Engineering Properties of Structural Particleboards from Forest Residues

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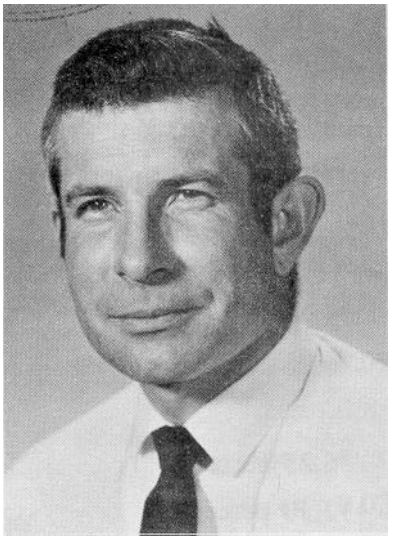
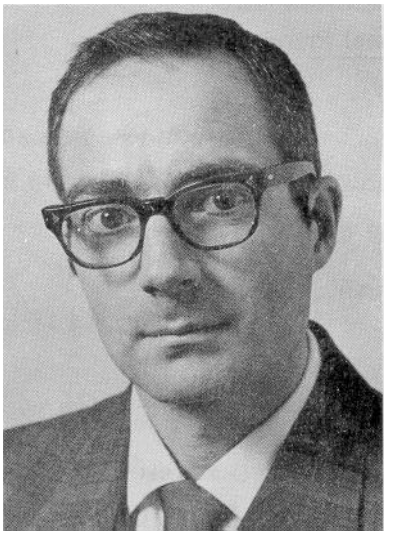




Introduction

The property requirements of structural particleboards will ultimately be determined by end-use criteria. Requirements for wall sheathing, for instance, are necessarily different from those of roof or floor sheathing and may best be fulfilled by a specific board type. Load-carrying capacity, stiffness, and dimensional stability properties are especially relevant to structural boards. An important consideration is that by manipulation of the processing technique particleboard may be manufactured to meet a variety of performance specifications. As structural particleboard gains acceptance, some existing plants will explore the possibility of converting a portion of their production to structural panels and new plants will be built to produce various specialized structural panel types.

Objective

The purpose of this study was to utilize forest residues, along with other raw material sources, to manufacture various types of particleboards with characteristics desired for structural uses, and to measure the basic mechanical properties of these panels. These data could then furnish necessary criteria for the further design and construction of structural-type panels. Requirements for specific applications will necessarily be established by those concerned with actual panel usage.

Experimental Procedure

Panel Preparation

Forest residues, primarily Douglas-fir, were obtained from the western slopes of the Cascade Range in Washington and Oregon. These materials were sorted into four different groups and combined as follows: [1]

Soundwood: +4 inches in diameter	75.00 percent
Bark	6.25 percent
Soundwood and bark: -4 inches in diameter (bark estimated at 25 percent of this portion)	6.25 percent
Wood containing visible decay	12.50 percent
	100.00 percent

From the residues, suitable amounts of the following particle types were prepared to manufacture the panels used in the study:

a. 0.020- by 0.5- by 2-inch flakes, disc flaked
b. 0.020- by 2-inch flakes, ring flaked from 2-inch chips
c. 0.020- by l-inch flakes, ring flaked from l-inch chips
d. planer shavings, hammermilled without screen
e. fiber, from MacMillan defiberizer
f. bark, processed through ring flaker.

The thickness, length, and width of disc-cut flakes are closely controlled and all surfaces are relatively smooth. Thus disc-cut flakes are generally considered to be of higher quality than ring-cut flakes. Ring-cut flakes are random in width, vary much more in length and vary a little more in thickness. Their ends may be ragged and the flakes may have cross-grain. More fines are created in production. In turn, planer shavings are generally considered to be of lower quality than ring-cut flakes because of more cross-grain and fines.

All material was processed in conditions as harvested, without further consideration to dirt and bark removal, dried to appropriate moisture content, and stored for use in preparation of 12 panel types:

Random Orientation

Homogeneous

1. 0.020- by l-inch ring-cut flakes
2. 0.020- by 2-inch ring-cut flakes
3. 0.020- by 0.5- by 2-inch disc-cut flakes

Three-layer

4. faces: 0.020- by l-inch ring-cut flakes
   core : milled shavings
5. faces: fiber
   core : 0.020- by 2-inch ring-cut flakes
6. faces: -1/8-inch mesh, 0.020- by l-inch ringcut flakes
   core : +1/8-inch mesh, 0.020- by l-inch ring-cut flakes
7. faces: 0.020- by 0.5- by 2-inch disc-cut flakes
   core: 0.020- by l-inch ring-cut flakes

A lined Particle Orientation

Homogeneous

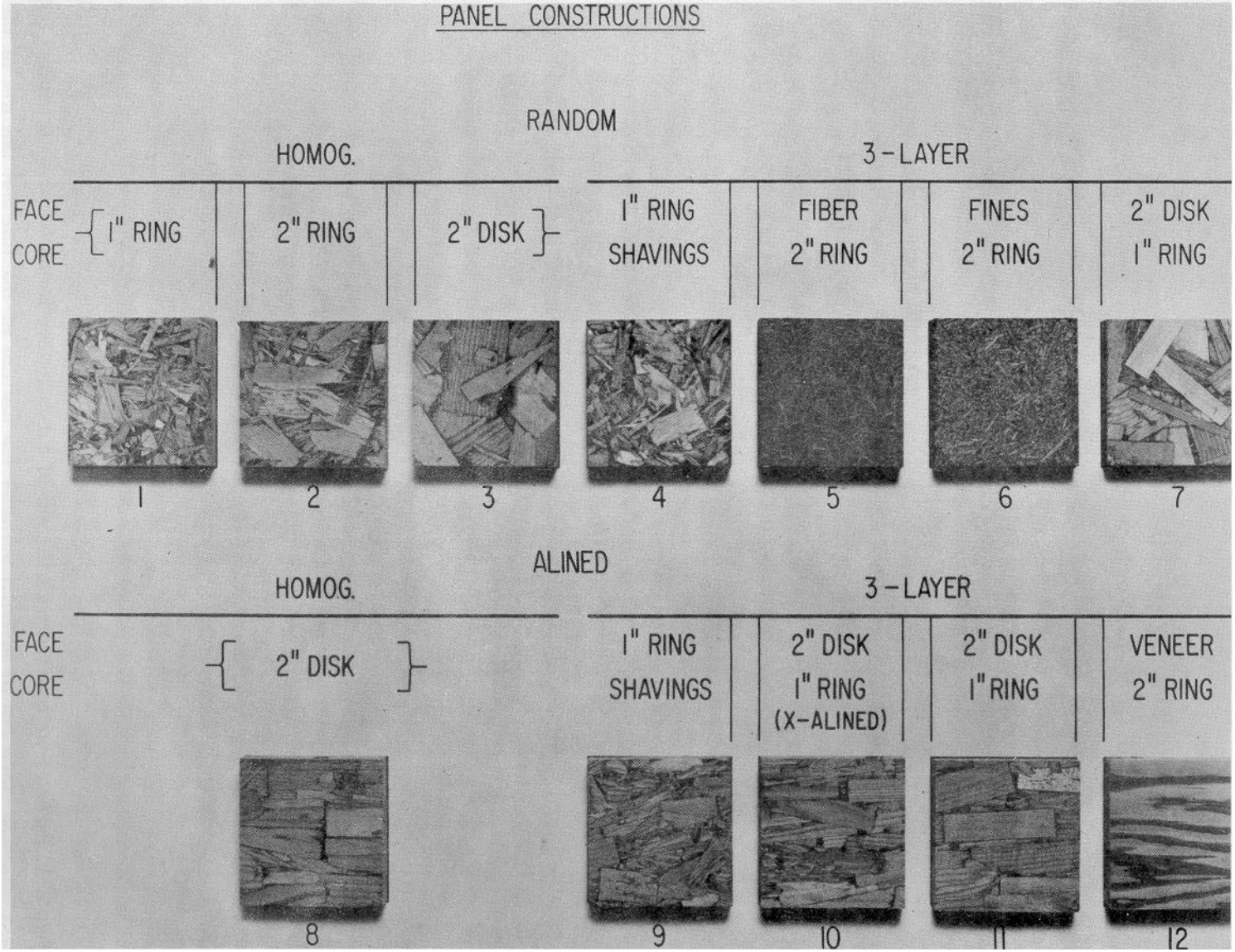
8. 0.020- by 0.5- by 2-inch disc-cut flakes

Three-layer

9. faces: 0.020- by l-inch ring-cut flakes
   core : milled shavings (nonoriented)
10. faces: 0.020- by 0.5- by 2-inch disc-cut flakes
    core : 0.020- by l-inch ring-cut flakes (cross-oriented)
11. faces: 0.020- by 0.5- by 2-inch disc-cut flakes
    core : 0.020- by l-inch ring-cut flakes (nonoriented)
12. faces: veneer (0.10 in. rotary cut from Douglas-fir logs)
    core: 0.020- by 2-inch ring-cut flakes (nonoriented)

The appearance of various panel types and materials of construction are illustrated in Figure 1. Particles were alined with the aid of a l-inch-deep frame fitted with parallel fins at 3/4 inch spacings. Free fall of material between the bottom of the fins and the top of the mat in construction was held to a minimum to achieve the best alinement possible with this equipment. Actual degree of alinement was not measured.

Figure 1. Panel Surfaces and Flake and Particle Composition of each of the 12 Panel Types Included in Study.



All panels were prepared using the previously outlined proportions of residues as nearly as possible. In three-layer panels, however, the bark portion was added to the core fraction only. The following conditions remained constant throughout the panel manufacturing phase, with noted exceptions.

Panel size : Rough, l/2 by 24 by 28 inches
Trimmed, l/2 by 22 by 26 inches

Density: 40 pounds per cubic food (ovendry [OD] weight, volume at 65 percent relative humidity [RH])

Face-core ratio of three-layer panels: 15-70-15 percent of panel weight

Face-core-Face ratio of veneered panels: 16-68-16 percent of panel weight

Resin : 5 percent phenol-formaldehyde (PF) (solids content based on OD weight wood weight). Panels 5 and 6 contained 7 percent PF in face materials. Bonding of veneer to core in the veneer-faced panel was done in a single operation during hot pressing. The veneer was sprayed with an amount of PF resin equivalent to one-half of a typical plywood glue spread (4 lb dry resin per 1,000 square feet of single glue line)

Wax: 1 percent wax emulsion (solids content based on OD wood weight)

Mat moisture content: 10 percent (based on OD weight of wood, resin, and wax)

Pressing conditions: 10 minutes at 350° F, 1 minute to final board thickness

Hot stacking: Panels were stored overnight in an insulated box following removal from press.

Testing

Five replications of each panel type were prepared for testing of basic engineering properties in this portion of the study. Ten additional replications of each of panel types 7, 8, 9, and 11 were prepared for later use in determination of effects of moisture content and loading conditions on engineering properties. After being removed from hot-stacking, panels were conditioned at 73° F, 64 percent relative humidity (RH) and cut into specimens for determination of the following properties using ASTM[2] Standard Test Methods. Panels were not sanded.

1. Static bending
   Modulus of rupture (MOR)
   Apparent modulus of elasticity (E_B)

2. Tension parallel to surface
   - Tensile strength (ST)
   - Apparent modulus of elasticity in tension (ET)
3. Compression parallel to surface
   - Compressive strength (S_C)
   - Apparent modulus of elasticity in compression (E_C)
4. Edgewise shear strength (SE)
5. Interlaminar shear
   - Shear strength (S_I)
   - Shear modulus (G_I)
6. Internal bond strength (IB)
7. Plate shear
   - Shear modulus (G_{PL})

One specimen of each type was prepared from each of the five replicate panels. All tests except 6 and 7 were made both parallel and perpendicular to the direction of surface grain alinement on those panels with oriented flakes or veneer overlays.

In addition to tests at standard conditions, static bending and internal bond tests were conducted after exposure to six cycles of accelerated aging (ASTM Standard D 1037-72a, Sections 120-122). Linear expansion, thickness swelling, and moisture content were determined at conditions of 212° F and 0 percent RH, 80° F and 12, 30, 42, 50, 65, 80, 90 percent RH, and vacuum-pressure-soak in water at 70° F.

Results and Discussion

Basic Engineering Properties

Strength properties: A summary of basic engineering properties of the 12 panel types is presented in Table 1. Corresponding coefficients of variation are shown in Table 2. The various property means are compared graphically in Figures 2, 3, 4, and 5. Bending, tension, and compression strength properties are shown in Figure 2. These properties follow the general pattern of improvements with better flake geometry and flake orientation. Addition of fiber and/or fines faces to boards (Nos. 5 and 6) made with l-inch ring-cut flakes was not detrimental

Table 1. Basic Engineering Properties of Structural Particleboards.

Panel type	Construction: Face	Construction: Core	Construction: Test direction	Specific gravity[1]	Bending: Modulus of rupture	Bending: Modulus of elasticity	Tension parallel: Strength	Tension parallel: Modulus of elasticity	Compression parallel: Strength	Compression parallel: Modulus of elasticity	Edgewise shear strength	Interlaminar shear: Strength	Interlaminar shear: Modulus of elasticity	Internal bond	Plate shear modulus
					Psi	Ksi	Psi	Ksi	Psi	Ksi	Psi	Psi	Ksi	Psi	Psi
					RANDOM, HOMOGENEOUS										
1	1-in. ring[2]	1-in. ring		0.64	3,620	530	2,190	493	2,570	551	1,660	387	43.8	119	246
2	2-in. ring	2-in. ring		.67	4,340	608	2,650	559	2,600	640	1,770	413	43.8	115	264
3	2-in. disk[3]	2-in. disk		.66	4,310	691	2,880	701	3,200	947	2,270	220	29.2	36	318
					RANDOM, THREE-LAYER[4]										
4	1-in. ring	Shavings		.67	3,220	504	1,600	364	2,080	405	1,230	384	47.8	136	240
5	Fiber	2-in. ring		.65	4,510	549	2,080	489	2,680	597	1,560	284	34.4	94	251
6	Fines, screened 1-in. ring	Flakes, screened 1-in. ring		.66	4,440	626	2,470	506	2,850	584	1,840	393	43.2	122	298
7	2-in. disk	1-in. ring		.67	5,430	842	2,360	539	2,870	683	1,940	332	38.8	113	313
					ALINED, HOMOGENEOUS										
8	2-in. disk	2-in. disk	Parallel	.65	8,650	1,696	4,860	1,554	5,560	1,866	690	561	102.2	115	181
			Perpendicular	.65	900	142	250	68	410	58	1,830	203	15.2		
					ALINED, THREE-LAYER[4]										
9	1-in. ring	Shavings	Parallel	.64	3,700	761	1,700	517	2,220	619	940	371	46.1	121	164
			Perpendicular	.65	1,680	226	700	189	970	178	1,310	287	29.3		
10	2-in. disk cross-alined	1-in. ring cross-alined	Parallel	.65	6,580	1,398	2,280	750	2,370	749	1,280	320	35.3	112	178
			Perpendicular	.63	3,110	412	1,220	380	1,340	466	1,620	275	33.6		
11	2-in. disk	1-in. ring	Parallel	.68	8,100	1,598	3,100	1,081	3,830	1,281	1,620	372	49.1	118	208
			Perpendicular	.65	2,020	267	1,190	268	1,670	328	1,890	278	30.6		
12	Veneer	2-in. ring	Parallel	.66	12,880	2,230	5,630	1,417	5,460	1,689	1,460	342	39.8	95	218
			Perpendicular	.66	2,370	282	1,190	363	1,630	345	1,890	298	21.2		

[1] Each value is average of 5 specimens.

[2] 1-in. chips flaked to 0.020-in. thickness in ring-type flaker.

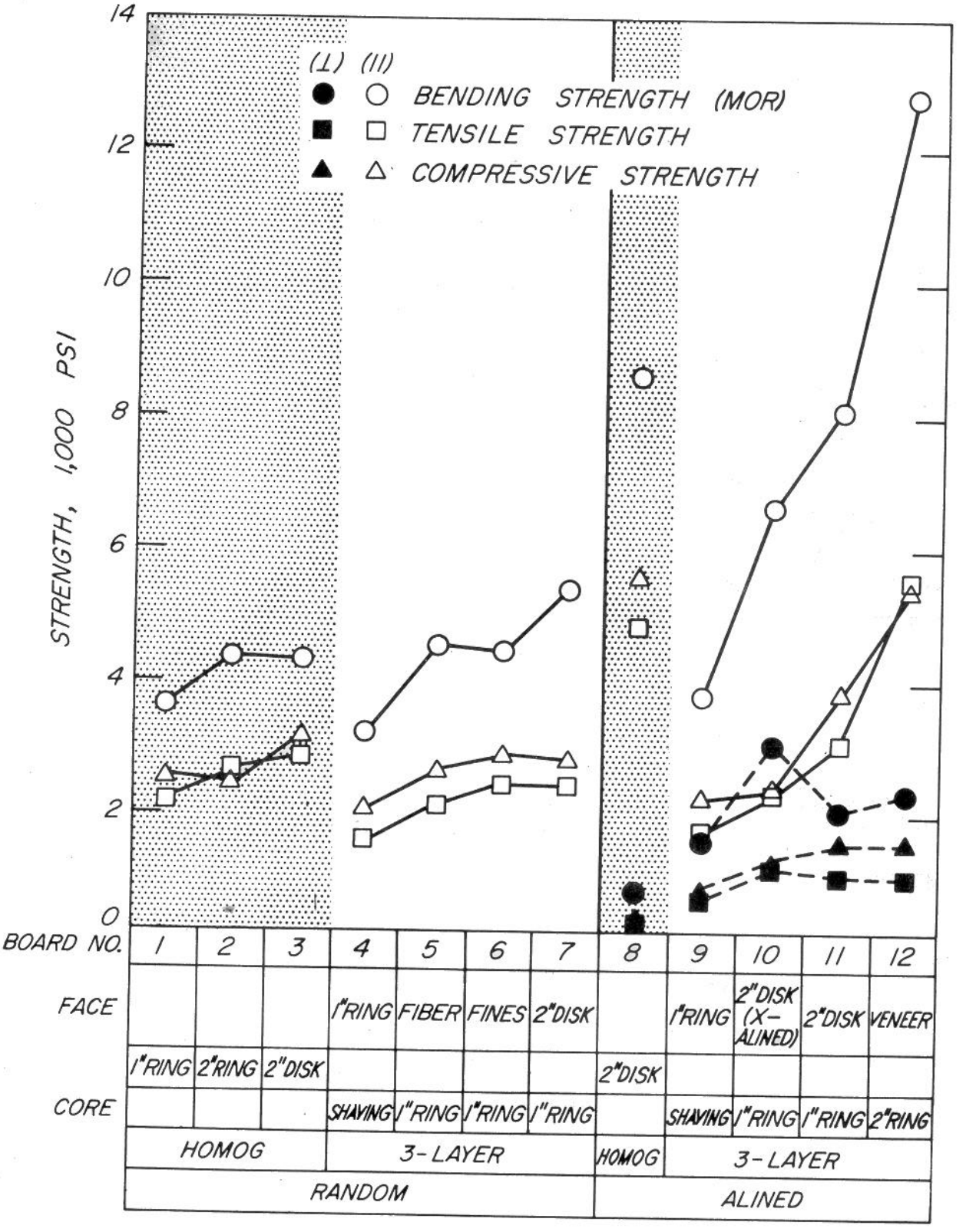
[3] 2-in. chips flaked to 0.020-in. thickness and 1/2-in. width in disk-type flaker.

[4] Face:core:face weight ratio is 15:70:15.

Table 2. Coefficient of Variation for Strength Values of Various Structural-Type Particleboards as Given in Table 1.

Panel type	Construction: Face	Construction: Core	Construction: Test direction	Specific gravity	Bending: Modulus of rupture	Bending: Modulus of elasticity	Tension parallel: Strength	Tension parallel: Modulus of elasticity	Compression parallel: Strength	Compression parallel: Modulus of elasticity	Edgewise shear strength	Interlaminar shear: Strength	Interlaminar shear: Modulus of elasticity	Internal bond	Plate shear modulus
							RANDOM, HOMOGENEOUS								
1	1-in. ring	1-in. ring		3	6	6	3	7	9	16	3	4	9	6	4
2	2-in. ring	2-in. ring		3	6	6	4	11	4	21	12	7	4	8	3
3	2-in. disk	2-in. disk		2	7	2	6	12	19	24	5	23	7	72	2
							RANDOM, THREE-LAYER								
4	1-in. ring	Shavings		3	13	7	10	7	7	13	6	4	4	9	5
5	Fiber	2-in. ring		3	9	9	13	11	13	9	8	15	18	10	5
6	Fines, screened 1-in. ring	Flakes, screened 1-in. ring		3	5	3	7	4	5	13	7	14	17	12	2
7	2-in. disk	1-in. ring		3	9	6	9	7	12	16	10	9	10	10	4
							ALINED, HOMOGENEOUS								
8	2-in. disk	2-in. disk	Parallel	3	5	7	19	15	10	9	22	8	2	10	3
			Perpendicular	2	15	6	33	38	40	52	8	9	8		
							ALINED, THREE-LAYER								
9	1-in. ring	Shavings	Parallel	2	12	5	14	9	20	20	10	6	7	8	4
			Perpendicular	3	9	10	12	8	12	8	11	7	8		
10	2-in. disk cross-alined	1-in. ring cross-alined	Parallel	5	7	7	17	17	14	16	8	6	11	14	5
			Perpendicular	5	13	7	14	16	17	20	10	16	16		
11	2-in. disk	1-in. ring	Parallel	2	12	4	7	15	8	20	8	4	5	8	4
			Perpendicular	5	16	10	12	7	20	11	6	11	7		
12	Veneer	2-in. ring	Parallel	2	6	3	28	19	7	5	9	7	5	10	3
			Perpendicular	3	7	7	13	29	10	12	6	5	11		

Figure 2. Comparison of Various Strength Properties of the 12 Structural Particleboards.



to bending strength. Use of 1-inch ring-cut flakes as faces for a planer shavings board (No. 4) improved MOR from an average of 2,200 psi (for an all-shavings board[3]) to 3,220 psi. However, this board still had the lowest MOR of the structural board types constructed. Alinement of the l-inch face flakes board type (No. 9) increased effective bending strength in the direction of alinement only 15 percent to 3,700 psi.

Use of quality, precision-cut, 2-inch disc-cut flakes in combination with a core of l-inch ring-cut flakes (No. 7) resulted in a much higher average panel bending strength of 5,430 psi. Alinement of the face flakes further increased the MOR of this board (No. 11) almost 50 percent to 8,100 psi in the direction of alinement.

The steam release problem inherent in manufacturing boards with large flakes was encountered in pressing the homogeneous, randomly formed flakeboard (No. 3) made of 2-inch disc-cut flakes. Although no “blows” were apparent, poor core integrity is indicated by the low average internal bond strength of the board (36 psi), and partially explains why the bending strength of the homogeneous board is below that of the three-layer board (No. 7). No problem was encountered with the homogeneous board of alined flakes (No. 8). This is in accord with work of Klimova et al. showing lower internal steam pressure in boards with alined particles.[4]

Apparent panel moduli of elasticity in bending, tension, and compression (Figure 3) show trends, by panel types, similar to those for strength properties. One noticeable difference was the higher tensile and compressive modulus (parallel to alinement) of the homogeneous flakeboard of alined flakes (No. 8) as compared to the veneer-overlaid panel (No. 12). Probably, this was related to the fact that all of the material in board No. 8 tended to be alined whereas only a fraction of the random core flakes in board No. 12 tended to lie in the same direction as the grain of the veneer faces. Panel No. 8, of course, suffered from low properties in the alternate panel direction.

Interlaminar shear and internal bond strengths, shown in Figure 4, are both measures of panel core integrity and as such are influenced only to a minor extent by face flake or particle geometry. With two exceptions (boards of random homogeneous disc-cut flakes (No. 3) and alined homogeneous disc-cut flakes (No. 8)) these two properties were quite similar in all panel types. Property levels were low with the random homogeneous panel of disc-cut flakes (No. 3) due to the poor bonding associated with poor steam release as described -earlier. The presence of alined flakes in the core of the alined homogeneous disc flake panel, on the other hand, resulted in higher interlaminar shear properties, parallel to flake alinement. As in other properties, interlaminar shear strength perpendicular to the flake alinement was lower than in other panel types. This effect was not apparent in the cross-alined board (No. 10).

Figure 3. Comparison of Various Apparent Moduli of Elasticity in the 12 Structural Particleboards.

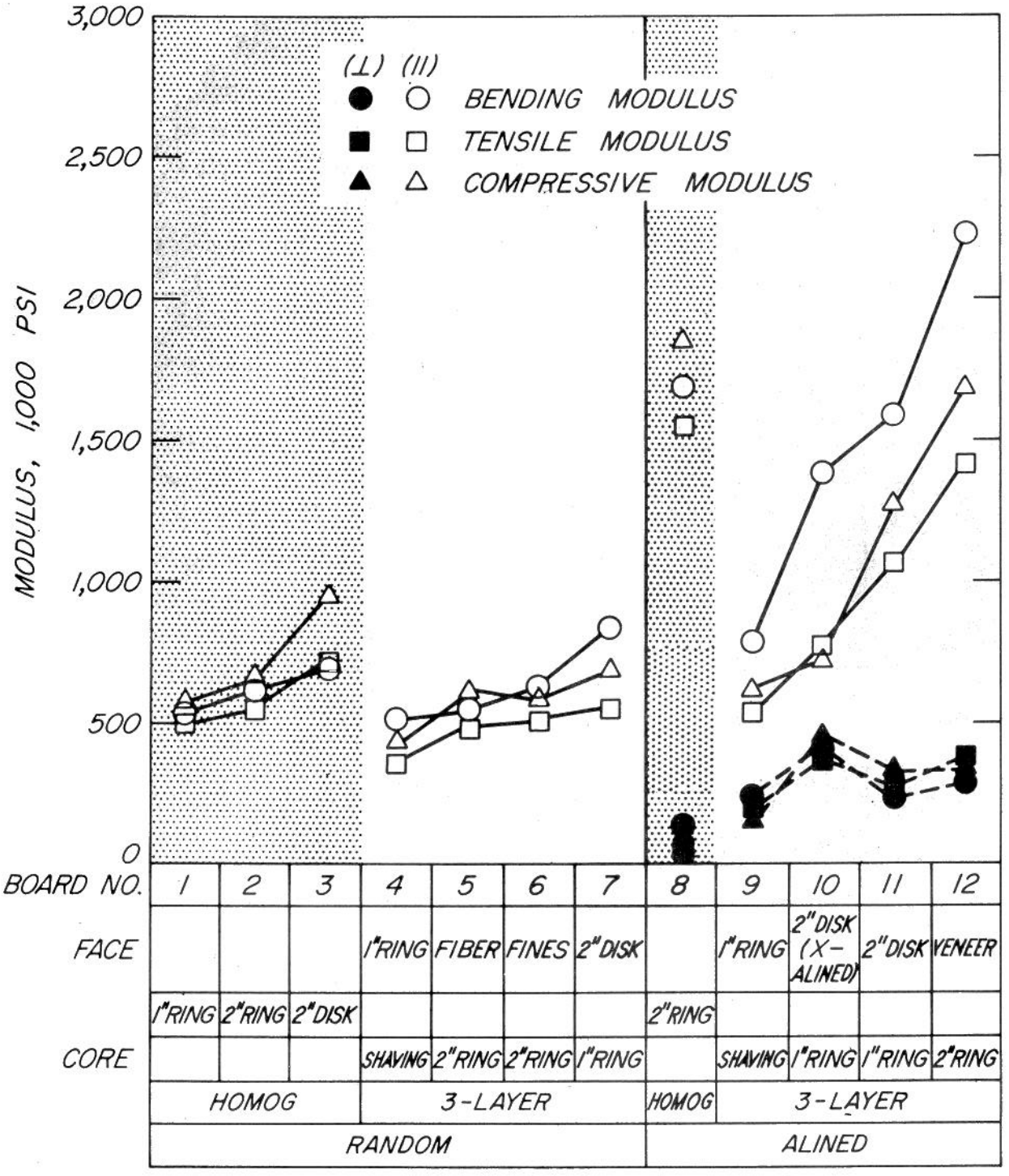
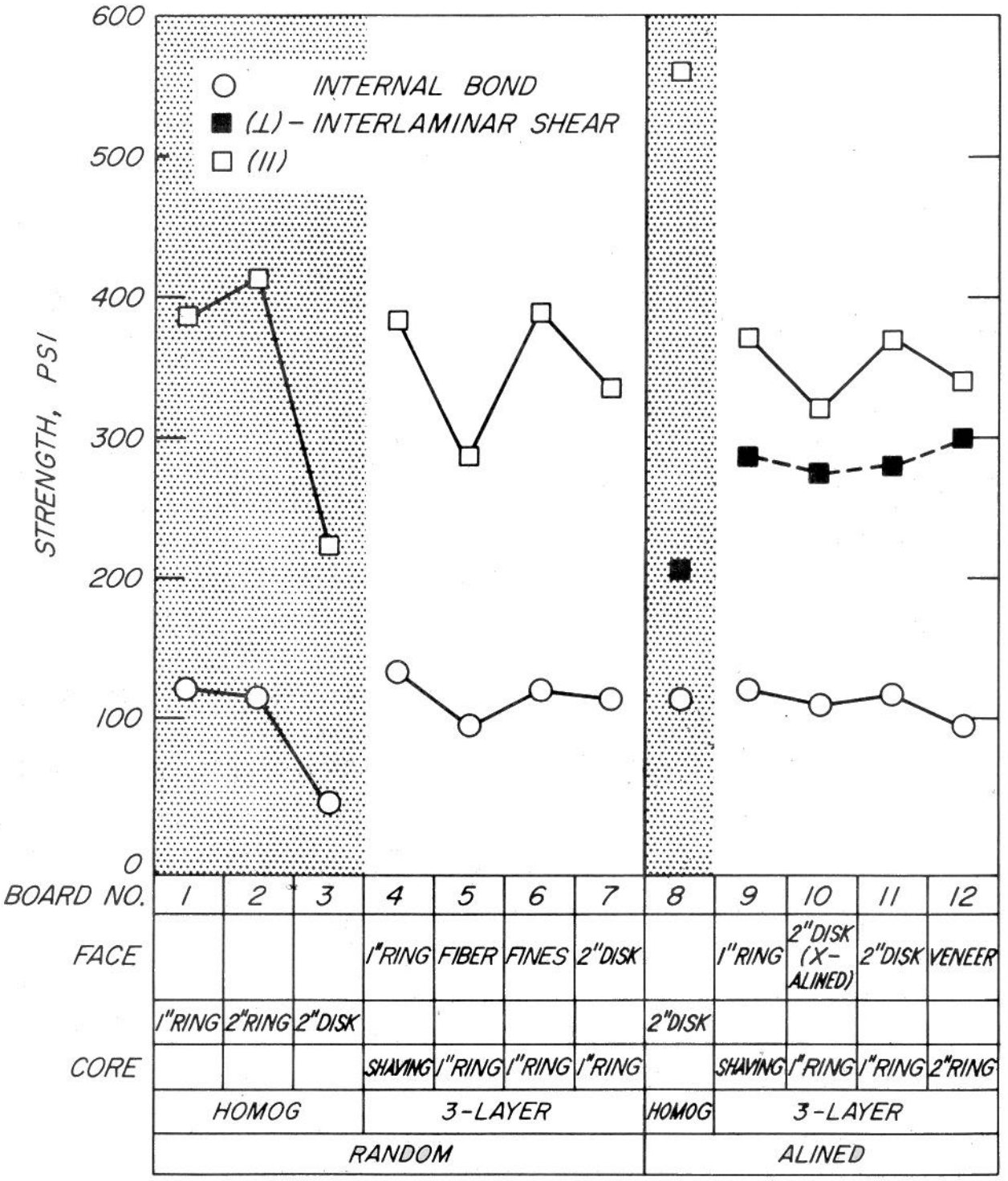


Figure 4. Comparison of Interlaminar Shear Strength and Internal Bond Strength in the 12 Structural Particleboards.



Property levels for plate shear modulus and interlaminar shear modulus are shown in Figure 5. Panels made of similar flake types had significantly higher plate shear moduli when flakes were randomly distributed than when flakes were alined.

Edgewise shear strength (not shown graphically) was also higher in random boards. As such, the random homogeneous 2-inch disc flakeboard (No. 3) had the highest edgewise shear strength, while the same board made with alined flakes (No. 8) possessed the lowest edgewise shear strength in a direction parallel to flake alinement.

Regression equations: Relationships between the various properties were developed through a series of linear and multiple linear regression equations. Previous research by McNatt[5] had shown several linear relationships to exist between various engineering properties of conventional particleboard panels. Highly correlated relationships would permit prediction of strength parameters which are more difficult to measure, from those properties which are more easily obtained.

Table 3 illustrates several examples of regression equations in which this principle may be used. Many of the properties evaluated are shown to be related for the 12 board types in this study; the most important are summarized:

a. Bending strength (MOR) properties may be confidently predicted from their corresponding bending stiffness (EB).
b. Bending properties after accelerated aging (ASTM D 1037)[2] can be predicted from initial bending tests.
c. Tensile and compressive strength and stiffness can be predicted from the bending strength or stiffness.
d. Compressive strength and stiffness correlates well with respective tensile strength or stiffness.

Thus the 11 basic engineering properties shown in Table 1, as well as the two static bending properties after aging, may be predicted by the following five tests: static bending, edgewise shear, interlaminar shear, plate shear, and internal bond.

The table shows, by means of selected multiple regressions, that interrelationship exists among various properties, and particularly illustrates the practicality of using nondestructive stiffness tests to predict strength. These relationships are likely to be different for other board types. For example, internal bond strength was not found to be closely related to any other property measured in this study; whereas in a previous study,[5] internal bond strength correlated well with interlaminar shear strength ($R^2 = 0.88$).

Accelerated aging: Properties of panels after exposure to the ASTM D 1037 accelerated aging procedure are shown in Table 4 and compared graphically in Figure 6.

Figure 5. Comparison Of Shear Moduli in 12 Structural Particleboards.

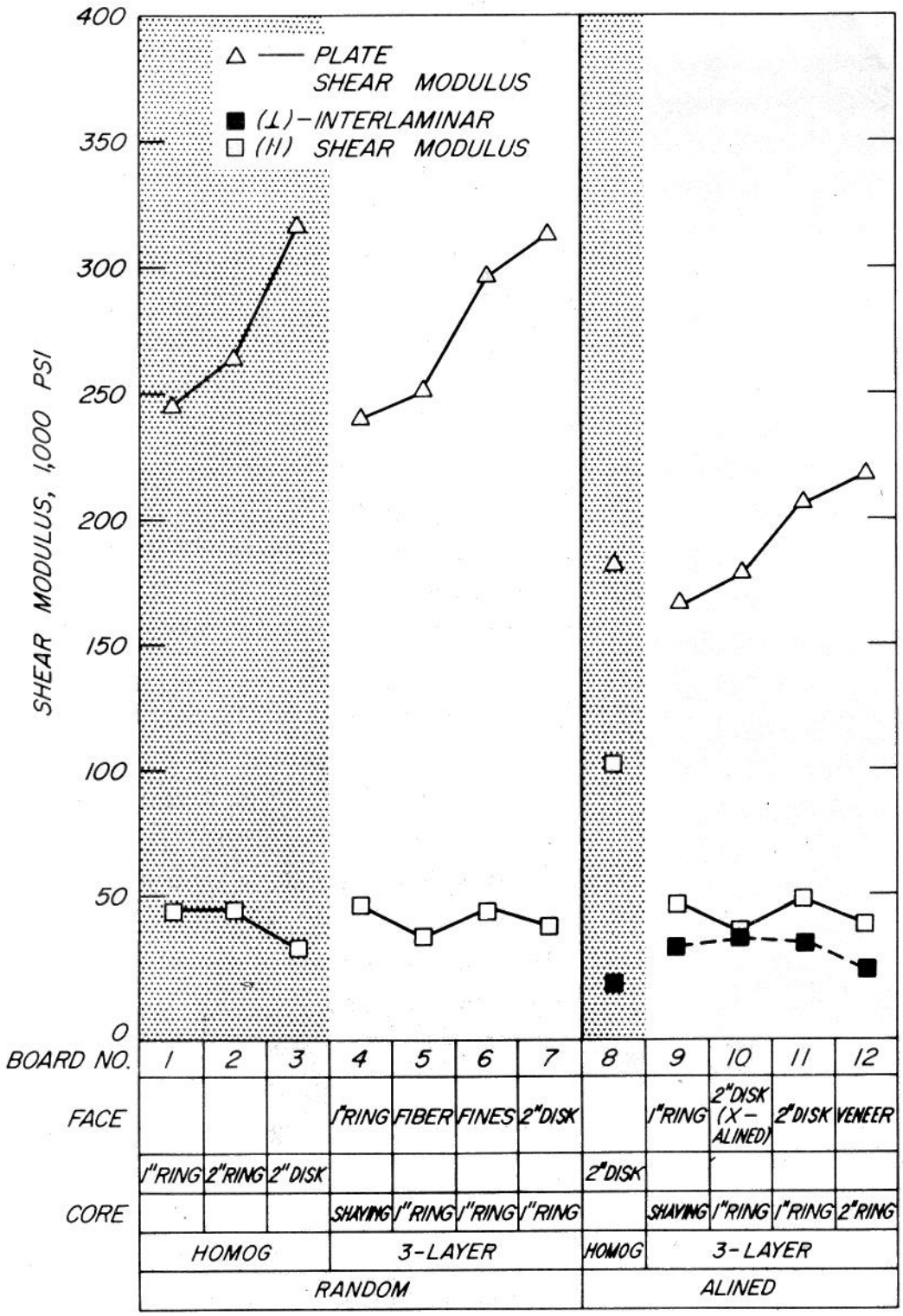


Table 3. Summary of Regression Equations[1]

	R^2	$S_{y \cdot x}$
Static bending		
$MOR = 835.3 + 4.913\ E_B$	0.95	689
$MOR\ (AA) = -648.6 + 0.9785\ MOR$	.91	886
$E_B\ (AA) = -141.6 + 1.0005\ E_B$	.95	127
Tension parallel to surface		
$S_T = 260.9 + 0.4250\ MOR$	.78	656
$S_T = 355.0 + 3.158\ E_T$	.83	578
$S_T = -203.6 + 0.9435\ S_c$	.85	544
$E_T = 99.35 + 0.6398\ E_B$	.83	167
$E_T = 51.51 + 0.2866\ E_B + 0.4616\ E_c$	.89	134
$E_T = 62.82 + 0.7652\ E_c$	.86	152
Compression parallel to surface		
$S_c = 649.2 + 0.4170\ MOR$	.79	635
$S_c = 742.7 + 2.646\ E_c$	.90	440
$S_c = -298.5 + 2.627\ E_c + 4.683\ G_{PL}$	.93	374
$E_c = 103.6 + 0.7651\ E_B$	.81	216
Interlaminar shear		
$S_I = 167.6 + 4.201\ G_I$	.80	39.2
Edgewise shear		
$S_E = 1.065 - 12.73\ G_I + 4.547\ G_{PL}$ [2]	.71	219
Plate shear		
$G_{PL} = 127.0 + 0.239\ E_B$ [3]	.70	17.9

[1] Strength in pounds per square inch, elastic moduli in 1,000 pounds per square inch. MOR = modulus of elasticity; E_B = apparent modulus of elasticity in bending; S_T = tensile strength; E_T = apparent modulus of elasticity in tension; S_c = compressive strength; E_c = apparent modulus of elasticity in compression; S_I = interlaminar shear strength; G_I = interlaminar shear modulus; S_E = edgewise shear strength; G_{PL} = plate shear modulus; (AA) = after accelerated aging.

[2] Panel types 8 through 12 only.

[3] Panel types 1 through 7 only.

Table 4. Panel Properties After Exposure to ASTM D 1037 Accelerated Aging Test.

Panel type	Construction: Face	Construction: Core	Construction: Test direction	After aging: Specific gravity	After aging: Modulus of rupture[1]	After aging: Modulus of elasticity[1]	After aging: Internal bond	Percent of initial: Specific gravity	Percent of initial: Modulus of rupture	Percent of initial: Modulus of elasticity	Percent of initial: Internal bond
					Psi	Ksi	Psi	Pct	Pct	Pct	Pct
				RANDOM, HOMOGENEOUS							
1	1-in. ring[2]	1-in. ring		0.53	2,790	362	59	82.8	77.1	68.3	49.6
2	2-in. ring	2-in. ring		.55	3,190	401	57	82.1	73.5	66.0	49.6
3	2-in. disk[3]	2-in. disk		.53	4,270	672	12	80.3	99.1	97.3	33.3
				RANDOM, THREE-LAYER[4]							
4	1-in. ring	Shavings		.58	2,590	409	75	86.6	80.4	81.2	55.1
5	Fiber	2-in. ring		.56	3,140	366	51	86.2	69.6	66.7	54.2
6	Fines, screened: 1-in. ring	Flakes, screened: 1-in. ring		.56	3,510	394	63	84.8	79.1	62.9	51.6
7	2-in. disk	1-in. ring		.55	4,470	582	41	82.1	82.3	69.1	36.3
				ALINED, HOMOGENEOUS							
8	2-in. disk	2-in. disk	Parallel	.64	9,500	1,777	91	98.5	109.8	104.8	79.1
			Perpendicular	.57	460	56		87.7	51.1	39.4	
				ALINED, THREE-LAYER[4]							
9	1-in. ring	Shavings	Parallel	.58	3,750	629	71	90.6	101.4	82.7	58.7
			Perpendicular	.54	1,070	126		83.1	63.7	55.8	
10	2-in. disk cross-alined	1-in. ring cross-alined	Parallel	.57	5,850	1,049	68	87.7	89.9	75.0	60.7
			Perpendicular	.55	2,330	335		87.3	74.9	81.3	
11	2-in. disk	1-in. ring	Parallel	.57	7,250	1,235	53	83.8	89.5	77.3	44.9
			Perpendicular	.55	1,610	308		84.6	79.7	115.4	
12	Veneer	2-in. ring	Parallel	.56	10,000	2,103	50	84.8	77.6	94.2	52.6
			Perpendicular	.52	1,320	159		78.8	55.7	55.0	

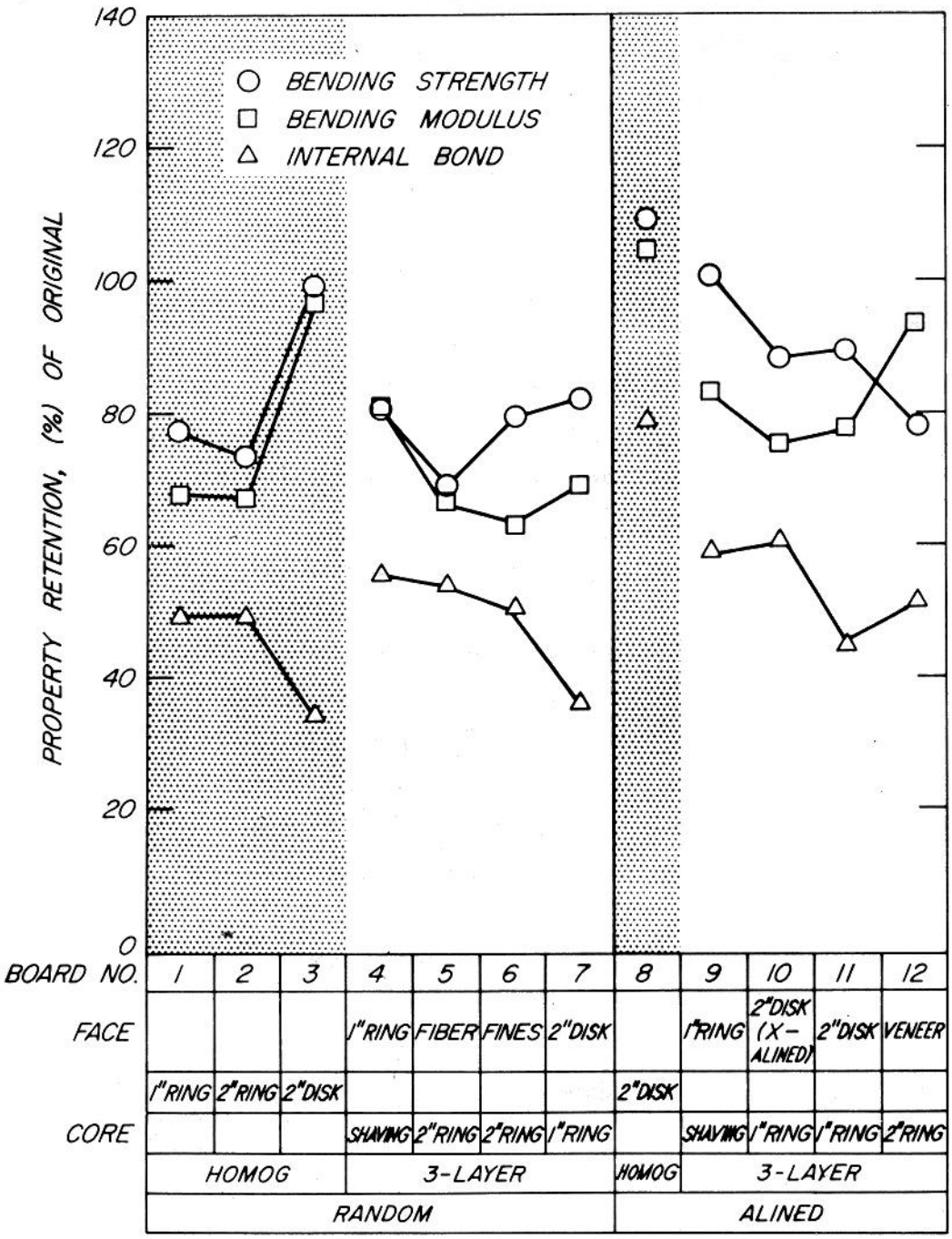
[1] Calculated using specimen dimensions before aging.

[2] 1-in. chips flaked to 0.020-in. thickness in ring-type flaker.

[3] 2-in. chips flaked to 0.020-in. thickness and 1/2-in. width in disk-type flaker.

[4] Face:core:face ratio is 15:70:15.

Figure 6. Retention of Internal Bond, Bending Strength, and Bending Modulus Following Accelerated Aging.



Internal bond levels were more seriously affected by the aging test than were the bending properties. Numerical bending strength and stiffness losses occurring during accelerated aging were approximately the same between panel types. Consequently the percent of strength loss was small for panels processing high initial strength values and large for those panels with initially low properties. Average retention levels for random and alined panels are shown in the following tabulation:

	Specific Gravity	MOR	MOE	IB
	(%)	(%)	(%)	(%)
Random	84	80	73	47
Alined parallel	89	93	87	59
Alined perpendicular	84	65	69	--

As shown, average retention levels in bending were best in the specimens with flakes alined parallel to the specimen length, but poorer when flakes were perpendicular to specimen length. Another indication of constant strength loss is shown in Table 3 where the linear regressions relating bending properties before and after aging indicated a relatively uniform reduction of about 650 psi in MOR and about 140,000 psi in MOE due to the aging, regardless of panel type or flake orientation.

Dimensional stability: Results of the various dimensional stability tests are summarized in Table 5. Thickness springback data after accelerated aging and reconditioning to 73° F and 64 percent RH also are included. OD-VPS thickness swelling data compared by panel types in Figure 7 show that better thickness stability is associated with shorter flakes or particles with the one exception of the alined homogeneous disc-cut flake panel (No. 8). Here, improved thickness stability is associated with fewer or lower glue line stresses inherent in an alined flake construction. Thickness swelling from 50 to 90 percent RH, from 30 to 90 percent RH, and springback after aging were all quite closely related, following the same trend as illustrated in Figure 7.

Thickness swelling curves from ovendry through various humidities to the soaked condition are shown in Figure 8 for seven representative panels and illustrate the similarity of swelling between panel types. Again, the notable exception is the homogeneous disc-cut flake panels having high swelling in the random flake construction and minimal swelling in the alined flake construction.

Linear expansion data from ovendry to vacuum-pressure-soak conditions are summarized by panel type in Figure 9. As opposed to thickness swelling, low lineal movement was associated with long flake length and thus good lineal stability was indirectly related to high strength. This

Table 5. Dimensional Stability Properties of Structural Particleboards.

Panel type	Construction: Face	Construction: Core	Construction: Test direction	50 to 90 percent relative humidity: Water absorption	50 to 90 percent relative humidity: Linear expansion	50 to 90 percent relative humidity: Thickness swelling	30 to 90 percent relative humidity: Water absorption	30 to 90 percent relative humidity: Linear expansion	30 to 90 percent relative humidity: Thickness swelling	Ovendry-vacuum-pressure-soak[1]: Water absorption	Ovendry-vacuum-pressure-soak[1]: Linear expansion	Ovendry-vacuum-pressure-soak[1]: Thickness swelling	Springback after aging
				Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct
						RANDOM, HOMOGENEOUS							
1	1-in. ring[2]	1-in. ring		9.7	0.09	10.8	12.1	0.17	12.0	110.3	0.46	22.1	24.0
2	2-in. ring	2-in. ring		9.8	.05	11.5	12.1	.11	13.0	110.6	.29	26.2	25.8
3	2-in. disk[3]	2-in. disk		9.9	.07	11.2	11.9	.13	12.4	100.1	.28	25.0	26.8
						RANDOM, THREE-LAYER[4]							
4	1-in. ring	Shavings		9.9	.26	10.0	11.9	.37	11.1	108.4	.72	22.7	19.7
5	Fiber	2-in. ring		9.9	.03	8.7	11.9	.09	9.7	103.4	.29	19.0	16.0
6	Fines, screened: 1-in. ring	Flakes, screened: 1-in. ring		9.8	.09	9.8	11.8	.16	10.7	93.8	.42	20.2	18.4
7	2-in. disk	1-in. ring		10.4	.05	11.2	12.3	.12	12.4	96.6	.32	23.5	23.6
						ALINED, HOMOGENEOUS							
8	2-in. disk	2-in. disk	Parallel	10.5	.00	9.4	12.5	.05	10.3	114.5	.14	19.0	14.3
			Perpendicular		1.92			2.28			3.86		17.4
						ALINED, THREE-LAYER[4]							
9	1-in. ring	Shavings	Parallel	10.3	.12	9.9	12.5	.21	11.0	115.1	.46	21.6	17.7
			Perpendicular		.68			.85			1.61		18.1
10	2-in. disk cross-alined	1-in. ring cross-alined	Parallel	10.6	.02	11.3	12.6	.08	12.4	116.9	.21	24.3	22.8
			Perpendicular		.16			.23			.46		21.1
11	2-in. disk	1-in. ring	Parallel	10.2	.01	11.4	12.5	.06	12.6	104.4	.21	24.7	23.7
			Perpendicular		.26			.38			.83		21.8
12	Veneer	2-in. ring	Parallel	9.9	.00	10.4	11.9	.03	11.4	97.0	.12	23.9	21.8
			Perpendicular		.19			.27			.56		23.6

[1] Total change of matched samples taken respectively to ovendry and vacuum-pressure-soaked conditions from 42 pct relative humidity.

[2] 1-in. chips flaked to 0.020-in. thickness in ring-type flaker.

[3] 2-in. chips flaked to 0.020-in. thickness and 1/2-in. width in disk-type flaker.

[4] Face:core:face ratio is 15:70:15.

Figure 7. Thickness Swelling by Panel Type as a Result of Exposure to OD-VPS.

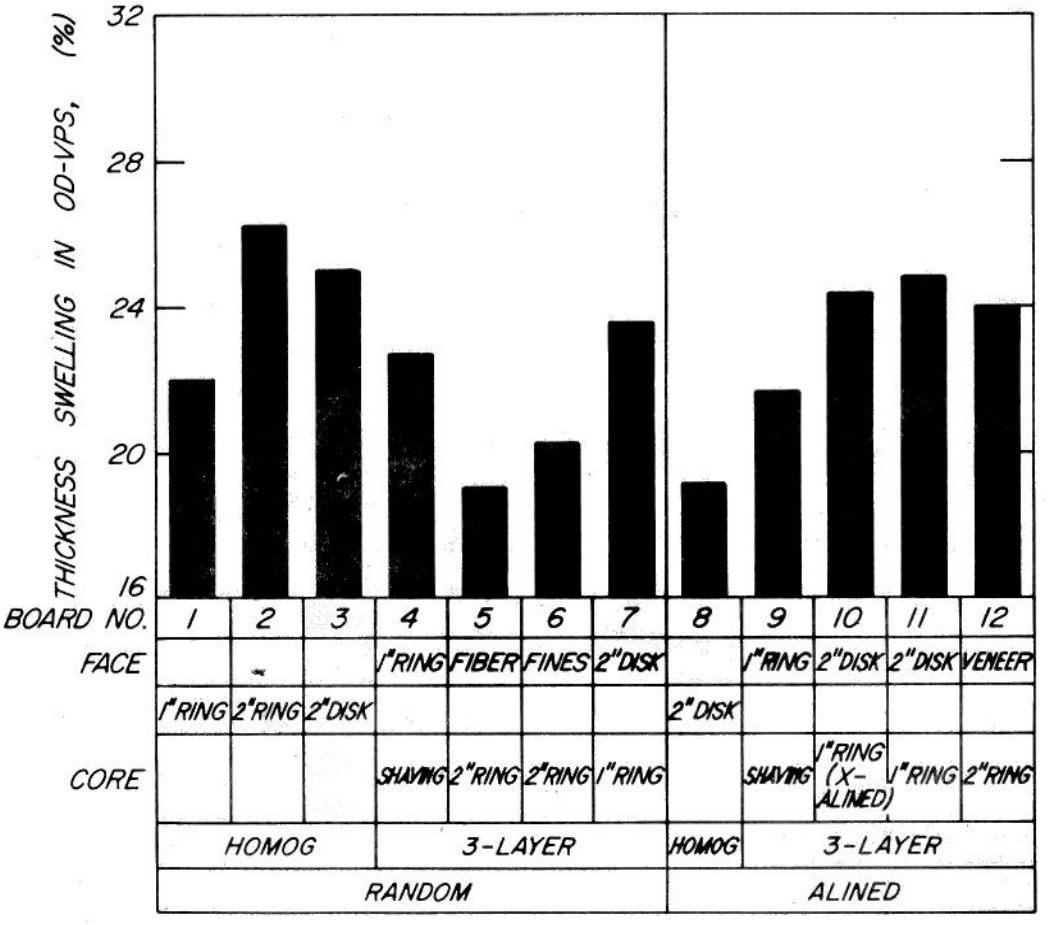


Figure 8. Thickness Swelling of Seven Panel Types from Ovendry Through Various Moisture Contents to Soaked Condition.

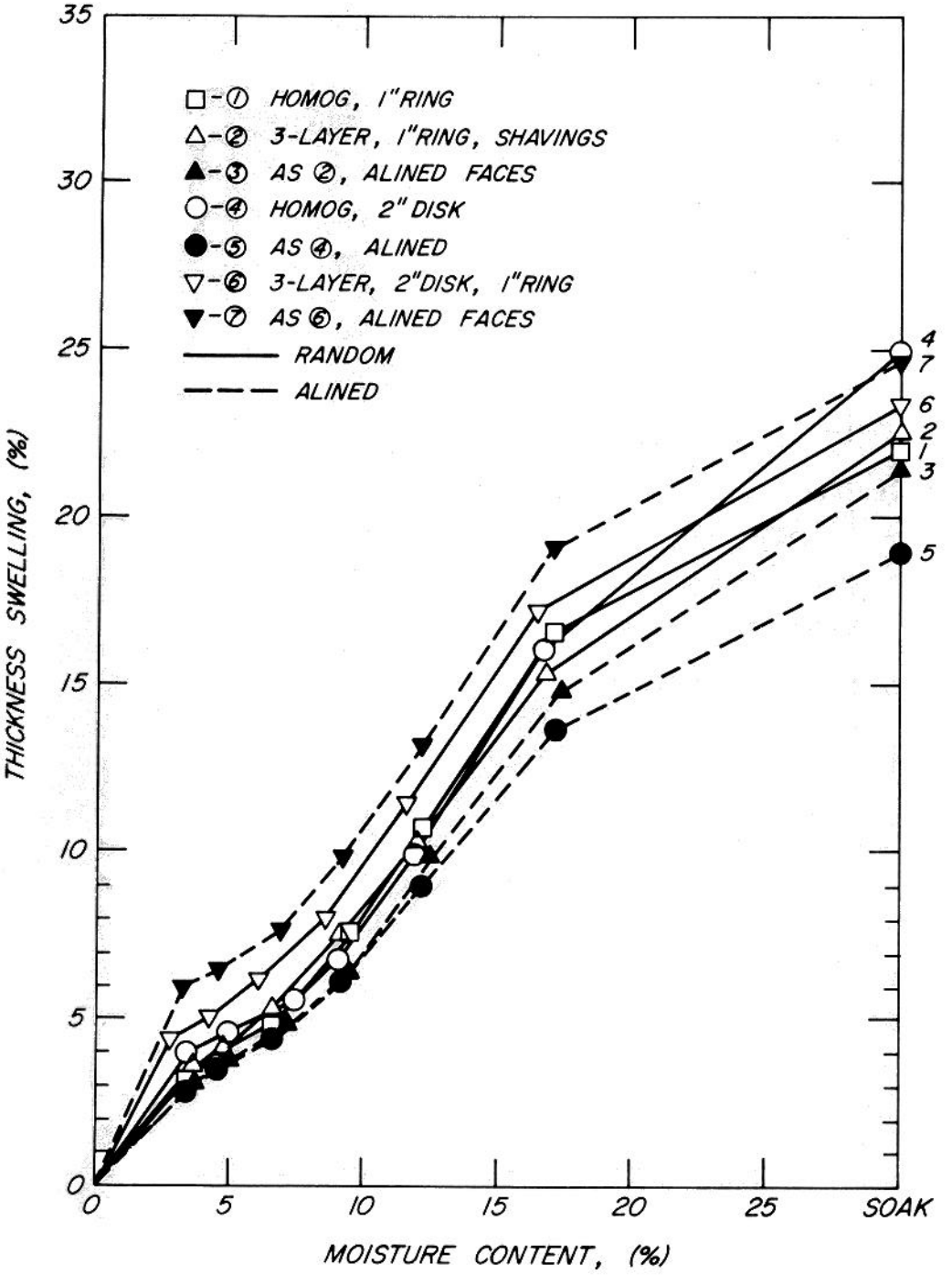


Figure 9. Linear Expansion by Panel Type After Exposure to OD-VPS-Conditions.

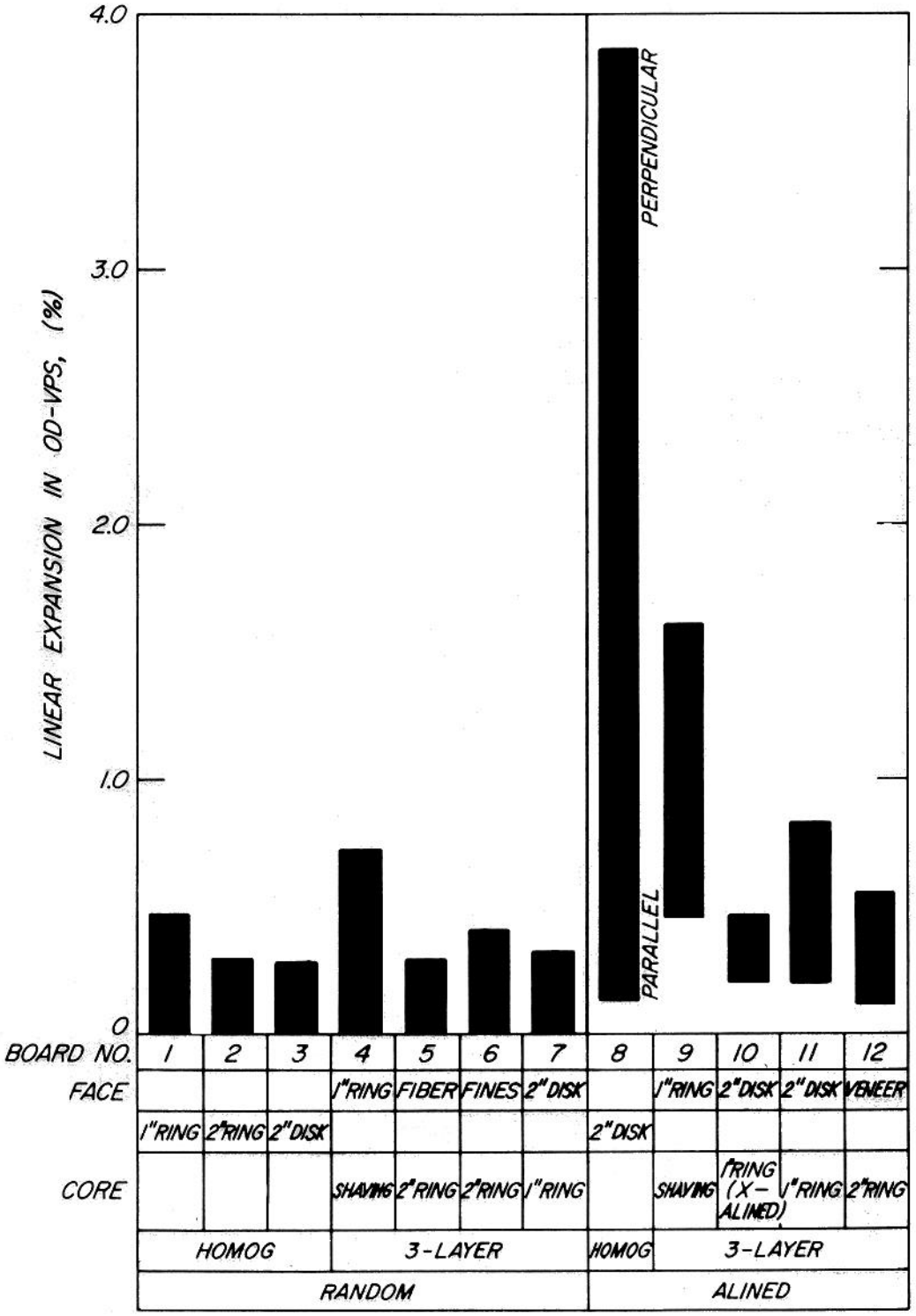


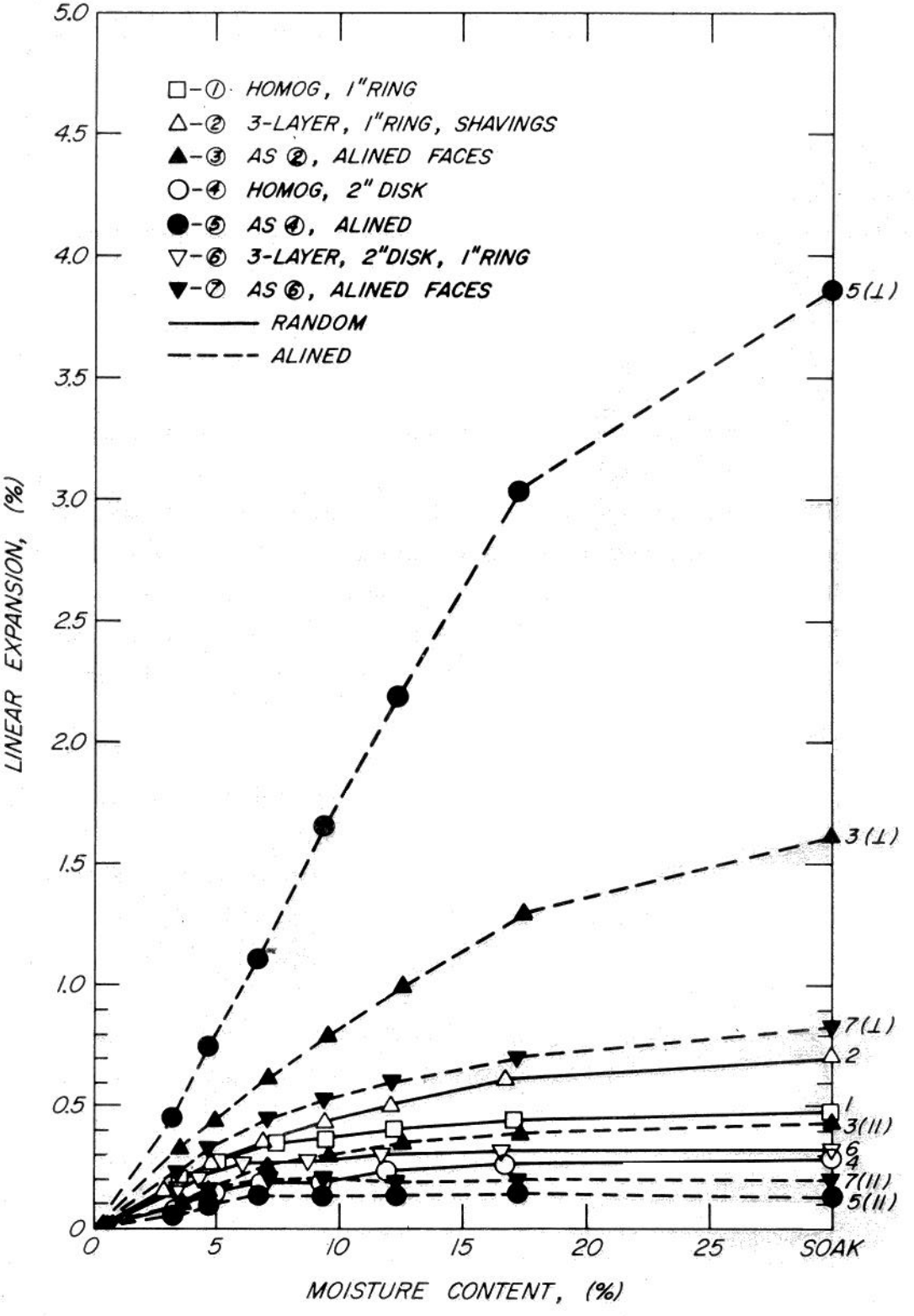
figure also demonstrates the high linear movement associated with the "cross-grain" flake direction in alined flake panels and the benefit or necessity of a random or cross-alined flake core layer in reducing this linear cross-panel dimensional change. Linear movement curves from ovendry through various humidities to the soaked condition are illustrated in Figure 10 for the same panel types as depicted in Figure 8. This graph demonstrates the high linear stability attained with alined flakes in the direction of fiber alinement, but also shows the great instability in the cross-panel direction. Panels made with long flakes randomly oriented are nearly equal in linear stability to that found in the fiber direction of an alined flakeboard. Most linear movement, in the more stable panels, occurred below 42 percent RH or at about the 7 percent MC level, with practically no lineal change occurring above this level even when soaked.

Conclusions

Within the scope of this research on structural particleboards from forest residues, the following conclusions are presented:

1. Highquality structural particleboards of many types can be made from forest residues containing as much as 8 percent bark and 12 percent decayed wood.
2. Depending on design criteria, some panel types are more efficient in usage of materials than others. Where stiffness is a controlling factor, thinner panels can be utilized if large flakes, oriented flakes, or veneer overlays are incorporated in the panel design.
3. Many engineering properties were closely interrelated; both tensile and compressive strength and stiffness could be predicted from bending tests. Internal bond was not well correlated with other properties.
4. Most panel types were quite durable as determined by the ASTM accelerated aging test (ASTM Standard D 1037-72a). The panels retained an average of 80 percent of their initial bending strength, 76 percent of initial bending stiffness, and 52 percent of initial internal bond strength.
5. Dimensional stability was closely related to flake or particle geometry and quality with best thickness stability associated with small particles and best linear stability with larger flakes.
6. The high instability and low strength in the cross-grain direction must be considered to insure proper use of an alined homogeneous flakeboard in structural applications.

Figure 10. Linear Expansion of Seven Panel Types from Ovendry Through Various Moisture Contents to Soaked Condition.



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