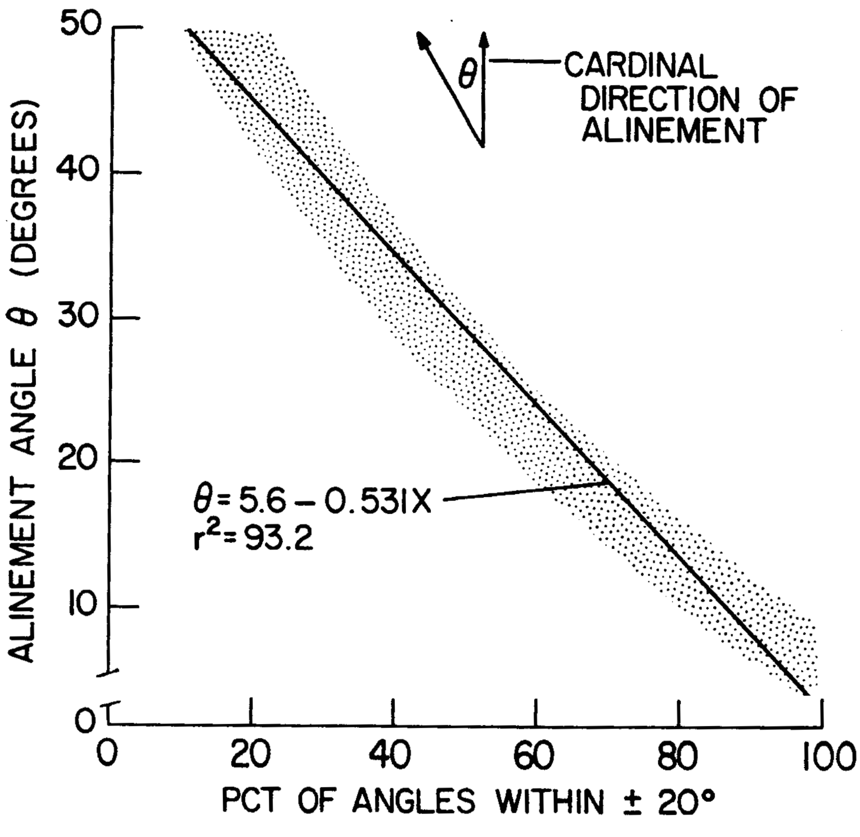

Figure 5. *Alignment angle (θ) as a function of the percent of flake angles falling within ± 20° of the cardinal direction of alignment. (Shaded area includes approximately 95% of all data.)*

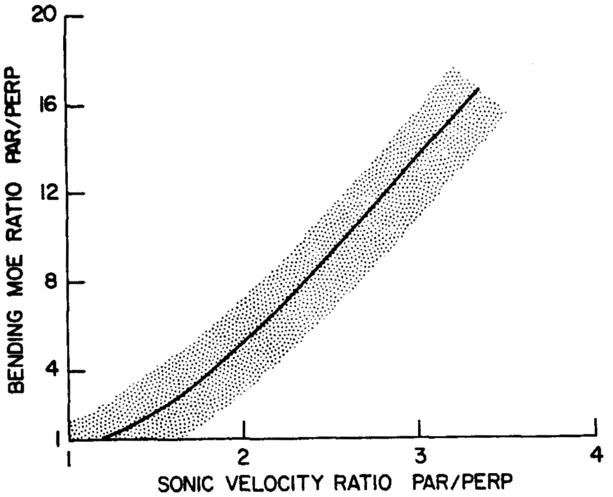

Figure 6. *Correlation between sonic velocity ratios and bending MOE ratios prompted use of sonic velocity as a measure of alignment. (Shaded area includes approximately 95 % of all data.)*

The relation is used later in data analysis comparing flexural strength and stiffness with specific gravity and alignment.

Sonic velocity depends slightly on specific gravity. Comparison of the sonic velocity in random (0% alignment) boards at various levels of density indicated that the velocity increased slightly with increasing specific gravity for most flake types (Figure 10).

Mathematical Relationships

The main purpose of this work was to establish the relation between strength or stiffness, specific gravity (sp gr), and alignment. A normal linear curve of the type:

$$\text{Strength or stiffness} = A + B\,(\text{sp gr}) + C\,(\text{alignment}) \tag{1}$$

implies that the variance is the same throughout the range of sampling. Analysis of the data showed the sampling variance to increase with increasing specific gravity and with increasing alignment (Figure 11). A model of the type:

$$\text{Stiffness or strength} = e^{\mu}\,(\text{sp gr})^{\alpha}\,(\text{alignment})^{\beta} \tag{2}$$

accounts for the changing variability of both specific gravity and alignment. Two forms of the equation have been studied. The first form,

$$\text{Stiffness or strength} = e^{\mu}\,(\text{sp gr})^{\alpha}\left(\frac{\text{sonic vel. }\parallel}{\text{sonic vel. }\perp}\right)^{\beta} \tag{3}$$

designates alignment as the ratio of the sonic velocities and implies that the velocities parallel and perpendicular to testing direction are equally important 'in predicting strength or stiffness. Actually, although

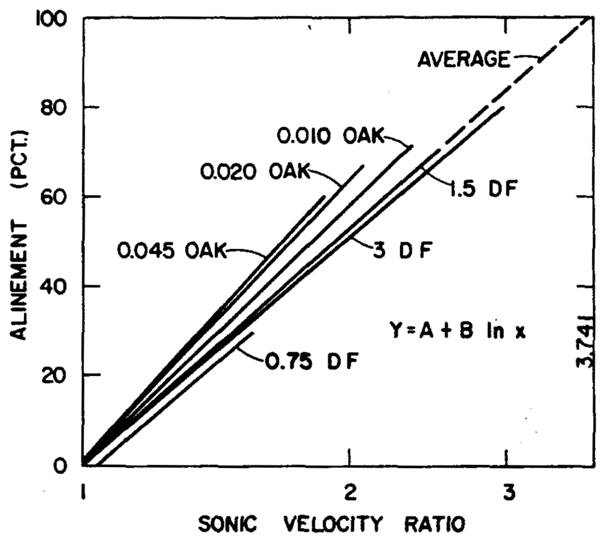

Figure 7. *Percent alignment versus sonic velocity ratio ||/⊥ for three lengths of Douglas-fir flakes and three thicknesses of oak flakes.*

	Constants Used in Regression Equation		Coefficient of Determination
	A	**B**	$\mathbf{R^2}$
Douglas-fir			
0.020 × 3 in. disk (0.508 × 76 mm)	—	73.1	92.2
0.020 × 1.5 disk (0.508 × 38)	—	76.0	87.5
0.020 × 0.75 ring (0.508 × 19)	−3.75	74.7	16.2
Oak			
0.010 × 3 in. disk (0.254 × 76 mm)	—	83.9	90.4
0.020 × 3 disk (0.508 × 76)	—	91.5	94.8
(0.045 × 2 ring (1.143 × 51)	—	95.1	91.4
Average	—	75.8	90.3

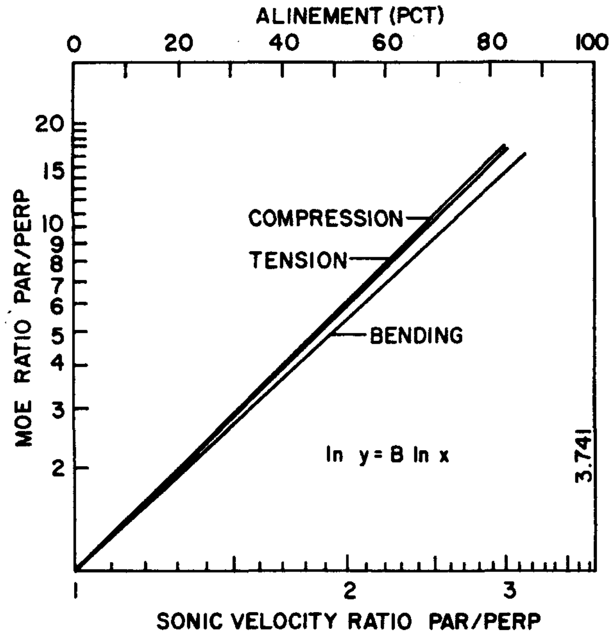

Figure 8. *Comparison of MOE ratio of compression, tension, and bending data to the sonic velocity ratios.*

	Constants Used in Regression Equation	*Coefficient of Determination*
	B	R^2
Bending	2.43	99.2
Tension	2.55	97.1
Compression	2.58	97.0

both measurements are needed to achieve high correlation coefficients, the velocity measured in the direction of testing does have more weight in determining the strength or stiffness values. The second form of the equation:

$$\text{Stiffness or strength} = e^{\mu}\,(\text{sp gr})^{\alpha}\,(\text{sonic vel. } \parallel)^{\beta}(\text{sonic vel. } \perp)^{\gamma} \quad (4)$$

provides for a better fit of the data in most cases but is more difficult to relate to degree of alignment. This is especially true with the 0.75 in. (19 mm) Douglas-fir flake type, where the narrow range of alignment and low correlation coefficients resulted in mathematical relationships between sonic velocity and alignment quite different from that of the other flake types (Figure 9).

Constants (μ, α, β, γ) for Equations (3) and (4) for the stiffness and strength properties of bending, tension, and compression are given in Tables 2 and 3. Since the "effective" bending properties of a layered board are largely determined by the combined reaction of tension and compression stresses in the outer layers, tension data are often used in predicting the effective bending MOE.

A graphical presentation of the relationship of tension MOE to specific gravity and alignment for each flake type is shown in Figures 12-17. The graph for the 0.75 in. (19 mm) flake type was developed using Equation (3), whereas the graphs for the rest of the flake types use the relations found in Equation (4).

Graphical comparisons of the properties of bending MOE, compression MOE, and tension stress at maximum load are presented for the 1.5 in. (38 mm) Douglas-fir flake type in Figures 18, 19, and 20. Curves for the other properties and other flake types may be created using the relations given in Tables 2 and 3 and Figures 7 and 9, in conjunction with either Equation (3) or (4).

The tension MOE data for the 1.5 in. (38 mm) Douglas-fir flake are plotted in a different fashion in Figure 21 and provide a better picture of the strong effects of alignment on stiffness. A maximum tension MOE of 4.1 million psi (28,269 MPa) was achieved in this study with a 3 in. (76 mm) Douglas-fir flake at a specific gravity of 0.929 and at a 70% alignment.

The relationships between MOE and modulus of rupture (MOR) (or stress at maximum load) as an average of all flake types for the properties of bending, tension, and compression are shown in Figure 22. Tension and compression curves are similar but have a much shallower slope (approximately half) than that of the bending curve. Straight-line regression constants and coefficients of determination for each flake type are given in Table 4.

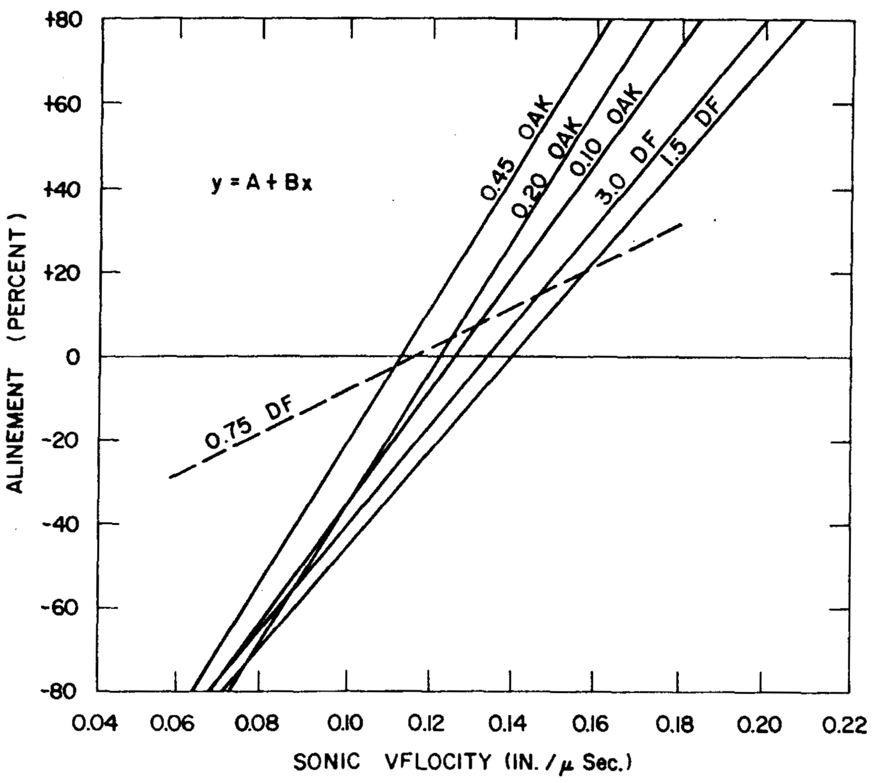

Figure 9. *Percent alignment as a function of the sonic velocity for three lengths of Douglas-.fir flakes and three thicknesses of oak flakes.*

	Constants Used in Regression Equation		*Coefficient of Determination*
	A	B	R^2
Douglas-fir			
0.020 × 3 in. disk (0.508 × 76 mm)	1157	1162	95.4
0.020 × 1.5 disk (0.508 × 38)	1159	1122	95.1
0.020 × 0.75 ring (0.508 × 19)	−51.7	482	23.4
Oak			
0.010 × 3 in. disk (0.254 × 76 mm)	−170	1335	94.4
0.020 × 3 disk (0.508 × 76)	- 190	1528	97.4
(0.045 × 2 ring (1.143 × 51)	- 180	1579	87.1

A strong correlation was found between the tension and bending properties. Equations for the average of all flake types are given below:

Tension MOE = − 12.7 + 1.18 bending MOE $\quad R^2 = 94$

Tension stress at maximum load =
− 164 + 0.629 bending MOR $\quad R^2 = 97$

Prediction and Design

To assess the usefulness and precision of the above data in predicting and designing bending MOE of a board having a normal density gradient, a series of boards was constructed using a normal hot pressing cycle. The three Douglas-fir flake types were used to make duplicate 0.5 in. (13 mm) thick

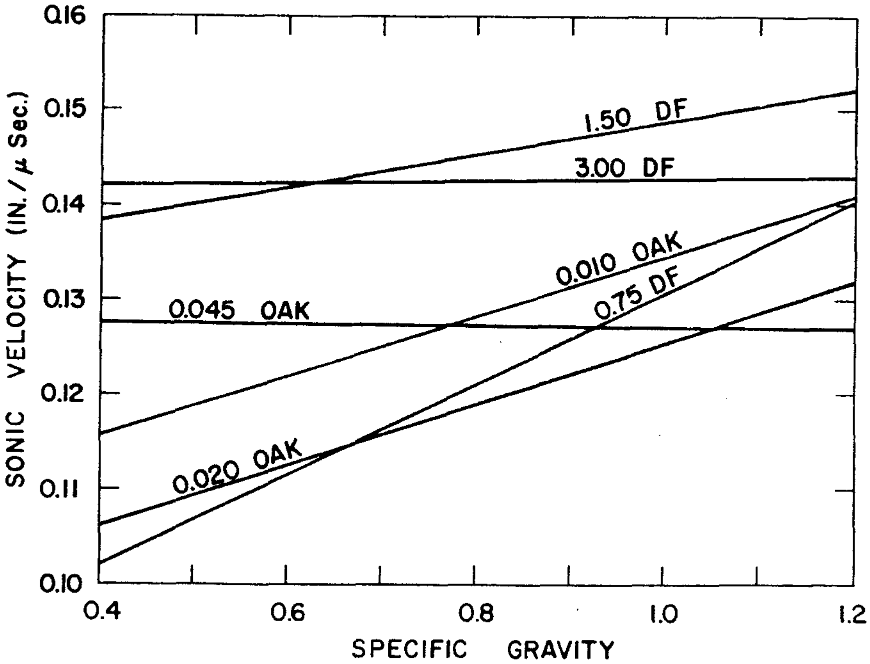

Figure 10. *Sonic velocity in random alignment boards ai various densities increased at higher specific gravities, except for 3 in. long (76 mm) Douglas-fir and 0.045 in. thick (1.143 mm) oak chips.*

boards of both a random and aligned flake configuration. Four other three-layer configurations were also constructed using 1.5 in. (38 mm) Douglas-fir flakes in the faces and 0.75 in. (19 mm) Douglas-fir flakes in the core (ratio 1:1). Boards were made at 40 lbs/ft^3 (641 kg/m^3) density (OD basis) and contained 5% phenolic resin. Mat moisture was 10%, closure time 1 minute and press time was 10 minutes at 350°F (177°C) platen temperature.

After conditioning at 65% relative humidity, the boards were tested and measured for their physical properties, density gradients, and flake alignment as described earlier. Layer density and alignment data were then combined with the relationships established in the uniform density equations above to determine the tension MOE of each layer. Finally, this information was used to predict the bending MOE of the normally pressed flakeboards using the multi-layer method described in earlier work [2].

Prediction accuracies for each board type based on measured values are shown in Table 5. Predictions were generally within ±20% of actual values. Predictions of random boards were generally lower than measured values while bending stiffness of aligned boards in the direction of alignment was somewhat overestimated.

As mentioned previously, tension MOE is quite often used to predict bending MOE of composite layered boards. Use of bending MOE derived from boards having a layer density gradient is inherently inaccurate; bending MOE of this type of board must be higher than that of a uniform density board due to the I-beam effect. It is theoretically

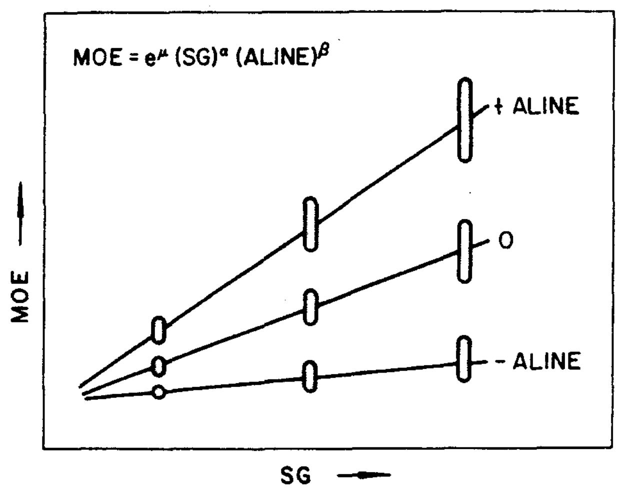

Figure 11. *Sampling variance increases with increasing specific gravity and alignment. (Shaded slots denote range.)*

Table 2
Constants for Equation 3

$$\text{Stiffness or Strength} = e^{\mu}(\text{specific gravity})^{a}\left(\frac{\text{sonic velocity par.}}{\text{sonic velocity perp.}}\right)^{b}$$

Flake Type[a]				*Bending*		*Tension*		*Compression*	
Thickness inches (mm)	*Length inches (mm)*	*Machine*	*Exponent*[b]	*MOE*	*MOR*	*MOE*	*Stress at max. load*	*MOE*	*Stress at max. load*
				Douglas-fir					
0.020 (0.508)	3 (76)	Disk	μ	6.82	8.9	6.90	8.33	6.79	8.43
			a	1.29	1.6	1.59	1.59	1.39	2.06
			b	1.23	1.00	1.31	1.14	1.27	0.75
			R^2	97.6	98.0	94.8	96.2	95.3	92.7
0.020 (0.508)	1.5 (38)	Disk	μ	6.95	8.9	7.06	8.43	6.91	8.42
			a	1.29	1.7	1.57	1.74	1.34	1.94
			b	1.25	0.90	1.32	1.00	1.25	0.76
			R^2	97.6	95.0	96.6	95.5	94.6	94.8
0.020 (0.508)	0.75 (19)	Ring	μ	6.77	8.7	7.03	8.28	6.77	8.43
			a	1.48	2.0	1.45	2.09	1.49	2.15
			b	1.12	0.69	1.27	0.84	1.25	0.57
			R^2	96.9	96.0	83.0	94.3	90.0	95.2
				Oak					
0.010 (0.254)	3 (76)	Disk	μ	6.98	9.1	7.23	8.63	6.92	8.44
			a	1.59	2.4	1.55	2.07	1.49	3.08
			b	1.25	1.07	1.27	1.31	1.26	0.40
			R^2	97.1	92.0	93.6	94.5	88.5	71.4
0.020 (0.508)	3 (76)	Disk	P	6.83	9.0	7.08	8.44	6.72	8.52
			a	1.20	1.5	1.55	1.78	1.63	2.55
			b	1.28	1.2	1.32	1.42	1.22	0.60
			R^2	98.4	96.0	93.8	95.3	93.1	87.8
0.045 (1.143)	2 (51)	Ring	μ	6.83	8.9	7.13	8.33	6.95	8.63
			a	2.06	2.6	2.04	2.36	2.46	2.92
			b	1.07	0.78	1.00	0.92	1.14	0.52
			R^2	97.3	95.0	93.1	96.2	95.0	98.2

[a] All flakes were random width.

[b] R^2 is coefficient of determination.

Table 3
Constants for Equation 4

$$\textit{Stiffness or Strength} = e^{\mu}(\textit{specific gravity})^{\alpha}(\textit{sonic velocity par.})^{\beta}(\textit{sonic velocity perp.})^{\gamma}$$

Flake Type[a]				*Bending*		*Tension*		*Compression*	
Thickness inches (mm)	*Length inches (mm)*	*Machine*	*Exponent*[b]	*MOE*	*MOR*	*MOE*	*Stress at max. load*	*MOE*	*Stress at max. load*
				Douglas-fir					
0.020	3	Disk	μ	9.45	10.1	8.98	10.75	9.41	9.36
(0.508)	(76)		a	1.15	1.53	1.51	1.54	1.28	2.02
			b	1.84	1.28	1.81	1.74	1.91	0.97
			γ	-0.56	-0.70	- 0.80	- 0.56	- 0.63	- 0.52
			R^2	99.4	98.0	95.6	97.8	96.7	93.0
0.020	1.5	Disk	μ	10.4	12.6	9.4	11.63	10.03	10.92
(0.508)	(38)		a	1.11	1.53	1.45	1.58	1.19	1.82
			b	2.07	1.76	1.92	1.82	2.04	1.39
			γ	-0.30	0.04	-0.72	- 0.19	- 0.456	-0.12
			R^2	99.1	97.0	97.2	96.9	95.7	95.7
0.020	0.75	Ring	μ	11.8	12.8	12.2	13.85	10.97	14.64
(0.508)	(19)		a	1.0	1.57	0.95	1.56	1.11	1.59
			b	2.29	1.65	2.55	2.23	2.27	2.09
			γ	0.15	0.36	-0.04	0.48	- 0.241	0.91
			R^2	98.7	97.0	85.0	95.4	91.2	96.8
				Oak					
0.010	3	Disk	μ	11.4	16.4	10.1	14.10	9.33	16.23
(0.254)	(76)		a	1.02	1.44	1.22	1.45	1.20	2.14
			b	2.29	2.78	1.94	2.62	1.86	2.34
			γ	-0.11	0.79	-0.55	0.06	- 0.68	01.45
			R^2	98.2	95.0	94.3	96.8	88.8	74.6
0.020	3	Disk	μ	10.7	13.0	7.75	13.20	11.74	14.97
(0.508)	(76)		a	1.09	1.42	1.53	1.66	1.47	2.35
			b	2.15	2.09	1.48	2.53	2.41	2.12
			γ	-0.31	-0.20	-1.16	- 0.29	- 0.03	0.93
			R^2	99.6	98.0	93.8	96.5	94.3	90.7
0.045	2	Ring	μ	10.2	12.5	6.68	9.48	9.26	10.21
(1.143)	(51)		a	1.62	2.13	2.09	2.22	2.18	2.73
			b	1.87	1.61	0.89	1.19	1.69	0.91
			γ	-0.224	0.10	-1.11	- 0.64	- 0.59	-0.15
			R^2	98.3	96.0	93.2	96.3	95.3	98.3

[a] All flakes were random width.

[b] R^2 is coefficient of determination.

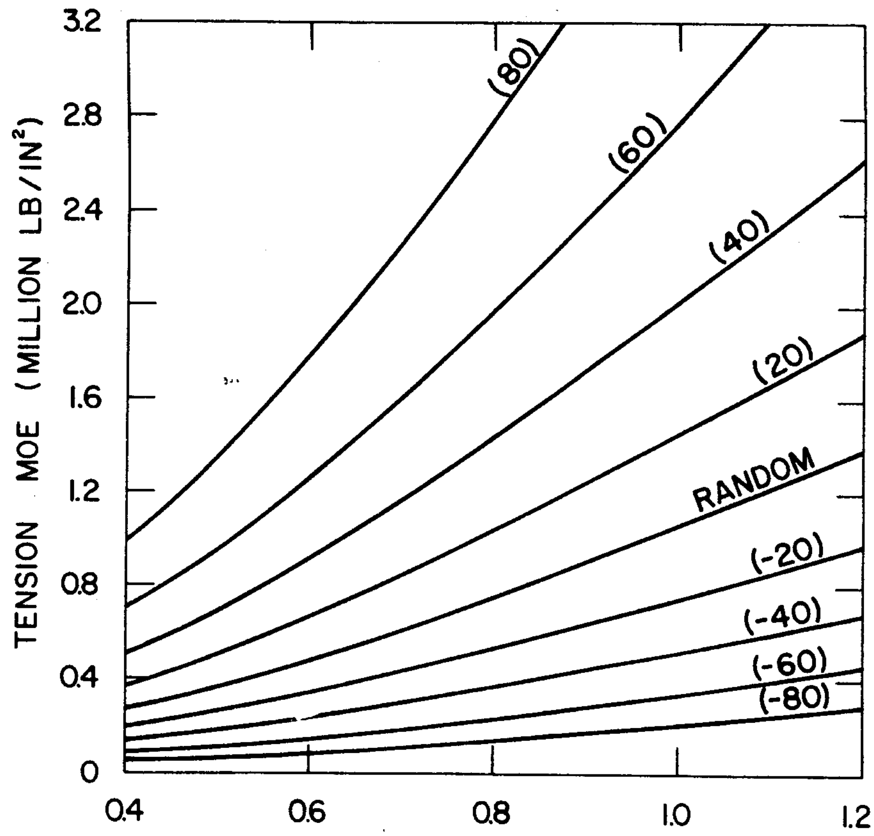

Figure 12. *Tension MOE design curves for 0.020 × 3 in. (0.508 × 76 mm) Douglas-fir disk flakes. (Numbers in parentheses represent percent of flake alignment.)*

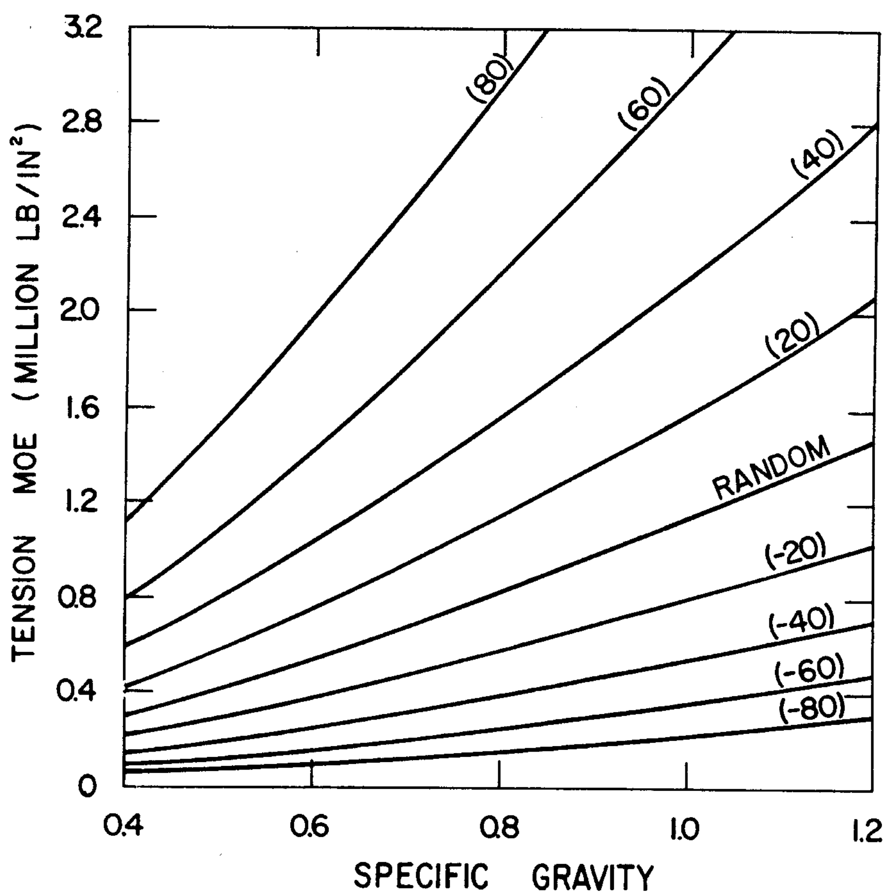

Figure 13. *Tension MOE design curves for 0.020 × 1.5 in. (0.058 × 38 mm) Douglas-fir disk flakes.*

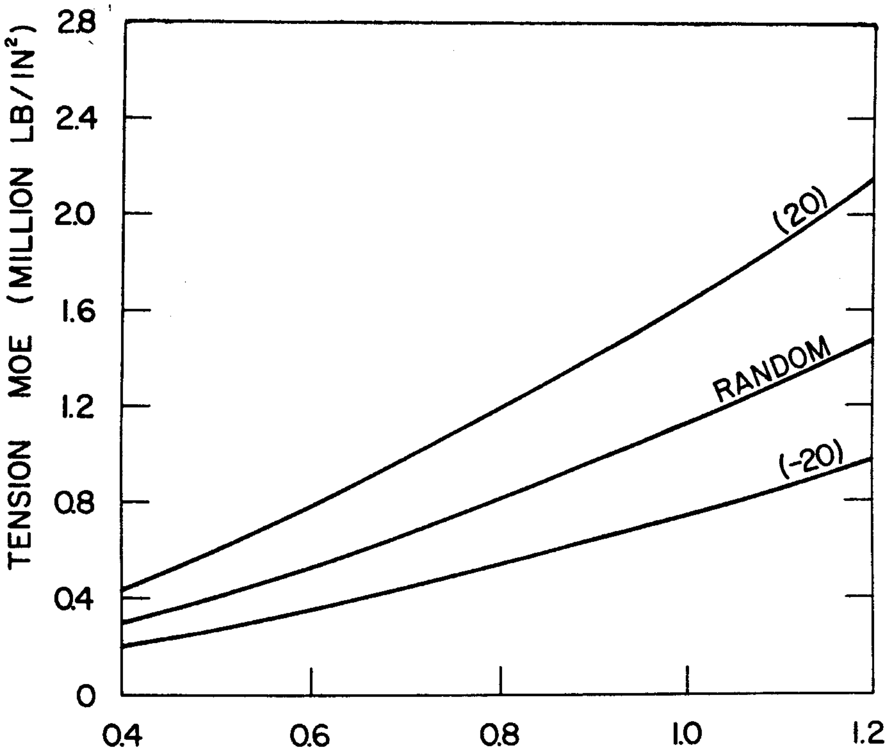

Figure 14. *Tension MOE design curves for 0.020 × 0.75 in. (0.508 × 19 mm) Douglas-fir ring flakes.*

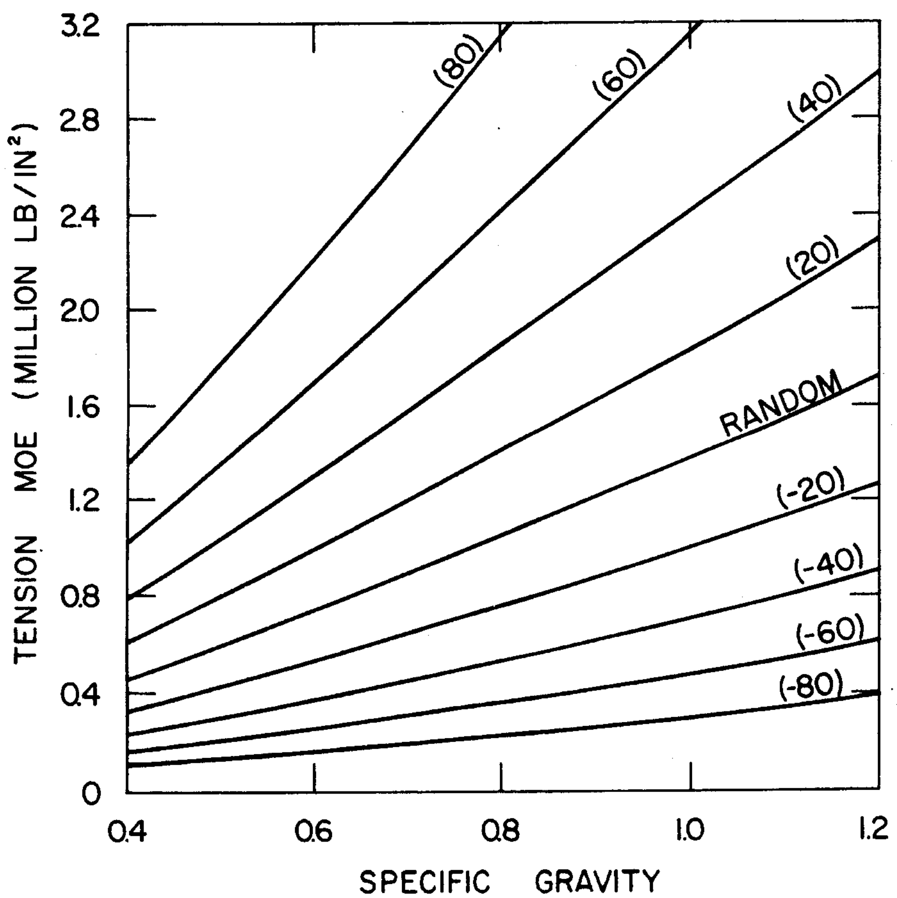

Figure 15. *Tension MOE design curves for 0.010 × 3 in. (0.254 × 76 mm) oak disk flakes.*

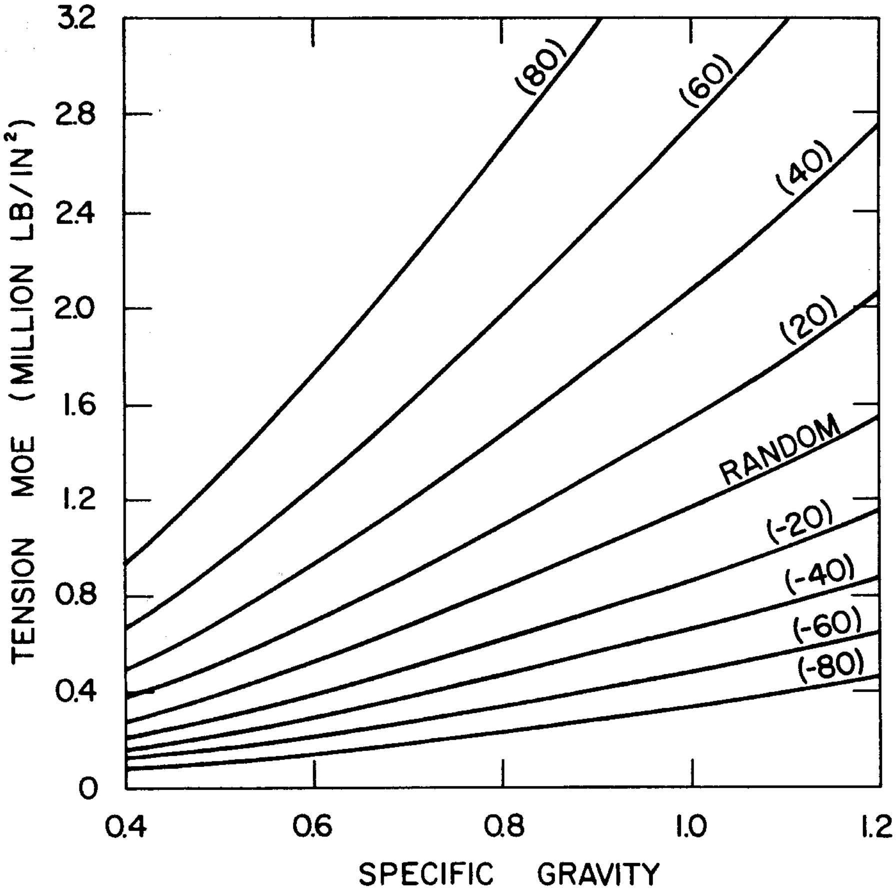

Figure 16. *Tension MOE design curves for 0.020 × 3 in. (0.508 × 76 mm) oak disk flakes.*

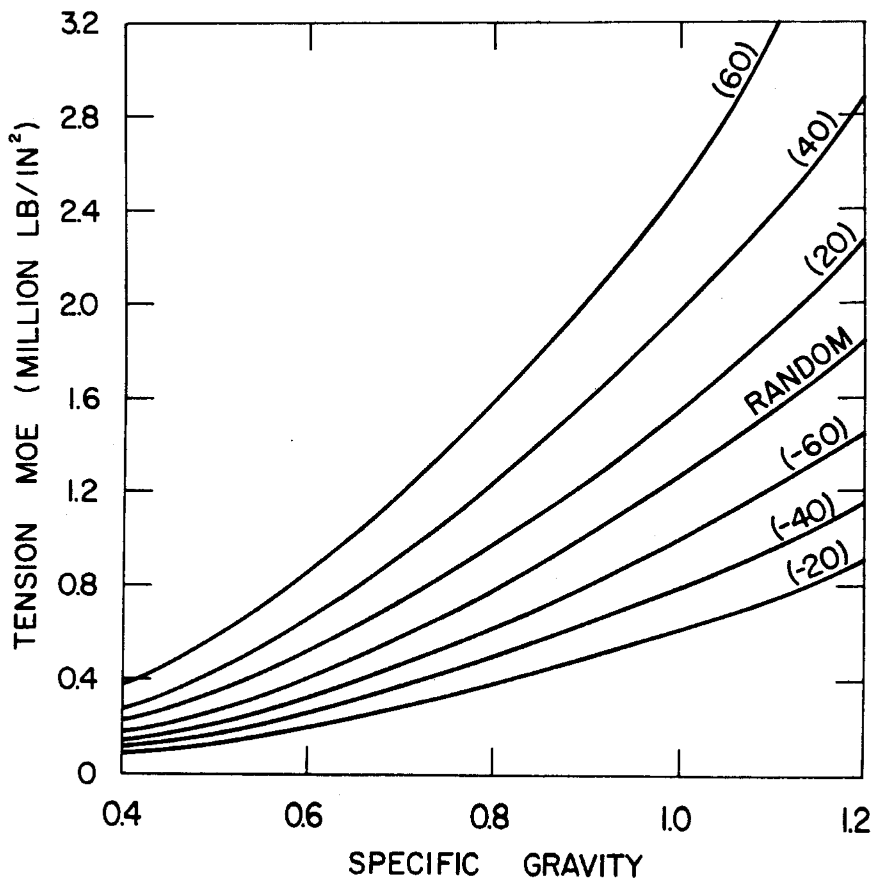

Figure 17. *Tension MOE design curves for 0.045 × 2 in. (1.143 × 51 mm) oak ring flakes.*

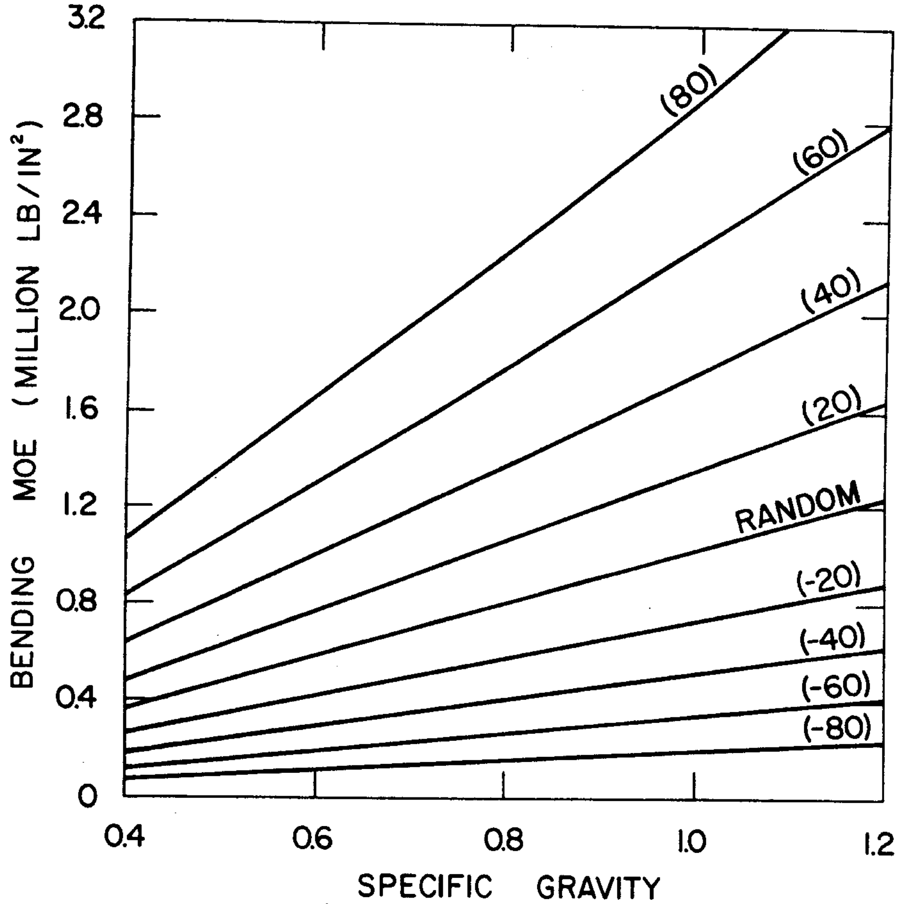

Figure 18. *Bending MOE as a function of specific gravity and percent alignment for 0.020 × 1.5 in. (0.508 × 38mm) Douglas-fir disk flakes.*

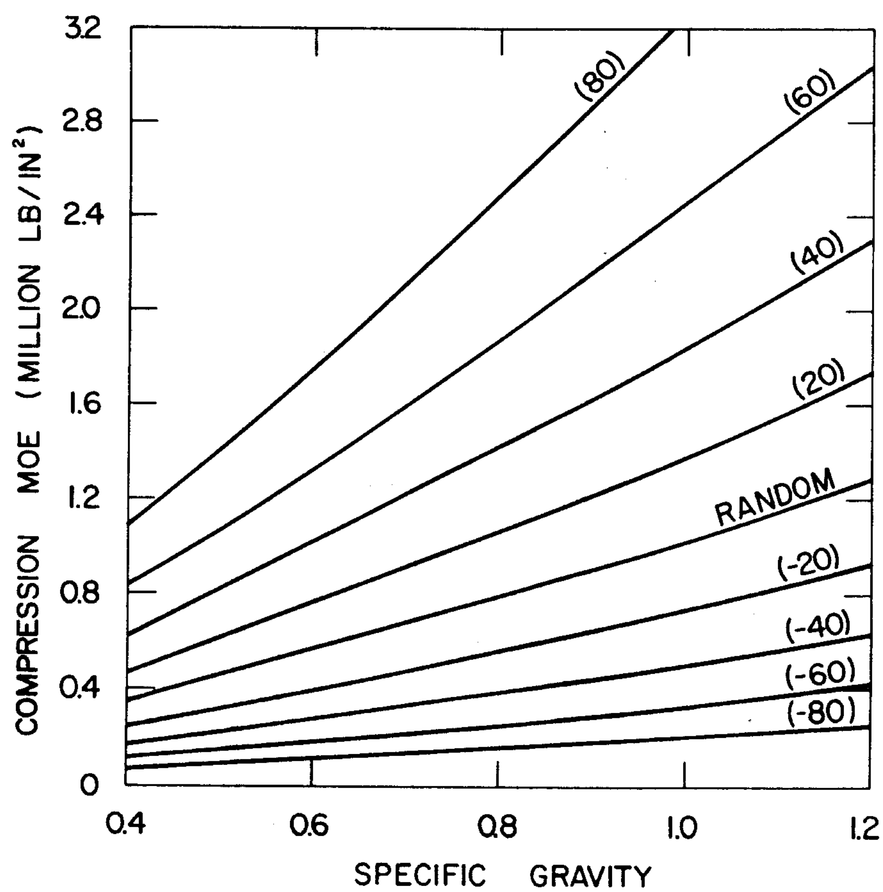

Figure 19. *Compression MOE as a function of specific gravity and percent alignment for 0.020 × 1.5 in. (0.508 × 38 mm) Douglas-fir disk flakes.*

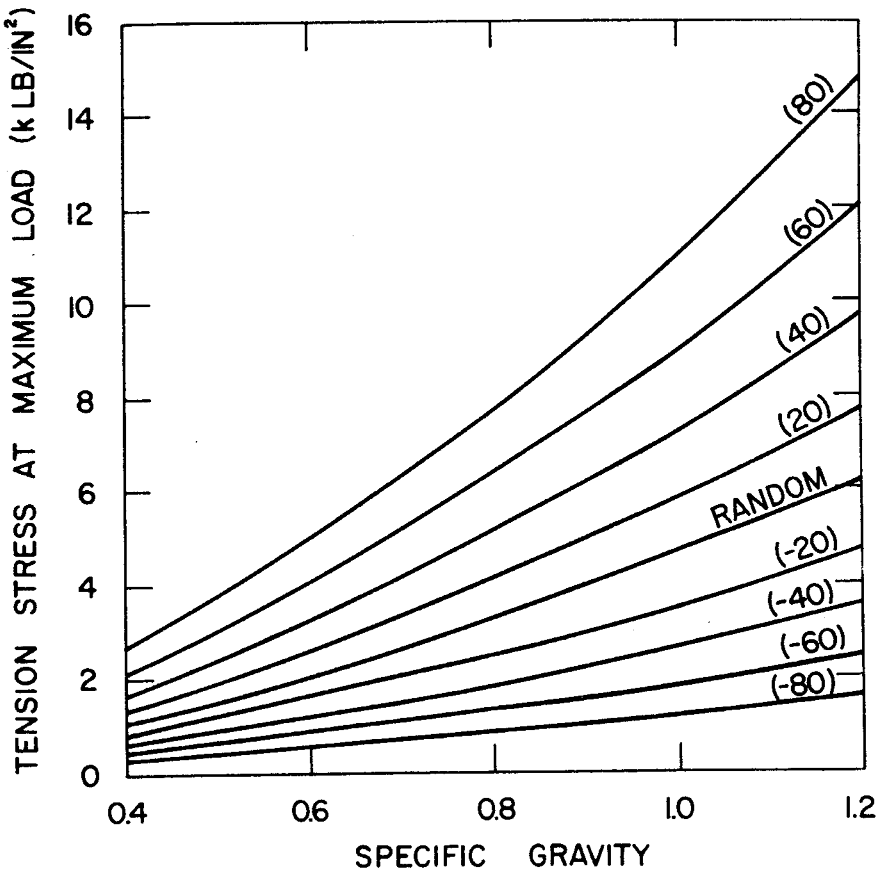

Figure 20. *Tension stress at maximum load as a function of specific gravity and percent alignment for 0.020 × 1.5 in. (0.508 × 38 mm)*

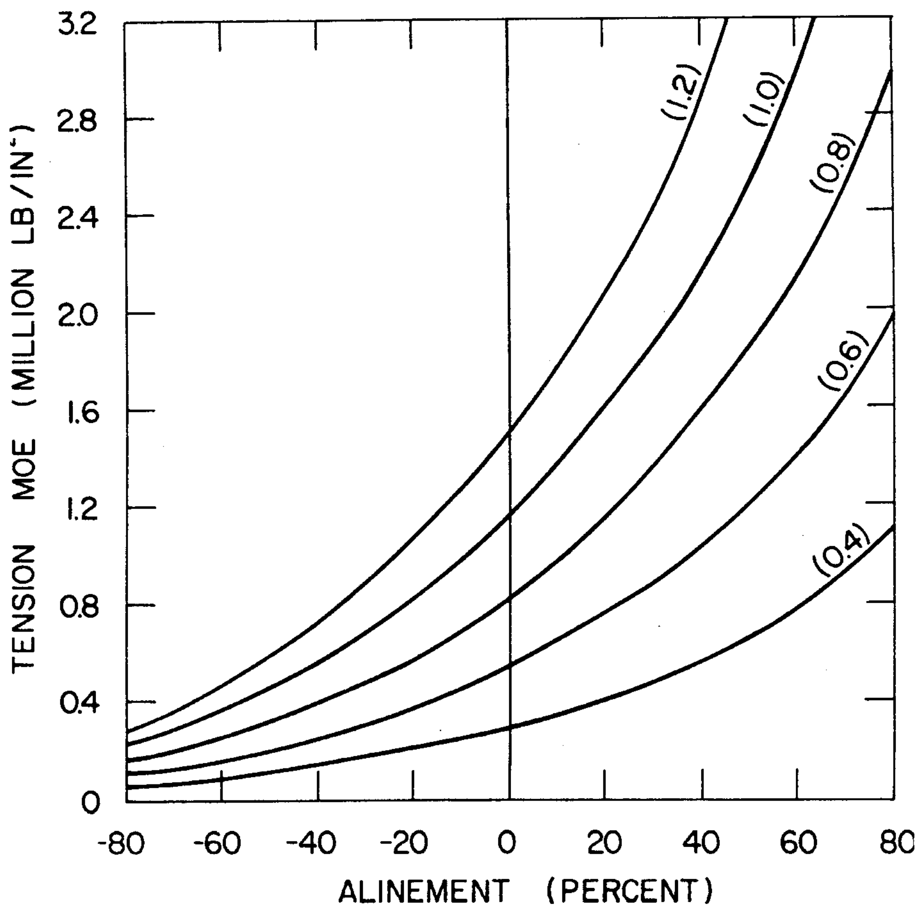

Figure 21. *Tension MOE versus alignment and specific gravity for 0.020 × 1.5 in. (0.508 × 38 mm) Douglas-fir disk flakes. Numbers in parentheses indicate specific gravity.*

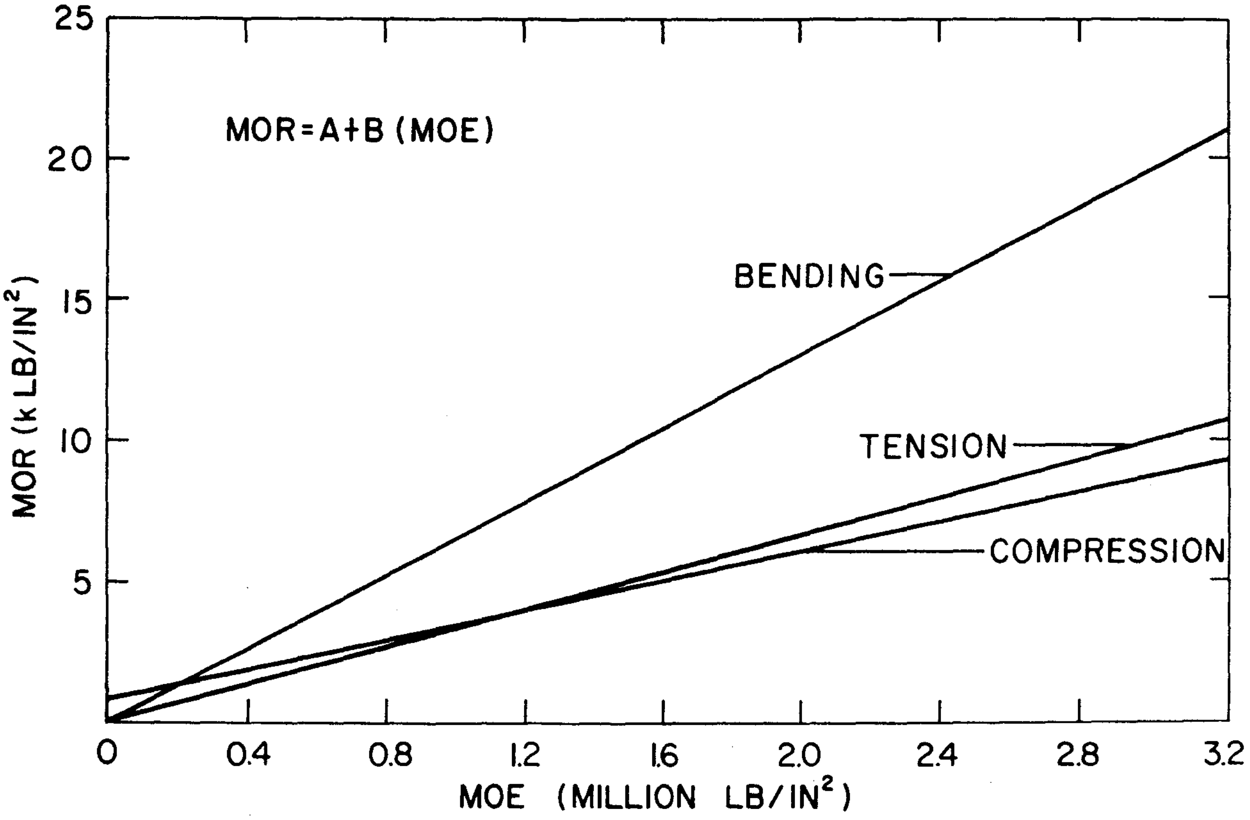

Figure 22. *Bending MOR is almost twice tension and compression stress at maximum load at comparable levels of MOE.*

	Constants Used in Regression Equation		*Coefficient of Determination*
	A	**B**	**R^2**
Bending	234	$6.36\ (10)^{-3}$	92
Tension	109	$3.32\ (10)^{-3}$	90
Compression	934	$2.65\ (10)^{-3}$	76

possible, however, that the tension stiffness of a uniform density board can be estimated by the tension MOE of a board possessing a density gradient but with the same average density. While this study did not include normally pressed boards (those having density gradients) at a variety of average densities, the tension data for boards normally pressed at 40 lbs/ft^3 are compared to uniform density boards (Table 6). In all cases, tension MOE values of the uniform density boards were below those of normally pressed boards, indicating that the density gradient does enhance tension MOE properties,

SUMMARY

Flakeboards made with uniform densities throughout their thickness and with different degrees of flake alignment were used to establish relationships between bending, tension, and compression values of MOE or MOR (or stress to maximum load) and the variables of specific gravity and flake alignment for three types of Douglas-fir flakes and three types of oak flakes. The sonic velocity through the board was highly correlated with degree of alignment and was used extensively throughout the course of data analysis. An equation of the type:

Table 4
Prediction of Strength from Stiffness

Constants for Equation: MOR (or stress at max. load) = A + B (MOE)

Flake Type[a]			Bending			Tension			Compression		
Thickness in. (mm)	Length in. (mm)	Machine	A	$B(10)^{-3}$	R^2	A	$B(10)^{-3}$	R^2	A	$B(10)^{-3}$	R^2
			Douglas-fir								
0.020 (0.508)	3 (76)	Disk	536	6.06	96	595	3.14	91	959	2.56	84
0.020 (0.508)	1.5 (38)	Disk	728	5.29	89	563	2.78	94	720	2.66	84
0.020 (0.508)	0.75 (19)	Ring	—	6.35	93	—	2.91	83	-305	4.99	88
			Oak								
0.010 (0.254)	3 (76)	Disk	—	7.67	94	—	3.79	94	1513	1.87	38
0.020 (0.508)	3 (76)	Disk	—	8.0	97	—	3.91	93	873	3.77	77
0.045 (1.143)	2 (51)	Ring	—	6.58	94	—	2.96	94	442	3.47	76
			All Data								
			234	6.36	92	109	3.32	90	934	2.65	76

[a] All flakes were random width.

$$\text{Stiffness or strength} = e^{\mu}\,(\text{sp gr})^{\alpha}\,(\text{sonic vel. } \parallel)^{\beta}(\text{sonic vel. } \perp)^{\gamma}$$

describes the relationship rather well over the broad range of specific gravities (0.4 to 1.2) and alignments (0 to 74%) studied in this work. Maximum bending stiffnesses of 3.0 million psi (20,685 MPa) and bending strengths of 19,700 psi (135.8 MPa) were obtained used 0.020 by random by 3 in. (0.509 by random by 76 mm) Douglas-fir disk flakes at flake alignments of 74% and board specific gravities of 1.0. MOR was highly correlated with MOE. Bending MOR, however, was almost double that of tension stress at maximum load at the same level of stiffness. The established relationships between tension MOE, specific gravity, and alignment were used to predict the bending stiffnesses of normally pressed boards (having a density gradient). Accuracies were generally within the range of ±20%. This work should provide a basis for further analysis of the basic properties of reconstituted boards to include such variables as bonding mechanisms and fracture mechanics.

Table 5
Bending Stiffness Prediction Precision
Using Uniform Density Tensile Stiffness Values[a]

Flake Type[b] Length in. (mm)	Flake Type[b] Machine	Board Layer	Alignment	Parallel	Perpendicular
		Homogeneous			
3 (76)	Disk[c]		Random	78	–
3 (76)	Disk[c]		Aligned	112	80
1.5 (38)	Disk[c]		Random	88	–
1.5 (38)	Disk[c]		Aligned	111	90
0.75 (19)	Ring		Random	115	–
0.75	Ring		Aligned	128	110
		Three-Layer			
1.5 (38)	Disk	Face	Random	95	–
0.75 (19)	Ring	Core	Random		
1.5 (38)	Disk	Face	Aligned	108	130
0.75 (19)	Ring	Core	Random		
1.5 (38)	Disk	Face	Aligned	108	116
0.75 (19)	Ring	Core	Aligned		
1.5 (38)	Disk	Face	Aligned	122	116
0.75 (19)	Ring	Core	Cross-aligned		

[a]Figures are predicted values as a percent of measured values.

[b]All flakes were Douglas-fir of random width and 0.020 in. (0.508 mm) thickness.

Tensile MOE values used were calculated using Equation (4). All other tensile MOE values used Equation (3).

Table 6
Comparison of Tension Properties of Uniform-Density Board to "Normal" Density Gradient Boards at Same Average Density[a]

Flake Type[b]				Stress at
Length in. *(mm)*	Machine	Alignment	MOE %	Max. Load %
3 (76)	Disk	Random	46	85
3 (76)	Disk	Aligned	58	118
1.5 (38)	Disk	Random	50	80
1.5 (38)	Disk	Aligned	66	96
0.75 (19)	Ring	Random	85	102
0.75 (19)	Ring	Aligned	83	93

[a]Numbers are uniform density properties shown as percent of normal density gradient properties.

[b]All flakes are Douglas-fir of random width.

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