AN ABSTRACT OF THE THESIS OF

Steven Zylkowski for the degree of Master of Science
in Forest Products presented on July 29, 1983
Title: PROPERTIES OF WAFERBOARD MANUFACTURED FROM ALDER AND COTTONWOOD

Abstract approved: Redacted for Privacy
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Old growth softwood inventories are declining, thus quality peeler logs for plywood are becoming more expensive, which increases the likelihood for introduction of new competitive products. Since its recent expansion the waferboard industry has captured about 8.4 percent of the structural panel market and this share is expected to reach 20 percent in 1990.

Western Washington and Western Oregon contain 6.99 billion cubic feet of red alder and 0.22 billion cubic feet of black cottonwood which is of low-value and presently underutilized. Alder and cottonwood have wood properties similar to aspen, the dominate species for waferboard production, a competitive product to softwood plywood. The availability and wood properties of these Northwest hardwoods suggest potential for waferboard production. The objective of this study is to develop the relationship between major production parameters and mechanical properties of waferboard and oriented strand board (OSB) manufactured from alder and cotton-

wood. These relationships are needed to identify the production parameters which will meet property requirements for structural panels and are needed before a comprehensive economic feasibiity study can be conducted.

Waferboard and OSB panels were manufactured from alder and cottonwood at densities of 34, 39, and 44 pounds per cubic foot (pcf). The waferboard panels used 2 and 3 percent powdered phenolic resin and the OSB panels used 3 and 6 percent liquid phenolic resin. The three-layered OSB panels had an average strand alignment of 29 percent. The internal bond (IB), modulus of rupture (MOR), and modulus of elasticity (MOE) were tested on dry samples. The linear expansion (LE) was calculated as the samples were cycled from 50 to 90 percent relative humidity (RH). MOR retention and thickness swelling (TS) were calculated on samples after a two-hour boil cycle and MOR retention was tested on samples after a one-cycle vacuum pressure soak (VPS).

At a density of 44 pcf and a resin content of 3 percent alder and cottonwood waferboard exhibited a MOE of 729,000 psi (5022 MPa) and 773,000 so (5326 MPa) respectively, and an IB of 142 psi (978 KPa) and 112 psi (772 KPa) respectively. At a density of 44 pcf and 6 percent resin content both alder and cottonwood OSB had a MOE of 1,206,000 psi (8309 MPa). The alder OSB had an IB of 152 psi (1047 KPa) and cottonwood OSB had an IB of 98 psi (674 KPa).

The test results led to the conclusion that alder and cottonwood waferboard at 2 percent resin and 39 pcf had properties superior to a commerical aspen waferboard. Likewise, alder and cottonwood OSB at 39 pcf density and 3 percent resin had properties superior to a commercial OSB made from a western softwood. At equal panel densities, cottonwood has more compaction than alder which results in slightly higher bending properties at low and medium densities. This compaction affect usually holds true for IB, however, alder has certain polyphenol extractives which must act as a natural binder which gives alder waferboard and OSB improved IB values. Given the distribution of strand angles in an OSB panel, the ratio of MOE parallel to MOE perpendicular to the panel axis can be estimated by calculating the contribution to MOE in each direction, of each strand using a Hankinson-type expression. This estimation is confounded by the density gradient through the panel thickness.

From the stand point of panel properties, alder and black cottonwood are two species indigenous to the Pacific Northwest which are suitable for waferboard or OSB production.

Properties of Waferboard Manufactured from Alder and Cottonwood

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 29, 1983

Commencement June 1984

APPROVED:

Redacted for Privacy

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Date thesis is presented July 29, 1983

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ACKNOWLEDGEMENT

I would like to thank James Wilson and Helmuth Resch for their professional assistance and financial support. Their encouragement and dedication to this project and to my education was invaluable.

Most importantly, I would like to acknowledge the emotional support I have always received from my wife Yvonne, and my parents, Judith and Jerry. Their steady devotion has been a tremendous asset.

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I. INTRODUCTION

Since the introduction of structural wood panels the market has been dominated by softwood plywood from the Pacific Northwest and the Southeast. Old growth softwood inventories are declining, thus high quality peeler logs for plywood are becoming more expensive, which increases the likelihood of marketing new competitive products. Reports by the Committee on Renewable Resources for Industrial Materials point to a need for new economical housing materials to meet future demand (Boyd et. al. 1976). This need for more cost competitive housing materials was responsible for the successful introduction of waferboard and oriented strand board (OSB) in the Midwestern and Eastern U.S.

Waferboard and OSB are made by combining wood wafers, phenol-formaldehyde resin, and wax under pressure and high temperatures. The large wafers impart high bending strengths so that waferboard and OSB are considered structural panels, (i.e. they are intended for use as floor, wall or roof sheathing). OSB differs from waferboard by using longer , aligned wafers to impact superior bending and dimensional stability properties in a desired direction.

Waferboard and OSB Industry is Expanding

The waferboard industry has captured a noticeable share of the structural panel market in the United States. The term "waferboard industry" is used generically to include waferboard and OSB. In 1982 the waferboard plant capacity and imports from Canada represented about 8.4% of all structural panel capacity in the U.S. and is expected to reach 20% of capacity by 1990 (Wilson 1981; Drake 1982). Currently the waferboard industry has plans to expand into Texas, Louisiana, California, and Idaho. Wherever low value stumpage is available near population centers, the industry has enjoyed a price advantage over softwood plywood. An overview of the expansion of the waferboard industry for the U.S. and Canada is presented in Table 1.

Pacific Northwest has Potential for Waferboard and OSB Production

Two Pacific Northwest hardwoods, red alder (*Alnus rubra*, Bong.) and black cottonwood (*Populus trichocarpa*, Torr. and Gray), have potential as a raw material source for production of waferboard and/or OSB. This potential is based upon availability, wood properties, and the under utilization of these species.

According to a Forest Service study conducted in 1977, Western Washington and Western Oregon contain 6.99 billion cubic feet of alder and 0.22 billion cubic feet of black cottonwood (Forest

Company	Location	1962-72	1973-78	1979	1980	1981	1982	1983
		Million sq. ft. per year capacity (3/8 in. basis)						
MacMillan Bloedel #1	Hudson Bay, Sask.	70	70	70	70	70	70	70
MacMillan Bloedel #2	Hudson Bay, Sask.	80	80	80	80	80	80	80
Waferboard Ltd.	Timmons, Ont.		60	60	60	60	60	60
Blandin	Grand Rapids, Minn.		90	90	90	170	170	170
Weldwood	Longlac, Ont.		130	130	130	130	130	130
Great Lakes Paper	Thunder Bay, Ont.		110	110	110	110	110	110
MacMillan Bloedel #3	Thunder Bay, Ont.		130	130	130	130	130	130
Northwood	Chatham, New Bruns,			160	160	160	160	160
Louisiana-Pacific #1	Hayward, Wis.			130	130	130	130	130
Georgia-Pacific	Woodland, Maine				165	165	165	165
Normick Perron	LaSarre, Quebec					60	120	120
Weldwood	Slave Lake, Alb.					130	130	130
Potlatch #1 *	Bemidji, Minn.					150	150	150
Northwood #2	Bemidji, Minn.					160	160	160
Elmendorf *	Claremont, New Hamp.					76	76	76
Waferboard Ltd.	Ste. Georges, Quebec					130	130	130
Louisiana-Pacific #2	Hayward, Wis.						130	130
Louisiana-Pacific #3	Houlton, Maine						130	130
Weyerhaeuser *	Grayling ,mich.						220	220
Forex	Val d'Or, Quebec						130	130
Potlatch #2	Cook, Minn.						160	160
Wilson-grant	Englehart, Ont.						120	120
Louisiana-Pacific #4	Corrigan, Tx.							130
J.M. Huber	Aroostock, Maine							130
Louisiana-Pacific #5	Idaho							140
Geogia-Pacific	Dudley, NC							165
Pelican Spruce	Edson, Alb.							150
Martin Lumber	Lemoyen, La.							130
Panofor Inc.	Val d'Or, Quebec							120
* OSB plants		150	670	960	1125	1831	2561	3526

Table 1. Location and capacity of North American waferboard and OSB plants

Service 1978). These alder inventories are spread over 1.8 million acres of Washington and 1.25 million acres of Oregon (Little 1978; Resch 1980). Most of the alder inventory propagated 30 to 50 years ago due to extensive harvesting of conifers and non-existent forest practice laws which allowed the aggressive species to flourish. These alder inventories will be mature and harvestable for the next two decades should there be a demand for alder beyond that for lumber.

The Department of Natural Resources in Washington reported that an enormous change in alder consumption is needed to use the potential that will be available in the near future. The supply exceeds by two to four times what little demand exists for hardwood pulp, lumber and firewood. There is some urgency to take advantage of these hardwood inventories because alder begins to rot at older ages of about 40 years (Little 1978).

Red alder and black cottonwood have wood properties which exhibit potential for waferboard or OSB production. Previous research of waferboard production parameters has shown that low density woods are preferred because the wafers can be compacted more during pressing. This greater compaction improves resin efficiency.

Aspen is the most common species used in the production of waferboard in the Midwest and Eastern United States. As presented in Table 2, alder and cottonwood have densities and wood properties which are similar to aspen.

Table 2. Wood properties of red alder, black cottonwood, and aspen (Wood Handbook 1974).

Properties	Alder	Black Cottonwood	Aspen
Density (pcf)[1]	25.6	21.8	21.8
MOR (psi)	9,800	8,500	8,400
MOE (10^6 psi)	1.30	1.27	1.18
Compression strength ⊥[2] (psi)	440	300	370
Tensile strength ⊥ (psi)	420	330	260

[1] Density is based on the oven dry weight and green volume

[2] ⊥ is perpendicular direction; // is parallel direction.

The availability and wood properties of alder have sparked interest in its feasibility for waferboard production in the Pacific Northwest. Black cottonwood has wood properties which suggest it could produce waferboard, however, currently there does not exist sufficient inventory to support significant production. It was included in this study because the Populus genus includes aspen and it has often been used for waferboard research, so it provides a standard for which to compare alder, and the possibility of extensively managed cottonwood stands could considerably increase the availability of cottonwood if demand for the wood existed.

The feasibility of using these Pacific Northwest hardwoods to produce waferboard and/or OSB depends upon the board's performance and its cost competitiveness with other structural panels. Before examining the economic feasibility of waferboard production from alder or cottonwood the relation between production parameters and board properties must be quantified.

II. OBJECTIVES

The objective of this study is to develop the relations between major production parameters and mechanical properties of waferboard and OSB made from alder and black cottonwood. These relationships are needed to identify the production parameters which will meet property requirements for structural panels and are needed before a comprehensive economic feasibility study can be conducted. It is hoped this paper will add impetus to a comprehensive study of the development of a waferboard and/or OSB industry in the Pacific Northwest. This industry would provide for the use of low-valued or presently unmerchantable hardwoods and hopefully provide less expensive structural panels for home construction, and provide much needed production jobs.

III. BACKGROUND

The performance of a waferboard or OSB panel is dependent upon a host of production variables used to manufacture that panel. Much research effort has gone into developing the relations between the many production variables and the ensuing performance of the panel. Table 3 shows the important production parameters and panel properties.

Particle Parameters

Wood Species

For a good glue bond, intimate contact between particles is needed during pressing of a panel. Since densification of the particles occurs during pressing, the panel density must be greater than the density of the wood. Wood density is species dependent and it is generally accepted that low density woods are advantageous when producing waferboard. The panel density divided by the wood density is called the compaction ratio. As the compaction ratio increases so does the contact between particles and most panel properties. Laboratory flakeboards made from nine southern hardwoods demonstrated that bending properties and internal bond strengths were highly correlated to the compaction ratio of the panel and that 1.24 was the minimum compaction ratio that produced

Table 3. Important production parameters and properties of waferboard and OSB.

PRODUCTION PARAMETERS	PANEL PROPERTIES
Particle Parameters	Physical Properties
Species	Density
- wood density	Density gradient through thickness
- wood strength	
Particle geometry	Strength Properties
- length	Modulus of rupture (MOR)
- thickness	Modulus of elasticity (MOE)
- width	Internal bond (IB)
Process Parameters	Durability in Use
Resin content	Thickness swell (TS)
Wax content	Linear expansion (LE)
Press cycle	Strength retention
- mat moisture content	
- press closing time	
- total press time	
- press temperature	
Strand orientation	
Board density	

satisfactory panels (Hse 1975). Table 4 shows the compaction ratio for aspen, alder, and black cottonwood at panel densities of 34, 39, and 44 pounds per cubic feet (pcf). An alder panel with a 34 pcf density will have a compaction ratio very near the minimum reported by Hse.

Table 4. Compaction ratio for alder, cottonwood and aspen at various panel densities.

PANEL DENSITY (pcf)[1]	Compaction Ratio Alder	 Cottonwood	 Aspen
34	1.30	1.51	1.43
39	1.49	1.73	1.65
44	1.70	1.96	1.86

[1] Panel density based on O.D. weight and volume at 50% relative humidity.

Certain species have extractives which can inhibit or complement bonding as the panel is pressed. Alder contains many polyphenol extractives, some of which have been identified by a cold acetone extraction process (Karchesy 1974). One of these extractives, Oregonin, is thought to be associated with the bright orange color that alder wood exhibits as it oxidizes when cut and air dried and it is suspected these extractives provide alder with a sort of natural binder.

Flakeboard is a panel made with small, thin flakes which does not compete with waferboard or OSB in general building but finds specific markets in such things as single floor sheathing in factory built housing since they can supply oversize boards spanning the full width of the house. Maloney (1978) manufactured some test flakeboards with alder flakes which were left to slowly air dry, thus allowing oxidation of the surface, while other flakes were dried immediately. The properties of these alder flakeboards are presented in Table 5. All properties were slightly lower for the oxidized flakes. It was noted that in commercial production all flakes are normally dried immediately after they are produced. The research showed that acceptable structural panels could be made from alder flakes and that the boards had excellent internal bond (IB) properties.

Table 5. Properties of alder flakeboard (Maloney 1978).

Flake Type	Density (pcf)	MOR (psi)	MOE (10^6 psi)	IB (psi)
		Board Properties		
Drum-cut	40.6	4360	0.613	145
	44.9	4700	0.730	159
Ring-cut				
Non-oxidized	40.6	4160	0.601	140
	45.6	5460	0.807	178
Oxidized	40.6	3820	0.575	133
	45.6	4960	0.726	168

Particle Geometry

Work done by researchers has yet to identify optimal particle geometry since trade-offs exist between resin costs, strength properties, and dimensional stability. But certain trends are well established.

It is commonly accepted that increasing the slenderness ratio, the ratio of wafer length to wafer thickness, will increase the modulus of elasticity (MOE) and the modulus of rupture (MOR) (Post 1958, Brumbaugh 1960, Lehmann 1974). This trend is valid to a slenderness ratio of about 300. A large slenderness ratio also facilitates orientation by either electrical or mechanical methods (Talbott and Stefanakos 1972).

While thinner flakes tend toward increased bending strengths, the resin coverage per surface area decreases. Thin, short particles used for flakeboards use 6-8% liquid phenolic resin while thicker particles used in waferboard use 2-3% powdered phenolic resin (Lehmann 1974). All resin and wax percentages are based upon 100% resin solids per pound of ovendry wood.

Production Parameters

Resin Content

Because resin is the material by which particles are bonded to form waferboard and OSB, the resin content dramatically influences strength and some dimensional properties. A decrease in resin content is detrimental to all strength properties and usually diminishes dimensional stability properties. However, phenol-formaldehyde resin is an expensive constituent in the production of waferboard and a balance exists between costs and benefits.

Given that the resin is applied efficiently, the necessary amount of heat needed to cure the resin depends upon the press temperature and press cycle duration. The trade-offs between time, resin content, machinery needed, etc. are very interrelated and entail many engineering and managerial decisions.

Panel Density

An increase in panel density increases all strength properties (Vital et al. 1974, Stewart and Lehmann 1973). For a given species of wood used to manufacture the panel, an increase in panel density increases the compaction ratio which subsequently increases the strength properties. But an increase of compaction ratio also increases the amount of compression set put into the panel and increases the vertical density gradient. This compression set is released when the moisture content of the wood increases and the plasticity of the wood increases. The release of this set increases thickness swelling.

The density gradient through the panel thickness is typically a U-shaped density profile. As heat and pressure are applied to the surface of a particleboard mat, the wood becomes plastic and the pressure overcomes the woods compression strength perpendicular to the grain. The wood near the surface is the first to densify since it heats up first. This density gradient affects the boards behavior, especially bending properties, since the modulus of elasticity of the surface increases with the density of the surface. The result is an I-beam effect for an advantageous increase in bending properties (Smith 1982).

As panel density increases, not only does the amount of wood in the panel increase, but the amount of wax and resin in the panel also increases (if the wax and resin content precent remains constant). Because the extra weight of the panel also adds to freight expense and may not be acceptable to the customer, increasing strength by increasing panel density is not always advantageous.

Orientation

Wood has much greater tensile and compression strength and stiffness properties, and much better dimensional stability in the longitudinal direction than in either the tangential or radial directions. Because of this anistropic nature of wood, orientation of particles in a panel by either mechanical or electrical methods dramatically changes the strength and dimensional stability properties of the panel. By using a three-layered panel with the faces aligned parallel to the long panel axis and the core cross aligned, the MOE and linear expansion (LE) properties are improved in one direction and the panel behaves similar to plywood.

Much research has been conducted to develop orienting systems and to develop the relationships between aligning variables and board performance. Electrical aligners use the dipolar effects of moisture in the wood and the large length of strands to impart an aligning torque on the strands as they pass through an electric field (Fyie et al. 1980). Electric orintators work well in laboratories and have been field tested, but mechanical orientators are still preferred by the industry (Keil 1977).

Mechanical orientators generally use parallel surfaces to align strands as they drop through. Simple in design and principal, mechanical orientators can impart various degrees of orientation depending upon orientator variables.

Turner (1977) attempted to model the stiffness of an oriented panel by considering the stiffness of the pure wood, the average angle between particle and panel axis, and the total of each flake's contribution to the stiffness of the panel. He used the Hankinson-type formula described in the Wood Handbook (1974) to estimate the stiffness of a particle whose angle to the cardinal panel direction is not zero. The panel's stiffness is estimated by summing the stiffness of all particles.

For a random, homogenous, one-layered, panel of the same density as the pure wood, Turner considered an even distribution of all flakes and then summed the stiffness in each interval of 10 degrees. Each fraction of 10 degrees contributes to the total MOE of the panel on the basis of 1/9 of the MOE at that angle.

For an aligned panel, Turner assumed that the aligning devise would restrain the flakes to a maximum angle dependent upon flake geometry and plate spacing. For example, for a 1.5 inch plate spacing and a 3 inch flake, the maximum permissible angle is 30 degrees. This maximum angle is divided into intervals and it was assumed there is an even distribution of flakes into each of these intervals. Using this technique for all possible maximum angles, a curve was developed, see Figure 1.

Geimer (1976) used an orientator comprised of parallel plates to develop the relation between orientation variables and panel properties. For a given particle geometry, the percent alignment was dependent upon free fall height, which is the distance from the bottom of the plates to the top of the mat on the caul, and was dependent upon the plate spacing, see Figure 2. Percent alignment is calculated by the equation

$$\text{percent alignment} = (45-\theta)/45 \times 100\%$$

where θ is the average angle in degrees between particle axis and the longitudinal direction of the panel. Figure 3 shows the relationship between free fall height, plate spacing, and percent alignment. The figure shows that the alignment percent increases as either the free fall height or plate spacing decreases.

Determining the average angle between particle and panel axis involved sampling flakes at 300 intersections of a specific grid. Because this was tedious and time consuming, a simpler method was devised. The percentage of flakes falling within 20 degrees of the cardinal angle was regressed with the actual average alignment angle. This relationship was used throughout his research and it eliminated the need to record and average 300 measurements. The correlation was strong, $r = .98$, and is estimated by the least squares equation

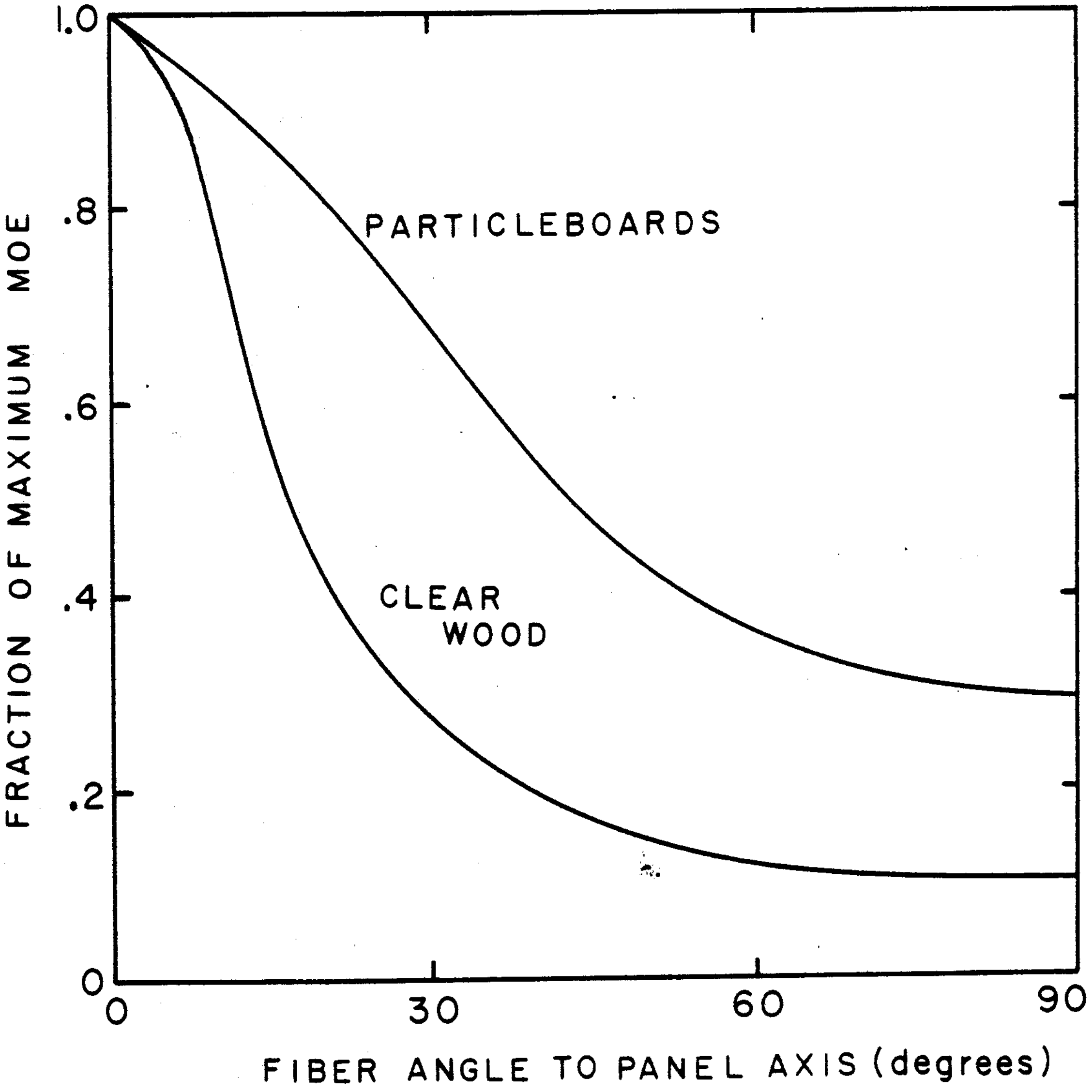

Figure 1. Relation between fiber angle and fraction of maximum MOE for clear wood and particleboards. The relation is described by a Hankinson-type equation for clear wood and by Turner's model for particleboards (Wood Handbook 1974, Turner 1977). For particleboard the fiber angle is the largest angle between a particle and the panel axis.

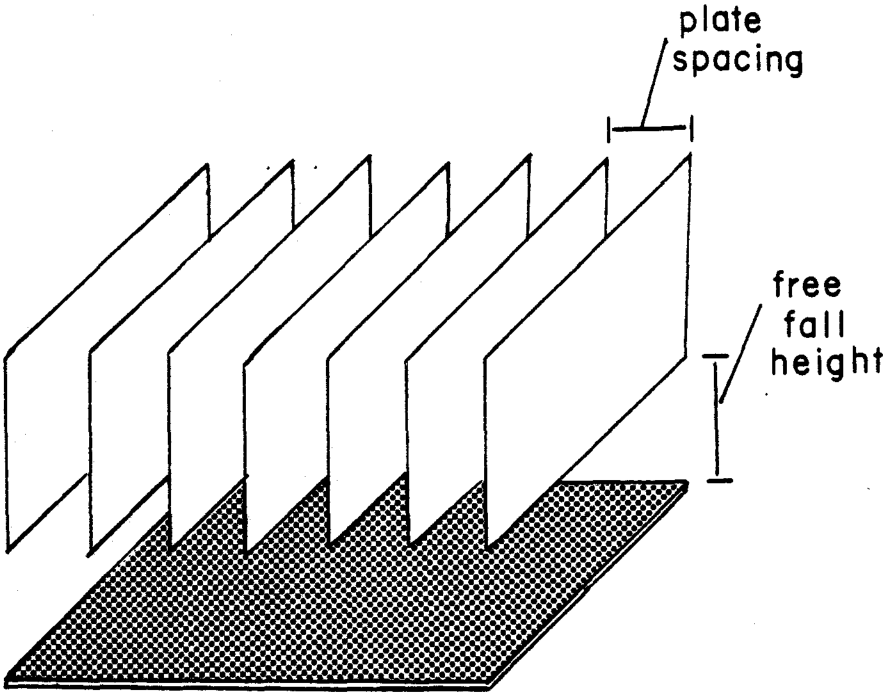

Figure 2. Variables which affect degree of particle orientation (Geimer 1976).

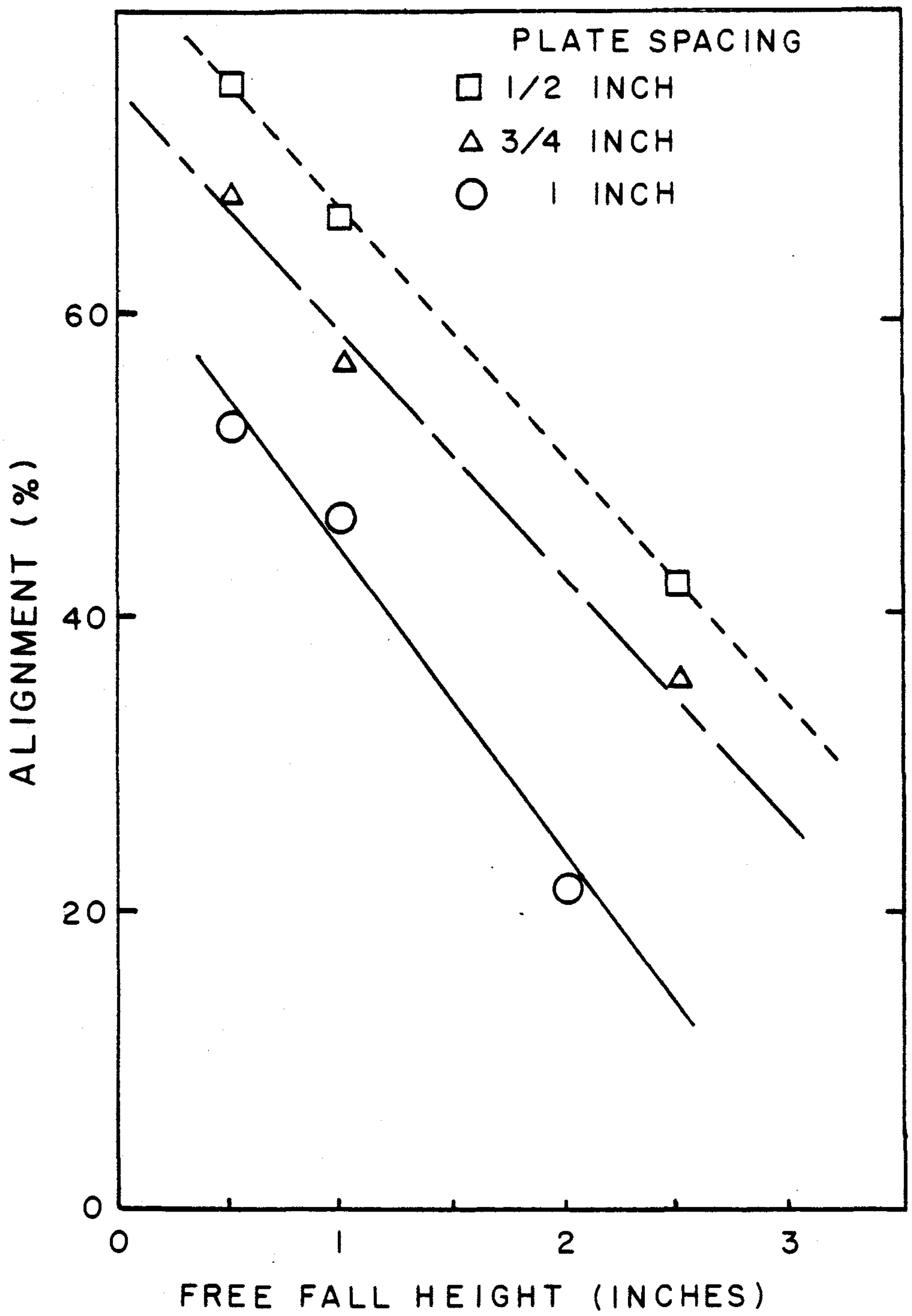

Figure 3. Relations between plate spacing, free fall height, and percent flake alignment (Geimer 1976).

$$\theta = 54.2 - 0.53Y$$

where Y is the percentage of flakes aligned ± 20 degrees from the panel axis and θ is the average alignment angle in degrees.

Geimer developed the relationship between properties and percent alignment by manufacturing an array of flakeboards with constant species, resin content, and density, and with various particle geometries and degrees of orientation. To minimize the vertical density gradient, Geimer pressed the mat to the desired thickness before introducing the heat needed to cure the resin. The homogeneous, one-layered boards were tested for bending properties and linear expansion in both the cross machine direction (_/_) and parallel to machine direction (//). Figure 4 shows the relationship between the ratio of MOE // to MOE _/_ as affected by orientation. Figure 5 illustrates the relationship between percent alignment and percent LE when the board was cycled from ovendry to a saturated state after a vacuum-pressure-soak (VPS) treatment.

Standards Applicable to Waferboard & OSB

As with other particleboards and sheathing panels, consistent performance is essential for waferboard and OSB. Various organizations develop and deploy standards to which most producers voluntarily subscribe in an effort to assure that minimum levels of performance are surpassed. Standards applicable to waferboard and OSB are

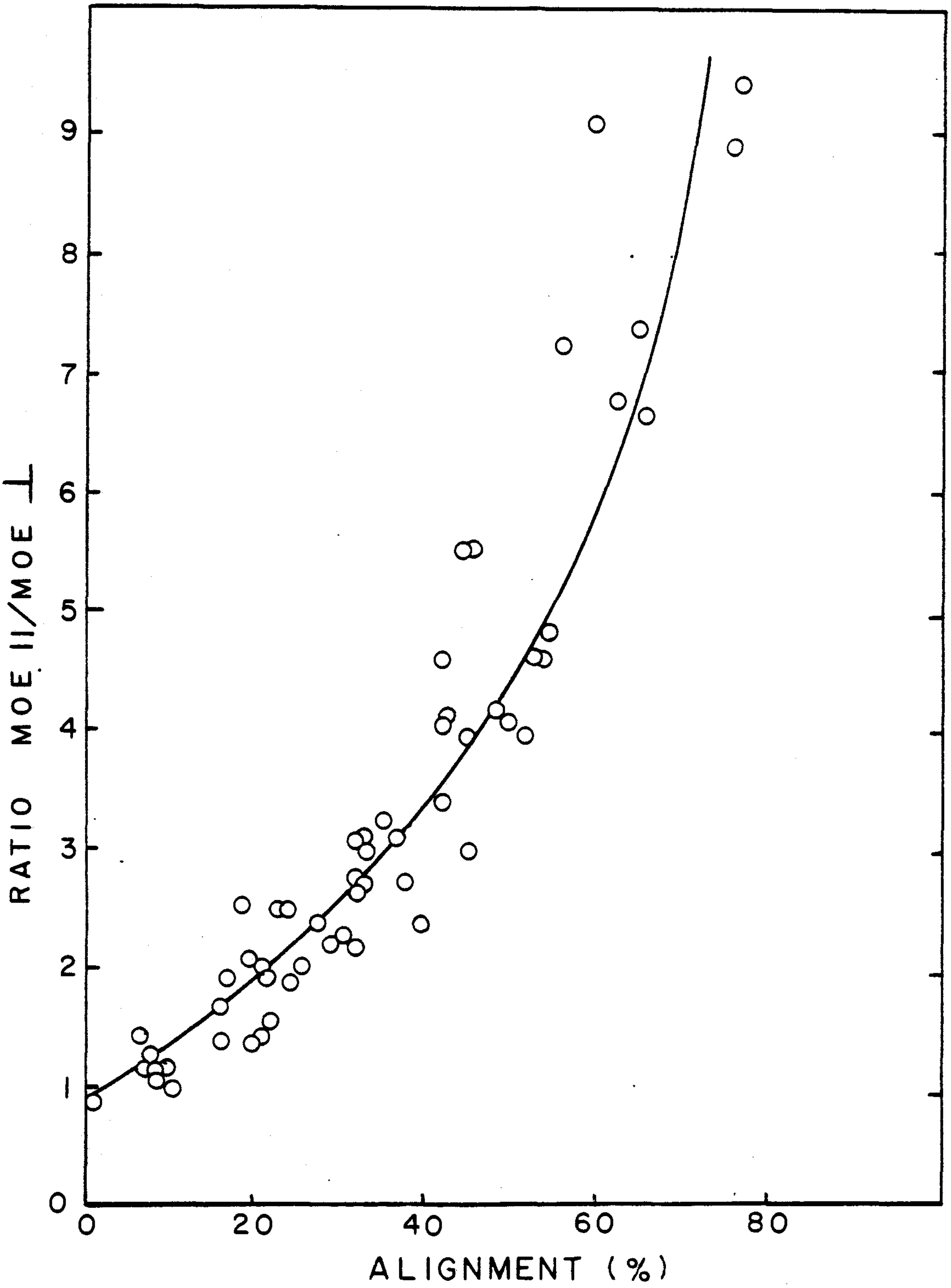

Figure 4. MOE ratio of Geimer's test boards as a function of percent flake alignment (Geimer 1976).

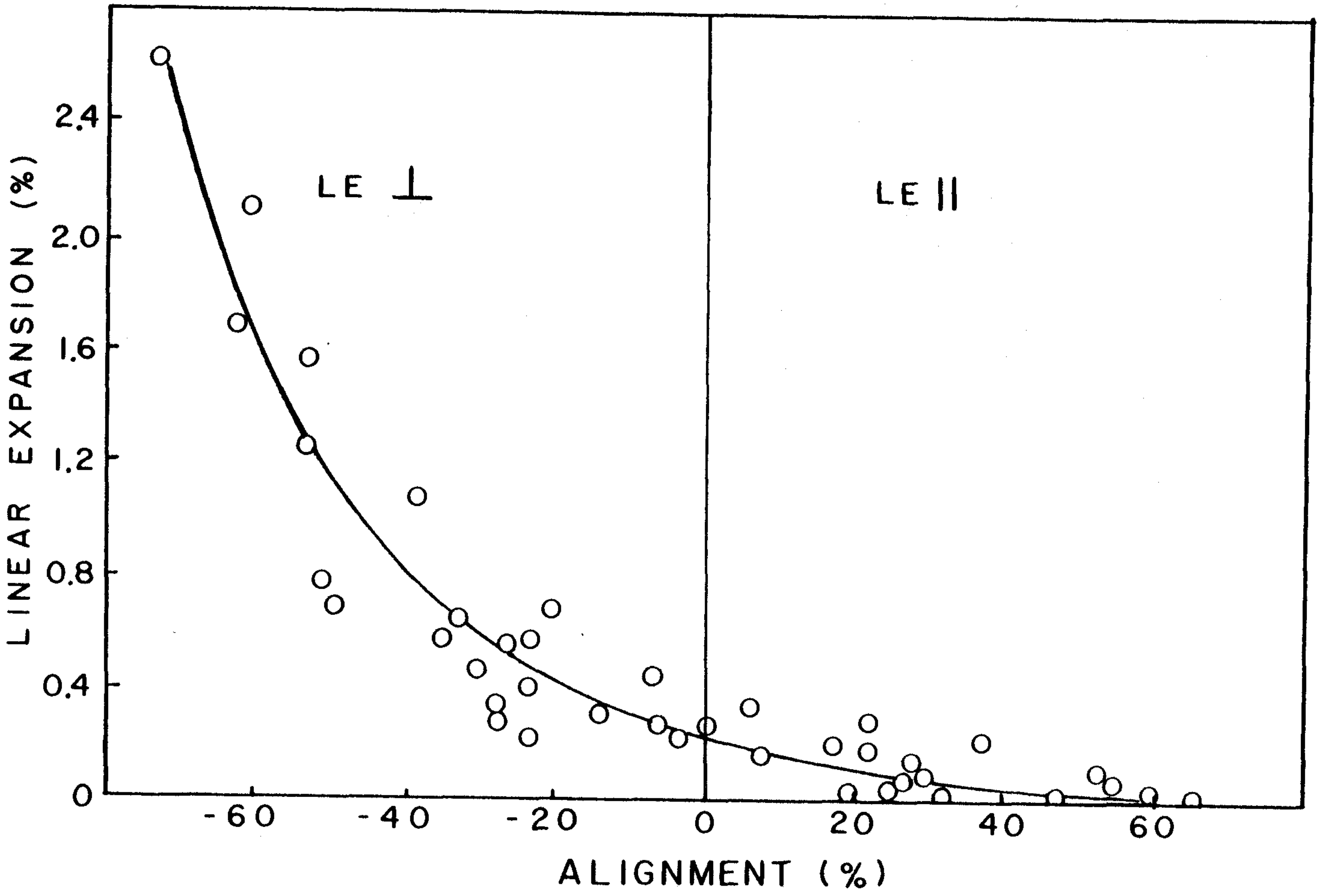

Figure 5. Relation between LE and alignment of Geimer's test boards (Geimer 1976).

deployed by the American National Standards Institute (ANSI), the Canadian Standards Association (CSA), and the American Plywood Association (APA).

ANSI standard A208.1 applies to mat formed particleboards of various composition (ANSI 1978). Waferboard and OSB fall into the category 2MW. CSA standard CAN2-0188.0-M78 apply to mat formed particleboards and waferboard (CSA 1978). The minimum properties for these standards are listed in Table 6

Table 6. Property values for Canadian Standards Association (CSA) and American National Standards Institute (ANSI).

	Panel Property				
	MOE (10^6 psi)	MOR (psi)	IB[1] (psi)	LE[2] (%)	MOR after 2HB (psi)[3]
CSA	0.391	2032	40.6	0.25	1016
ANSI (2MW)[4]	0.450	2500	50.0	0.20	----

[1] IB is the internal bond strength of the panel in tension $\underline{/}$ to surface.

[2] LE when tested from 50% to 90% relative humidity.

[3] MOR when tested wet after the CSA two-hour boil cycle.

[4] 2MW is the ANSI grade that applies to products made with wafers.

Unlike ANSI and CSA, whose standards are applied to the quality control samples in a mill, APA applies its standards towards the end use of the product. As a mill submits panels for qualification based on performance, panels of the same manufacturing lot are evaluated for properties (e.g., density, internal bond, strength retention) which can be measured on a day-to-day quality control basis (APA 1982). A product specification, specific to the mill, is written and becomes the quality control instrument for that product's future production.

Typical Sheathing Properties

Lehmann (1977) studied the effects of resin and wax content on panel properties before and after exposure to natural and accelerated aging. Included in the study were several commercial panels which included plywood sheathing, aspen waferboard, and an OSB made from a western softwood. Laboratory flakeboard panels were manufactured from Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) with various particle geometries and resin contents ranging from three to seven percent. All panel types were tested dry and most were cycled through various aging regimes including a one-cycle vacuum-pressure-soak and a two-hour boil regime. Table 7 shows some of the results of this study which include some commercial waferboard and OSB properties.

Table 7. Properties of commercial and experimental panels (Lehmann 1977).

		DRY			VPS 1-CYCLE			2-HOUR BOIL		
		MOE 10^6 psi	MOR psi	IB psi	TS[1] %	MOE % retained	MOR % retained	TS %	MOE % retained	MOR % retained
Plywood, three ply exterior glue	//	.998	6920	106	1	128	103	5	79	68
	⊥	.065	1300	88						
OSB, western softwood	//	.839	5240	134						
	⊥	.368	3110	122						
waferboard, aspen		.489	2280	68	12	97	103	46	79	48
ave. of all experimental flakeboards		.701	4480	116	15	94	95	28	80	60

[1] TS is thickness swelling

Performance in Use

An installed waferboard or OSB panel must be able to support its intended load for the life of the structure even as the environment changes. The thickness required for this has been determined more on a basis of experience than by engineering design and no allowable design values have been assigned to either product. There is no problem measuring the dry strength, for example by the procedures in American Society for Testing and Materials D 1037-72 (ASTM 1977) but for design purposes the dry strength values have to allow for use at high moisture content and to allow for the fact that wood creeps when a load is applied. The long-term loading on the glue bonds also have to be considered.

End use performance must consider the fact that as the relative humidity gets above about 80 percent, the board undergoes thickness swelling and the board strength properties deteriorate. This swelling is an irreversible recovery of the compression of the wood that took place as the board was pressed. The potential thickness swelling is a function of resin content, particle type, species, and density (Carroll 1980). A panel that was mismanufactured or had an incomplete cure of the resin will exhibit a severe loss of strength as thickness swelling occurs.

Organizations concerned with the standards for particleboards have developed numerous aging cycles that either simulate severe conditions that could exist in use, or subject the boards to a treatment which causes the maximum loss of strength that could result from full weather exposure. Table 8 illustrates some of these cycles. The ASTM 6-cycle test is a long, complicated series of weathering cycles which simulate the most severe conditions an exposed panel would be subjected to. The ASTM cycle causes maximum strength loss. The CSA two-hour boil cycle is another cycle aimed at identifying maximum strength loss. This rapid test is used by the industry to detect mismanufacturing which is usually evident when less than 50 percent of the dry strength is retained. The APA one-cycle vacuum-pressure-soak (VPS) simulates saturation of the panel when exposed on a job site and the subsequent re-drying of the panel when in service. Poor strength retention after any of these aging cycles is an indication of mismanufacturing.

Table 8. Three aging procedures used in testing particleboards.

CSA Standard
CAN 30188.OM
two-hour boil

Boil: two hr.

Cool in water: one hour

Test west

ASTM D1037
six cycle

Spray: 199 F, 3 hr.

Freeze: 10.4 F, 20 hr.

Thaw: 212 F, 3 hr.

Spray: 199 F, 3 hr.

Dry: 212 F, 18 hr.

Repeat 6 times

Recondition

APA D-4
one-cycle VPS

Submerge in water: 150 F

Vacuum: 15 inches Hg, 1/2 hr.

Release Vacuum:

Soak: 1/2 hr.

Redry: 180 F, 16 hr.

IV. PROCEDURES

Obtaining Materials

About 35 cubic feet of freshly cut red alder and black cottonwood were obtained from the MacDonald-Dunn Forest of Oregon State University. The bolts were about 18 inches in diameter and two feet long.

The logs were sawn into lumber and cross cut into blocks which were kept submerged under water until they were waferized on a laboratory disk flaker. Ten samples of each species were taken to determine that the specific gravity of red alder and black cottonwood was 0.42 and 0.36 respectively. The dimensions of the manufactured wafers for waferboard were about 2.0 x 1.0 x 0.030 inch and the strands for strand board were about 3.0 x 0.75 x 0.030 inch.

The green flakes were laid out on the laboratory floor and fan dried until the moisture content (MC) was about 7% (ovendry basis). These flakes were intended to approximate industrial flakes, therefore about 40 percent of the wafers and about 60 percent of the strands were passed through a hammermill without a screen to generate flakes with a deviation in particle geometry. The hammermilled furnish and unmilled furnish were homogenized and then screened for fines over a 1/8 inch screen. The wafers and strands were then bagged until the time they were used.

An industrial wax emulsion, commonly used by the waferboard industry, and liquid and powdered phenol-formaldehyde resins were supplied by commercial producers.

Orientation

Orientation of strands provides an increase of bending properties and dimensional stability in one direction. By using a three-layered design with a cross-ply in the center, the panel will have restrained LE in the cross direction. The desired degree of particle orientation will affect the directional properties of the OSB panel and must be determined before manufacturing OSB from alder and black cottonwood. The average particle angle of two commercial OSB samples and one pilot plant sample were obtained by measuring the angles at the intersection of a three by one inch grid. The percent alignments were calculated from the average angle and are presented in Table 9. The average of the three boards was 36 percent.

Orientation was achieved throughout this study by using a series of parallel plates spaced 1.5 inch apart. Every other plate was recessed 1.5 inch to prevent the 3 inch strands from bridging across the top of the orientator. Before manufacturing the boards the relationship between percent orientation and free fall height had to be determined.

Table 9. Orientation of three commercial OSB.

Manufacturer	Orientation (%) Side 1	Orientation (%) Side 2
Potlatch, Oxboard®. Five layered	59	41
Potlatch, Stranwood®. Three layered	29	27
Elmendorf, OSB. Three layered	21	39

average: 36%

A batch of strands were hand felted through the orientator at free fall heights of 2.0, 2.5, 3.0, and 3.5 inches and the distribution of angles between particle axis and panel axis were measured. Figure 6 shows the histogram of particle angles at different heights. Figure 7 graphically depicts the relationship between the free fall height and the average orientation angle. The least squares equation that describes the relation is

$$Y = 6.84X + 8.11 \qquad (r = .85)$$

where Y is the average angle in degrees and X is the free fall height in inches.

The percentage of particles that are within 20 degrees of the cardinal angle was calculated and the least squares estimate of average angle is

$$Y = 50.6 - 0.444X \qquad (r = .95)$$

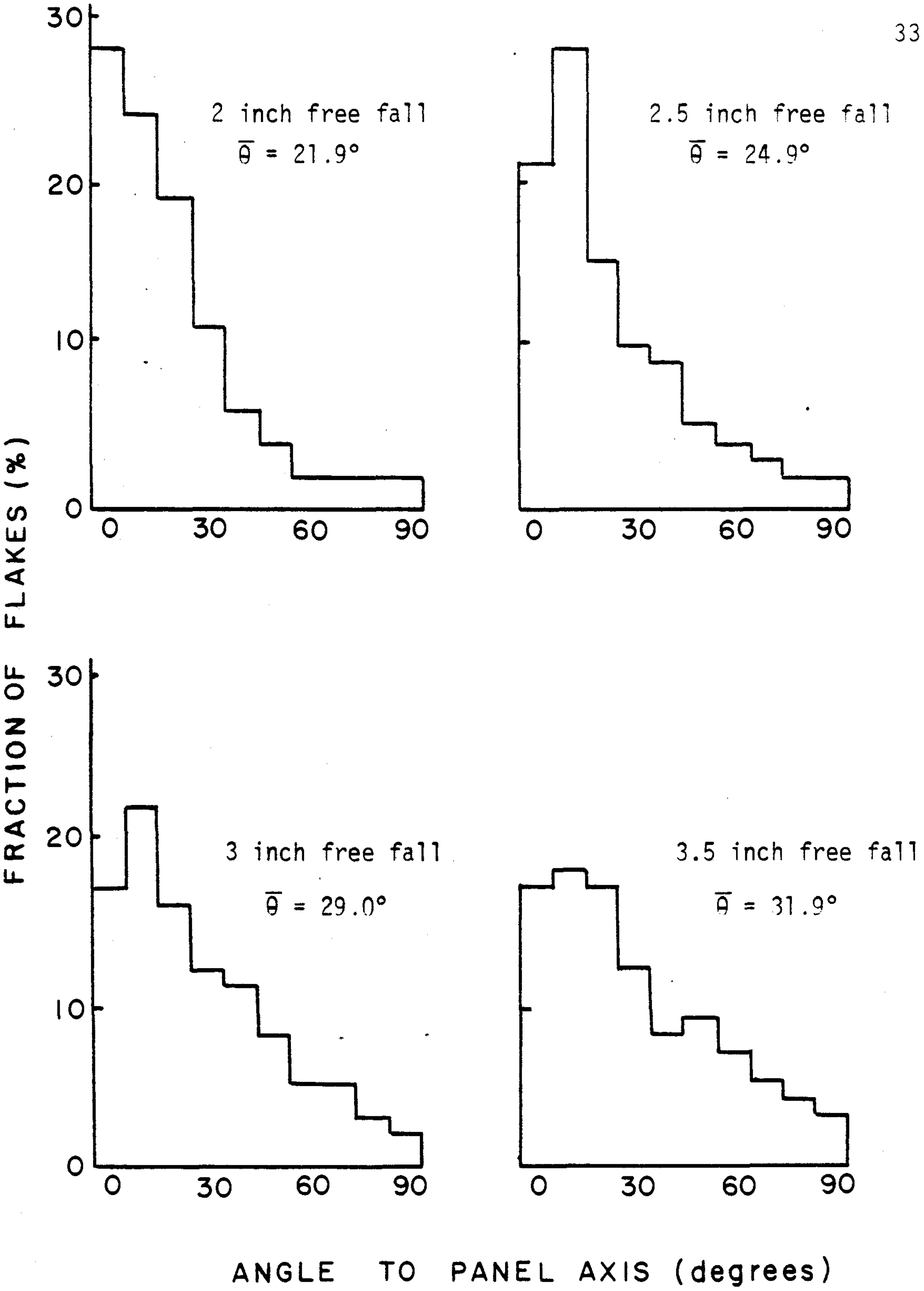

Figure 6. Distribution of strand angles with variation in free fall height.

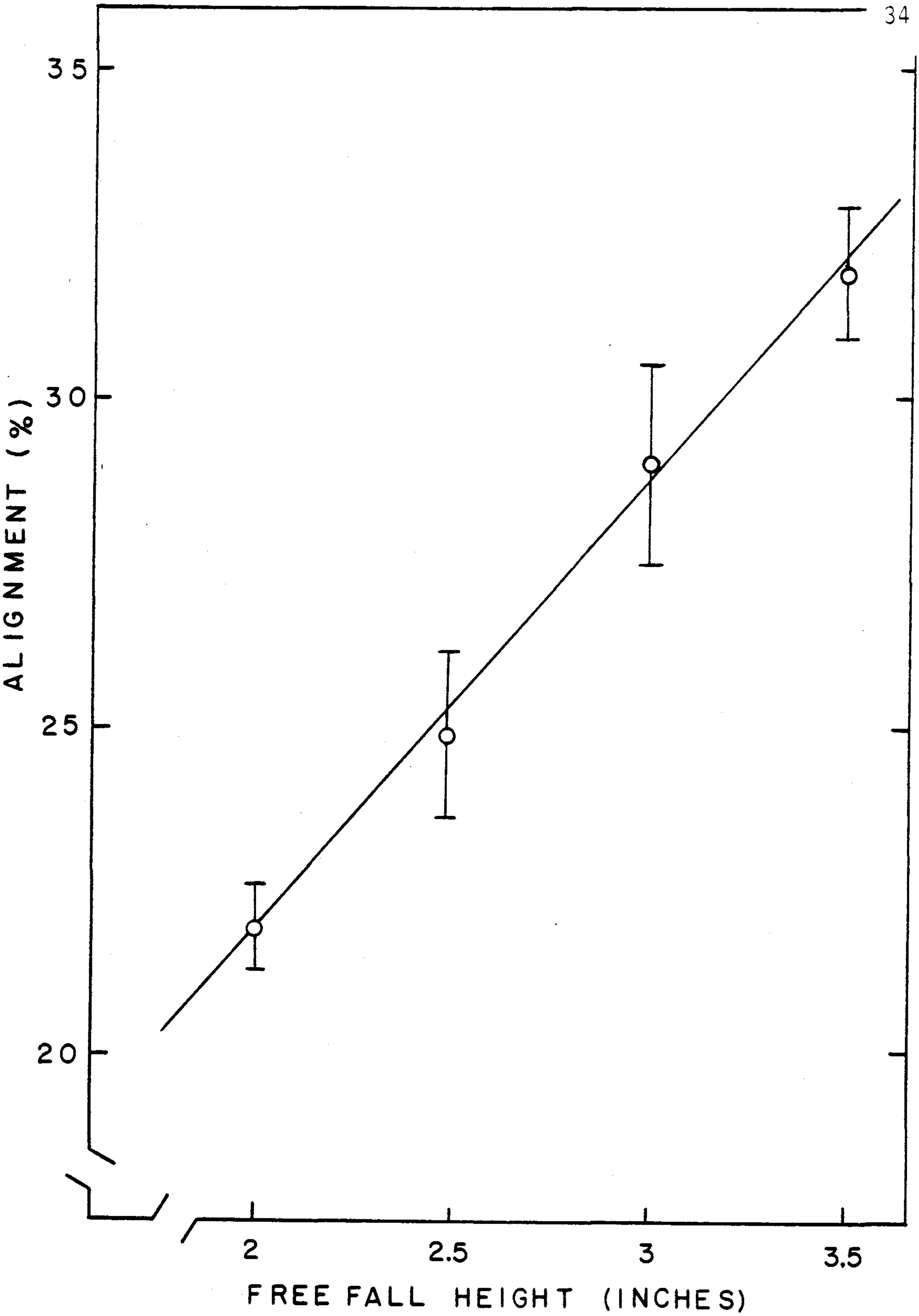

Figure 7. Relation between free fall height and alignment for the orientator used in this study. Points represent the average and standard error of five runs.

where X is the percent of strands within 20 degrees of perfect alignment and Y is the average angle. This relation is plotted in Figure 8. Geimer (1976) relied upon this relation to dispense with the tedious and time consuming procedure of measuring, recording, and averaging particle angles. This technique was used throughout the rest of this study to determine the average angle.

Turner's model was based on a Hankinson-type formula and on even distribution of flake angles to model the MOE of a panel without perfect alignment as a percent of one with perfect alignment. A similar technique was applied in this study using the actual distribution of flake angles at a certain free fall height. The MOE of a strand at a given angle, θ, is estimated by the Hankinson-type equation

$$N_\theta \doteqdot PQ/(P \sin^n \theta + Q \cos^n \theta)$$

where θ is the flake orientation angle, N_θ is the MOE of the strand at angle θ, P is the MOE // of the strand, Q is the MOE ⊥ of the strand and n is an empirical variable which equals 2 for MOE.

In order to use this equation, the MOE ⊥ of alder and cottonwood had to be estimated. No data on MOE ⊥ could be found for alder or cottonwood, but the Wood Handbook (1974) has a table of values for MOE ⊥ for six commercial U.S. species. The MOE ⊥ is 0.05 (±.007) x MOE // for all of the species. This value was used

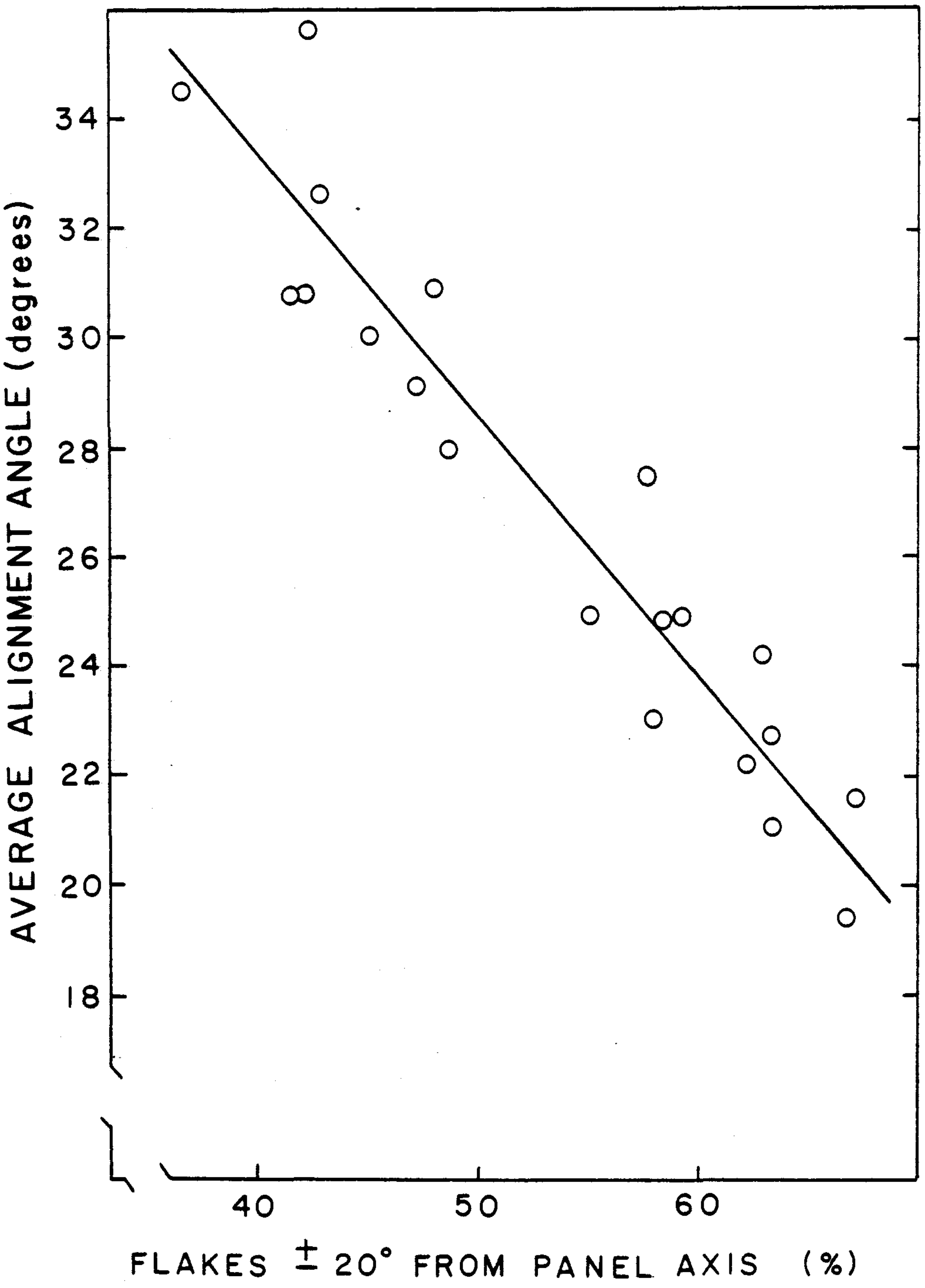

Figure 8. Average alignment angle as a function of the percent of particles that are within 20 degrees of perfect alignment.

to approximate the MOE ⊥ of alder and cottonwood so that the equation can be simplified to

$$(\mathrm{N/P})_{\theta} = (20 \sin^{2} \theta + \cos^{2} \theta)^{-1}$$

when $Q/P = 0.05$. N/P_{θ} is the ratio of MOE at an angle θ to the MOE //. Figure 9 shows this relation between θ and N/P_{θ}.

The ratio of (MOE //) /(MOE ⊥) for a homogenous panel was modeled be weighting each flakes contribution based upon the distribution of flake angles according to the equation

$$\frac{\mathrm{MOE}//}{\mathrm{MOE}\perp} = \frac{\sum(\ N/P_{\theta} \times D_{\theta})}{\sum(\ N/P_{(90-\theta)} \times D_{(90-\theta}\ )}$$

where D_{θ} and $D_{90-\theta}$ are the percentages of flakes at θ and at the complementary angle, $90 - \theta$. This model assumes that each flake contributes to MOE // and MOE ⊥ (of the homogenous layer) based upon the Hankinson relation between θ and N/P.

Modeling the MOE ratio of a three-layered panel considers the (MOE //) /(MOE ⊥) of each layer and the effective moment of inertia, I, of each layer (Gurfinkel 1973). The face layers have their inertia transposed to the same axis as the core layer (Shigley 1976). For a three-layered panel with equal thicknesses, the MOE ratio for the panel can be calculated by

$$\frac{\mathrm{MOE}//}{\mathrm{MOE}\perp} = \frac{26 + (\mathrm{MOE}\perp/\ \mathrm{MOE}//)}{26\ (\mathrm{MOE}\perp/\ \mathrm{MOE}//) + 1}$$

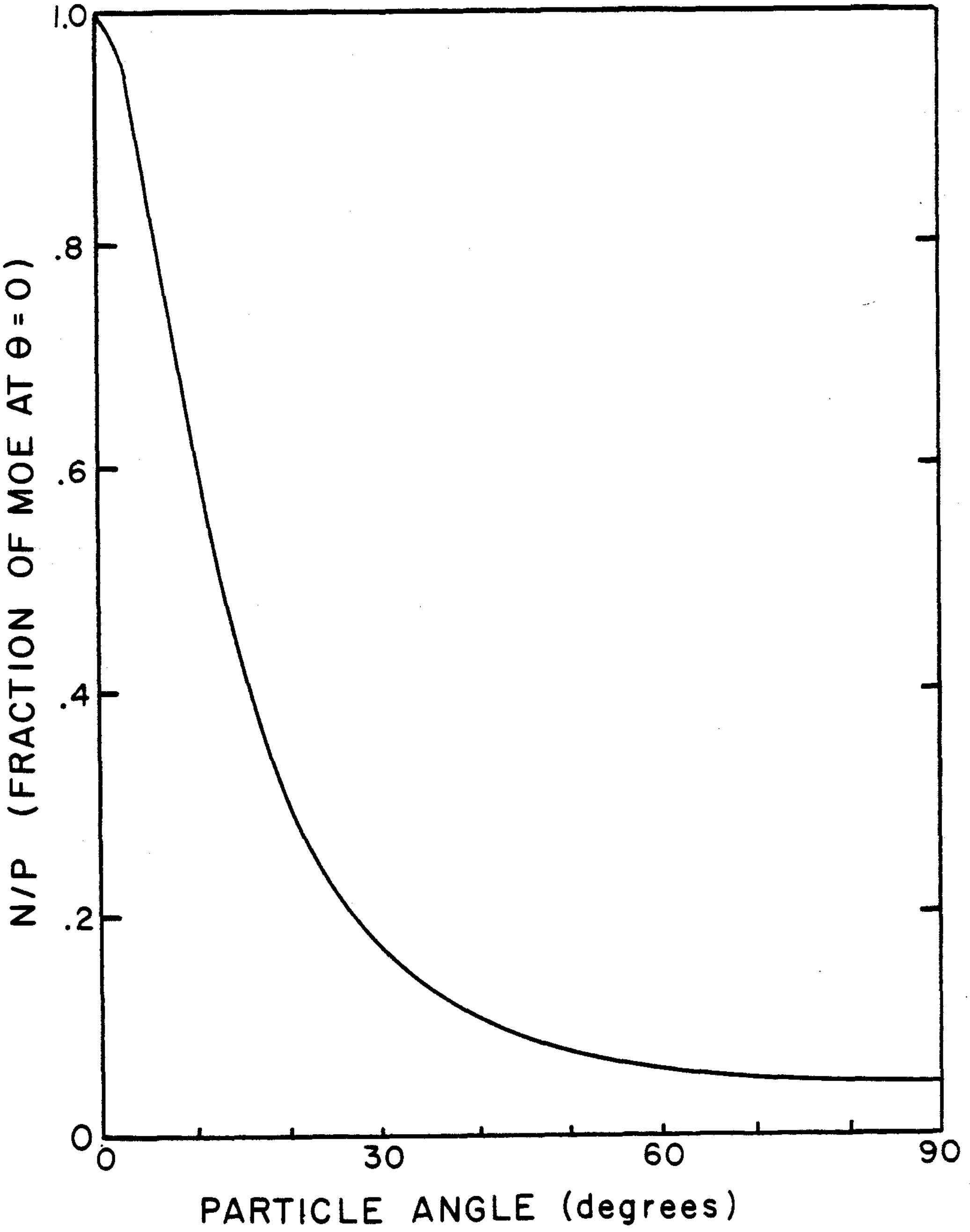

Figure 9. Fraction of maximum MOE with variation in the particle angle. Presented is the case when Q/P= 0.05 (Wood Handbook 1974).

From this equation the MOE ratio can be estimated for a three-layered panel with equal thicknesses and the center layer orientated as a cross-ply. Table 10 shows the (MOE //) /(MOE ⊥) for a one-layered and for a three-layered panel for each of the free fall heights used in this study.

Table 10. MOE ratio as developed by model.

	(MOE //) /(MOE ⊥)	
Free fall height (inches)	one-layered	three-layered
2.0	4.70	4.01
2.5	3.82	3.36
3.0	3.09	2.80
3.5	2.58	2.38

Figure 10 shows the relation between percent orientation and the (MOE //) /(MOE ⊥) that Geimer developed and also plotted is the (MOE //) /(MOE ⊥) predicted by this model for free fall heights of 2.0, 2.5, 3.0 and 3.5 inches. This study uses an orientator similar to Geimer's, so the angle distributions are similar and the (MOE //) /(MOE ⊥) predictions closely match the actual relation. Figure 10 also shows the (MOE //) /(MOE ⊥) predicted by this model for a three-layered board with equal thickness layers and the center layer cross orientated.

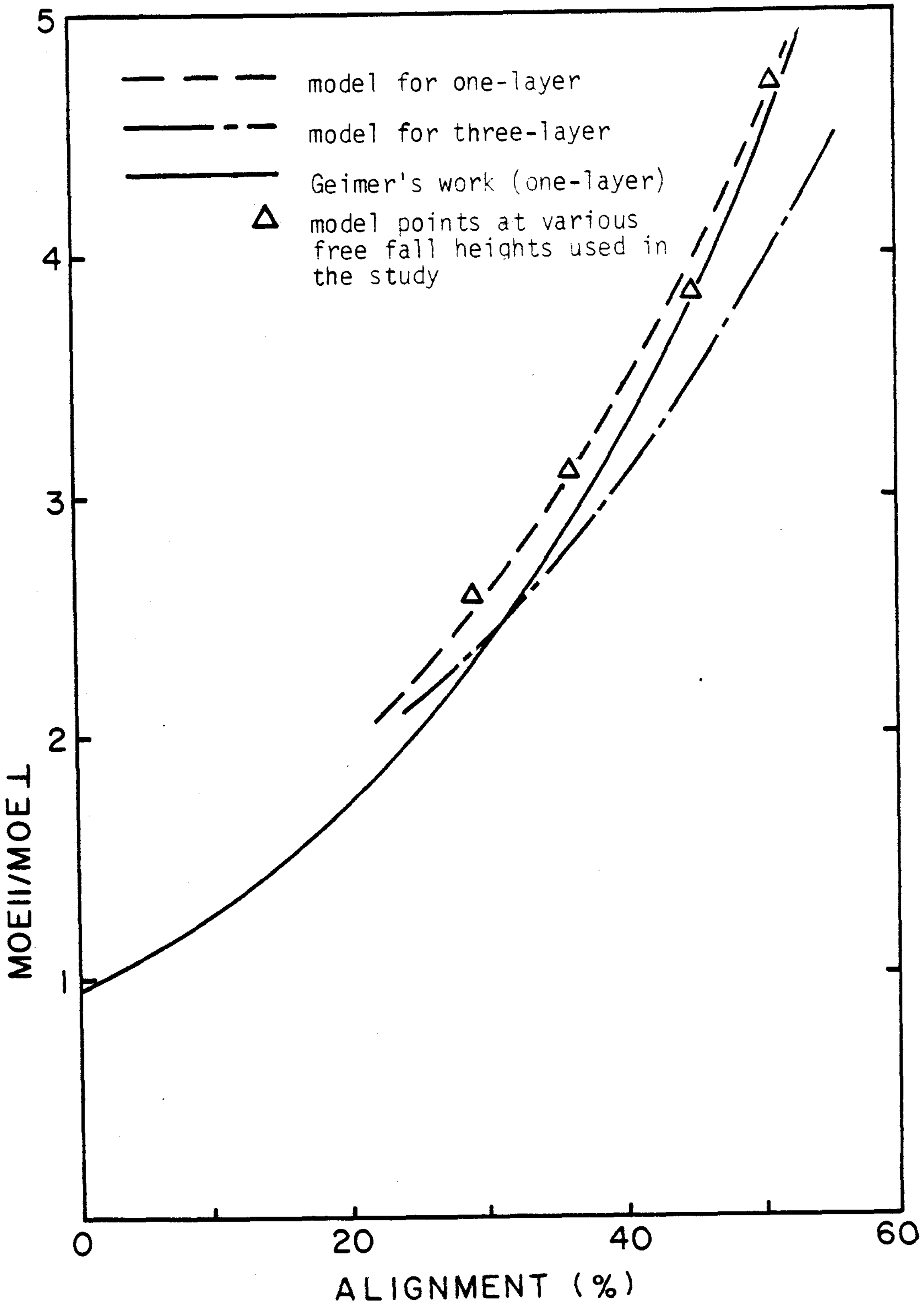

Figure 10. Relationship between MOE ratio and percent alignment for models of one and three layered OSB and for Geimer's work (Geimer 1976).

This study will use a free fall height of 3.5 inches so that the predicted percent orientation will be about 29 percent, which is an orientation similar to two of the three commercial panels measured. The model predicts that the MOE // /MOE $\underline{\ /\ }$ should be about 2.4 for the three-layered boards to be manufactured.

Manufacturing Boards

This study considers the relation between major production variables and the ensuing panel performance. To develop these relations, OSB and waferboard panels were made with various species, densities, and resin contents. Table 11 shows the factorial design of the boards which were manufactured. Two replications of the waferboard panels were manufactured and three replications of OSB were needed to provide enough samples to consider the directional properties.

The blending of wood particles, wax, and resin were accomplished using a four-foot diameter drum-type blender. Liquid wax and liquid resin were applied with an air-spray gun mounted horizontally in the center of the blender which rotated at 3.5 rpm.

The sequence of blending was as follows. A moisture content sample of the wood furnish was taken before blending and enough water was added to the liquid wax so that the moisture content of the furnish was 10 percent (on an OD basis) when the mat was placed in the press. After the wax and water mixture was sprayed onto the tumbling particles, the resin was applied. Waferboard furnish used powdered phenol-formaldehyde resin and OSB furnish was sprayed with liquid phenol-formaldehyde. Three minutes of blending followed resin application to ensure efficient distribution of the resin. Enough furnish for one panel was blended at a time.

Table 11. Board types manufactured in study. 2 reps of 12 waferboard types plus 3 reps of 12 OSB types equals 60 boards.

Sample Type Number	Panel Type	Specie	Resin (%)	Density (pcf)
1	waferboard	alder	2	34
2	waferboard	cottonwood	2	34
3	waferboard	alder	2	39
4	waferboard	cottonwood	2	39
5	waferboard	alder	2	44
6	waferboard	cottonwood	2	44
7	waferboard	alder	3	34
8	waferboard	cottonwood	3	34
9	waferboard	alder	3	39
10	waferboard	cottonwood	3	39
11	waferboard	alder	3	44
12	waferboard	cottonwood	3	44
13	OSB	alder	3	34
14	OSB	cottonwood	3	34
15	OSB	alder	3	39
16	OSB	cottonwood	3	39
17	OSB	alder	3	44
18	OSB	cottonwood	3	44
19	OSB	alder	6	34
20	OSB	cottonwood	6	34
21	OSB	alder	6	39
22	OSB	cottonwood	6	39
23	OSB	alder	6	44
24	OSB	cottonwood	6	44

The mats were formed by hand felting the blended particles onto a stainless steel caul surrounded by a 21 x 21 inch deckel box. Panel density was controlled by the weight of material which was felted onto the cauls. Waferboard mats were randomly orientated while the OSB particles were orientated as they passed through the orientator which was maintained at a height of 3.5 inches above of the mat or caul. OSB mats were laid down in three layers of equal weight with each layer orientated perpendicular to the previous.

The mats were hot pressed in a 24 x 24 inch press. Appropriate pressure was applied so that the mat was pressed to a 7/16 inch thickness in 30 seconds. This amount of pressure depended upon species and panel density and it varied between 500 and 1200 psi. After hitting the stop bars, the waferboard mat was pressed at 400 degrees Farenheit for 5.5 minutes and the OSB was pressed at 375 degrees for 6.5 minutes. At the end of the press cycle the pressure was gradually reduced to zero to prevent steam damage to the panel interior. The panels were hot stacked in an insulated box for about 18 hours to simulate hot stacking as done by the particleboard industry to aid post press curing. Each of these procedures attempted to simulate industrial practices.

Boards were labeled as to board type (1-12 for waferboard and 13-24 for OSB) and as to replication (A-B for waferboard and A-C for OSB).

Sample Allocation

All boards were cut into 3 x 12 inch samples as shown in Figure 11 and numbered so that the location of the sample was known. The OSB board types had replicates A and C cut so that five samples were orientated parallel to the long axis (//) and one sample orientated in the cross direction ($\underline{\ /\ }$). Replicate B had five // and one $\underline{\ /}$ samples. Direction of waferboard samples were not important since they were randomly orientated. All samples were labeled on the surface which was on top when pressed and this surface was kept on top during all testing.

Table 12 shows the allocation of samples into the three test regimes and the properties which were measured in each regime.

Static Bending

Samples allocated to the dry test regime were equilibrated at 65 percent relative humidity and tested for bending properties according to ASTM D-1037. The VPS and 2HB samples were tested after they were aged according to their treatment regime.

The test specimens were supported on both ends as a concentrated load was applied at the center at a rate of 0.5 cm per minute until failure occurred. The MOE and MOR were determined according to the equation

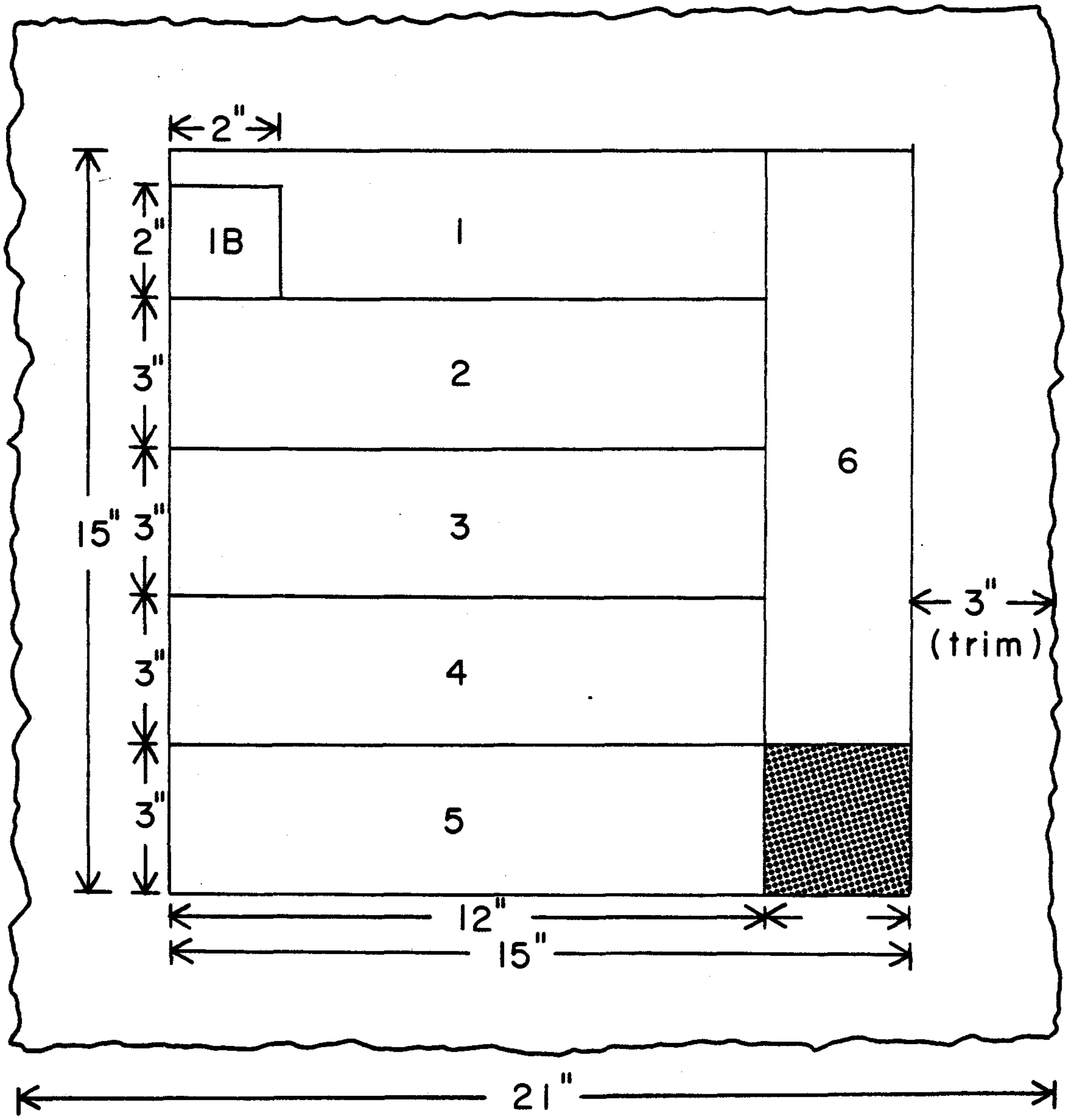

Figure 11. Board cutting diagram. Two IB samples were cut from the intact portion of the dry bending samples.

Table 12. Sample allocation of test specimens.

Test Regime	Properties Measured	Samples Allocated	
		Waferboard	OSB
Dry[1]	MOE,MOR,IB	A3, A6 B1, B4	A3, A6 B3, B6 C1, C4, C6
50-90% Relative humidity cycle	LE	A1, A2, A4 A5, B2, B3 B5, B6	A2, A4, A5 B1, B2, B4 B5, C2, C3, C5
Two-Hour Boil[2]	TS(50% RH-wet) MOR(wet)	A1, A2, A4 A5, B2, B3 B5, B6	A2, A4, A5 B1, B2, B4 B5, C2, C3, C6
Vacuum-Pressure-Soak[3] One cycle	MOE(re-dry),MOR(re-dry)	A2, A5 B3, B6	A2, A5 B2, B5 C3

[1] Tested in accordance with the American Society of Testing and Materials ASTM D1037 (ASTM 1977).

[2] Tested in accordance with Canadian Standards Association standard CAN3-0188.0M78 (CSA 1978).

[3] Tested in accordance with American Plywood Association test method D-4 (APA 1982).

$$MOE = (P_1L^3)/(4bd^3y_1)$$

$$MOR = (3PL)/(2bd^2)$$

where P is the maximum load, L is the span, b is the sample width, d is the sample thickness when dry, P_1 is the load at the proportional limit, and y_1 is the deflection at the proportional limit.

Two-Hour Boil

The 2HB samples were boiled in water for two hours and then soaked in cold water for one hour and then tested wet as in accordance with Canadian Standards Association Standard CAN3-0188.0-M78 (1978). Bending calculations were based upon dry sample thickness.

Vacuum-Pressure-Soak

The one cycle vacuum pressure soak treatment was performed in accordance with APA test cycle D-4. Test specimens were placed in a pressure cylinder such that enough free space was around them to allow for swelling. The cylinder was filled with water at 150 degrees Fahrenheit. A vacuum of 15 inches of mercury was pulled for 30 minutes. The samples were allowed to soak for 30 minutes at atmospheric pressure and then dried for 16 hours at 180 degrees Fahrenheit. The samples were then tested dry.

Internal Bond

Internal bond (IB) is the tensile strength perpendicular to the plane of the panel. Two IB samples, 2 inch by 2 inch, were cut from the intact portion of each dry bending sample. A hot-melt adhesive was used to attach the specimen to metal blocks which were pulled apart at a rate of 0.1 cm per minute until the sample failed. The IB strength is the ultimate load divided by the specimen area.

Linear Expansion

Linear expansion is the dimensional change in the plane of the panel caused by a change in moisture content. The VPS and 2HB samples were equilibrated before aging with an environment at 50 percent relative humdity. The distance between two reference points 1/2 inch from the ends was recorded. The entire length of the sample was not used because the extreme expansion at the edges causes unrealistic values. The samples were re-equilibrated at 90 percent humidity and measured. Linear expansion is calculated by

$$LE = (L_2 - L_1)/L_1 \times 100\%$$

where L_2 is the length at 90 percent humidity and L_1 is the length at 50 percent humidity.

Thickness Swelling

Thickness swelling (TS) is the dimensional change perpendicular to the panel plane caused by a change in moisture content. The thickness of the 2HB samples were measured at 50 percent relative humidity and after the two-hour boil aging process. Thickness swell is calculated by

$$TS = (T_2 - T_1)/T_1 \times 100\%$$

where T_2 is the wet thickness after the two-hour boil and T_1 is the thickness at 50 percent relative humidity.

Statistical Treatment

Previous research has determined that MOE, MOR and IB are highly correlated with the density of the specimen. Within each target density, there is variation around the target. MOE, MOR, and IB were adjusted to the target density by using the least squares fit of a second degree polynomial regression curve. LE and TS are reported at their nominal density. Figure 12 shows a typical plot of IB as a function of density.

To determine if increases in resin content or density significantly affect the properties, each property was linearly regressed with species, resin contents and densities. Indicator variables were used for species, resin contents and densities (i.e., alder =

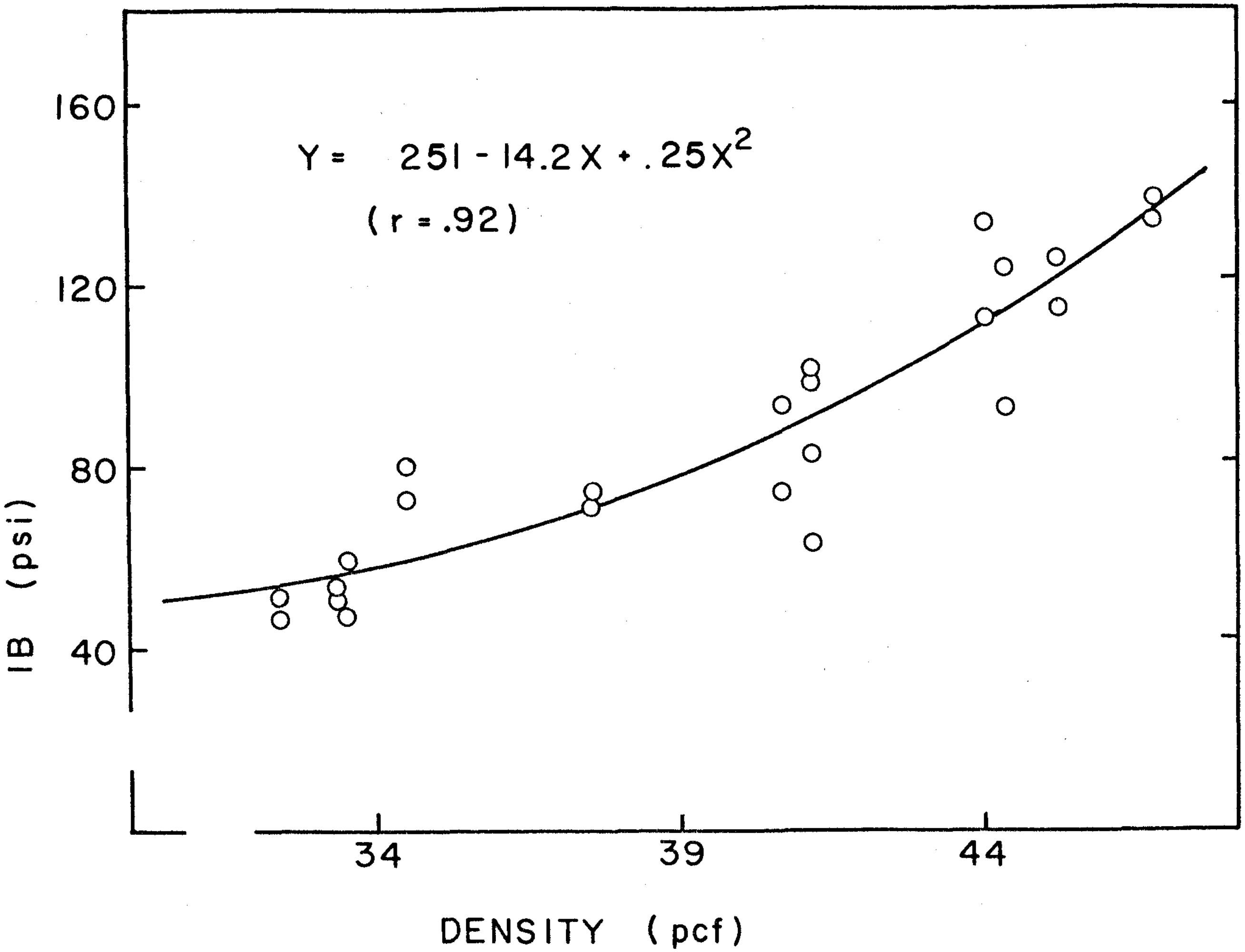

Figure 12. Typical second degree polynomial curve used to adjust IB to 34,39, and 44 pcf density. This was also performed on MOE and MOR with less success.

0, cottonwood = 1 for the species variable). The regression was done on the Statistical Interactive Programming System (SIPS) which calculates the p-value for each variable. One minus the p-value is the confidence that the particular production variable had an affect on that particular property. If the p-value is less than .05 the production variable is significant. This method determines the overall affect of a variable on a property and does not consider specific affects (Neter et al. 1983).

V. RESULTS AND DISCUSSION

A total of 60 boards were manufactured to determine the properties of alder and cottonwood waferboard and OSB at a range of densities and at two resin contents. The waferboard results are presented in Table 13 , and the alder OSB and cottonwood OSB results are presented in Tables 14 and 15 respectively.

Bending Properties

All waferboards and all OSB panels had bending properties which surpassed CSA standards for mat formed particleboards and waferboard. All OSB boards and all waferboards at 39 and 44 pcf densities surpassed ANSI standards for mat formed particleboards. These standards give little indication of end use performance but are used for laboratory produced boards or as a quality control tool for mills. However, alder and cottonwood waferboard at 39 pcf, a common density for waferboard, had bending properties which were superior to the commercial aspen waferboard tested by Lehmann (1977). Similarly, the OSB manufactured from alder and cottonwood performed at least as well as the commercial counterpart tested by Lehmann.

Geimer (1976) reported that the MOR and MOE of his laboratory produced OSB's were very correlated, so only the MOE results were discussed. Likewise, the MOR and MOE of waferboard and OSB made

Table 13. Alder and cottonwood waferboard properties.

Specie	Density[1]	%Resin	MOE 10^6 psi	MOR psi	IB psi	LE[2] %	TS[3] %	% MOE retention VPS	% MOE retention 2HB	% MOR retention VPS	% MOR retention 2HB
Alder	34	2	.414	2457	58	.111	64	95	65	79	49
		3	.443	2652	85	.109	50	88	70	79	55
	39	2	.540	3478	86	.106	72	109	73	87	55
		3	.573	3548	118	.112	61	105	80	91	55
	44	2	.700	4777	119	.104	73	115	77	94	63
		3	.729	5232	142	.115	72	109	84	92	56
Cottonwood	34	2	.506	2844	51	.090	49	86	60	80	52
		3	.474	3142	59	.088	40	74	69	88	57
	39	2	.569	3724	72	.102	64	104	72	85	52
		3	.638	4421	79	.105	50	99	67	91	52
	44	2	.713	4601	96	.094	63	114	73	101	59
		3	.773	5515	112	.091	56	109	71	97	55

[1] Density in lbs. per ft^3. MOE, MOR, and IB are density adjusted.

[2] LE is measured from 50 to 90% relative humidity.

[3] TS is measured from 50% relative humidity to wet condition after 2 hour boil.

Table 14. Properties of alder OSB.

Dens.[1]	% Resin and Direction		MOE 10^6 psi	MOR psi	IB psi	LE[2] %	TS[3] %	% MOE retention VPS	% MOE retention 2HB	% MOR retention VPS	% MOR retention 2HB
34	3	//	.605	4056	68	.111	55	96	84	86	76
		⊥	.327	2668		.130		77	82	72	54
	6	//	.711	4688	104	.090	34	84	67	89	59
		⊥	.345	2999		.125		82	71	62	54
39	3	//	.811	5390	88	.088	61	101	79	100	80
		⊥	.373	3407		.143		95	68	78	50
	6	//	.971	6862	138	.088	39	82	69	89	56
		⊥	.395	3484		.123		81	63	69	56
44	3	//	1.131	7616	108	.069	66	90	69	85	66
		⊥	.483	4277		.105		81	72	66	49
	6	//	1.206	8374	152	.058	41	83	60	81	56
		⊥	.442	4087		.105		99	78	72	63

[1] Density in lbs. per ft^3. MOE, MOR, and IB are density adjusted.

[2] LE is measured from 50 to 90% relative humidity.

[3] TS is measured from 50% relative humidity to wet condition after 2 hour boil.

Table 15. Properties of cottonwood OSB.

Dens.[1]	% Resin and Direction		MOE 10^6 psi	MOR psi	IB psi	LE[2] %	TS[3] %	% MOE retention		% MOR retention	
								VPS	2HB	VPS	2HB
34	3	//	.671	3786	50	.100	48	89	62	65	59
		⊥	.322	2067		.143		91	54	89	43
	6	//	.793	5744	78	.070	34	88	61	92	54
		⊥	.299	2618		.112		88	64	79	55
39	3	//	.862	5383	59	.081	75	85	69	79	64
		⊥	.350	2848		.143		89	65	55	31
	6	//	1.014	7044	83	.066	36	88	61	74	52
		⊥	.379	3414		.162		85	64	81	60
44	3	//	1.133	7554	59	.069	77	72	59	59	44
		⊥	.448	3565		.116		84	60	64	50
	6	//	1.207	7953	98	.063	44	86	65	83	57
		⊥	.460	3977		.094		91	74	80	66

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[1] Density in lbs. per ft^3. MOE, MOR, and IB are density adjusted.

[2] LE is measured from 50 to 90% relative humidity.

[3] TS is measured from 50% relative humidity to wet condition after 2 hour boil.

from alder and cottonwood are also very correlated. MOR is estimated by the least squares equation

$$\text{MOR} = .007(\text{MOE}) - 583 \qquad (r = .94)$$

for waferboard, and

$$\text{MOR} = .0062(\text{MOE}) + 274 \qquad (r = .93)$$

for OSB, where MOR and MOE are both in psi.

As well established by other researchers, the bending properties of these panels produced from alder and cottonwood increased as either resin content or density increased. This is evident in Figures 13 and 14. Cottonwood had slightly higher bending properties, especially at the lower densities. This is explained by the lower compaction ratio (see Table 4) that alder has than cottonwood at 34 pcf.

OSB panel types had samples tested dry in both directions after the percent alignment was estimated by determining the percentage of particles within 20 degrees of perfect alignment. From the bending results the ratio of MOE // to MOE $\underline{/}$ can be calculated. The previously developed model predicts that when the orientator is maintained at 3.5 inches off the mat, an orientation of 29 percent will result and the three-layered panel will have a MOE ratio of 2.4. The average orientation of all OSB types was 28.9 percent and the MOE ratio turned out to be 2.39 with a standard deviation of 0.24.

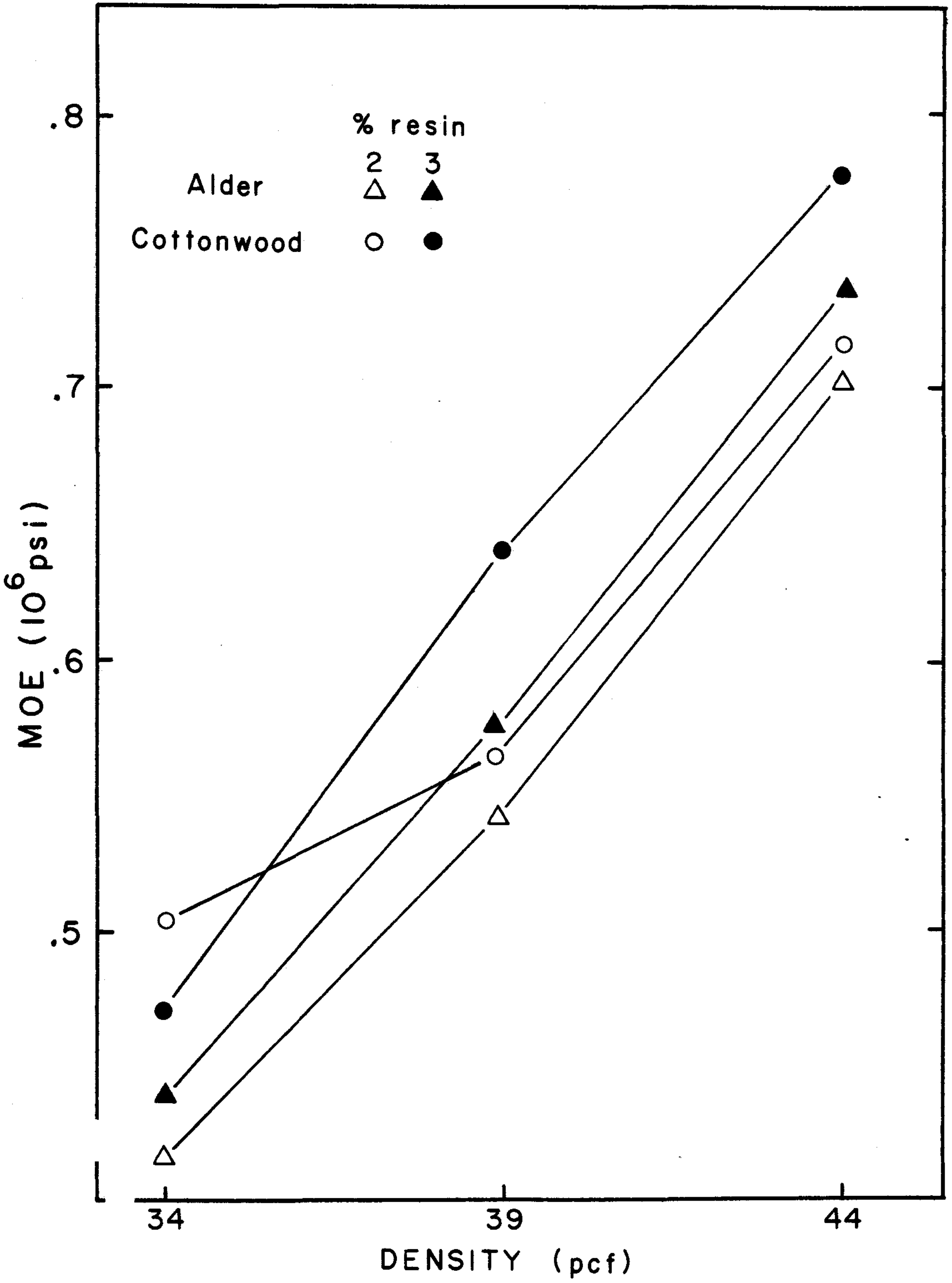

Figure 13. MOE of alder and cottonwood waferboard.

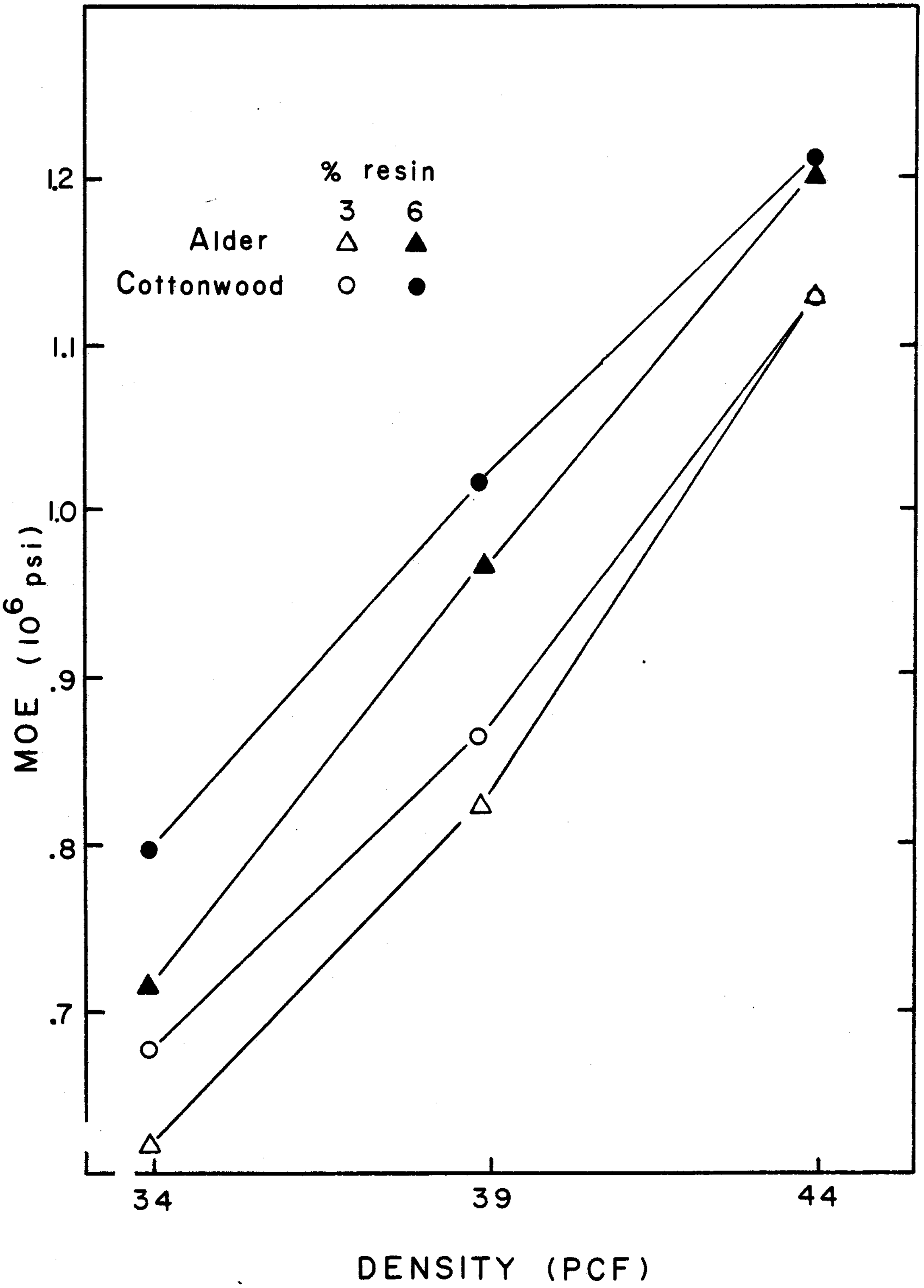

Figure 14. MOE of alder and cottonwood OSB.

APPENDIX B shows that the specie and panel density both had a significant affect on the MOE ratio. What little variation there was in the alignment did not significantly (at the 95 percent level) influence the MOE ratio. The species and density affects are evident in Figure 15 which shows the MOE ratio as a function of orientation and also the predicted curve for a three-layered OSB.

The species and density of the panel both influence the vertical density gradient of the panel which explains the increase of the MOE ratio. As the panel density increases from 34 pcf to 39 pcf the density gradient becomes U-shaped through its thickness. The increased density of the surface increases the MOE //, so the MOE ratio increases.

Cottonwood has lower compression strength perpendicular to the grain so it densifies much more than alder at similar panel densities.

Internal Bond

All OSB types and all waferboard types had internal bond strength that surpassed CSA and ANSI standards for mat formed particleboards and waferboard. At common densities for commercial OSB and waferboard the cottonwood waferboard panels had similar IB values and alder had superior values to those of commercial aspen waferboard. As well established by other researchers, IB values

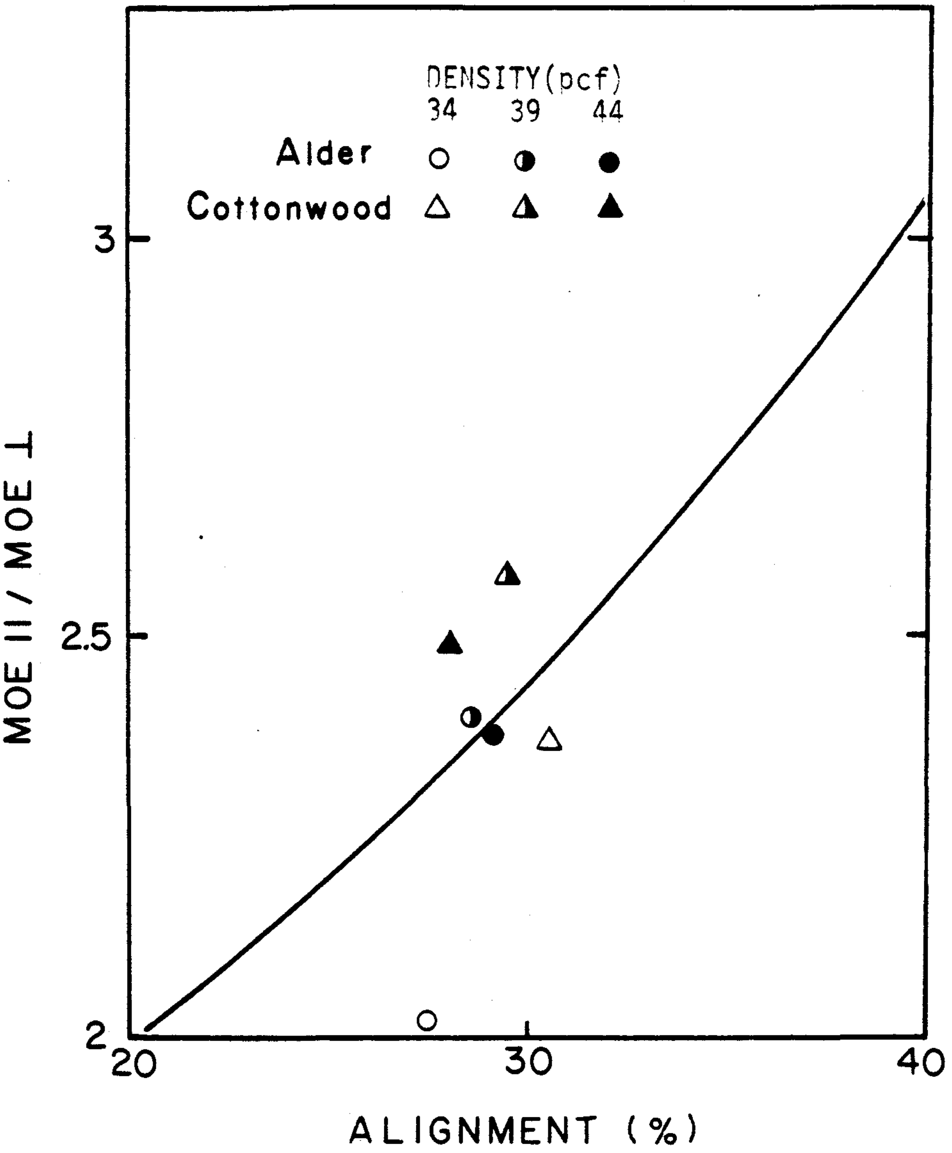

Figure 15. MOE ratio of three- layered OSB test panels.

increase as either resin content or density increase. This is evident in Figure 16 which shows the IB values for alder and cottonwood waferboard as a function of resin content and density.

Alder IB values are superior to values for aspen or cottonwood. IB strength depends upon the tensile strength perpendicular to the grain of the wood and upon the strength of the glue bond between adjacent particles. Alder has greater tensile strength perpendicular to grain (see Table 2), and as noted by Karchesy (1974), alder has numerous extractives, some of which may act as a natural binder. These factors may account for alder's superior IB value.

Dimensional Stability

Dimension stability, measured by linear expansion and thickness swelling, is the boards ability to resist dimensional change as the moisture content changes. All waferboard and OSB types meet the general standard, established by groups such as APA, CSA, and ANSI, that the linear expansion remain less than 0.20 percent when measured between 50 percent and 90 percent relative humidity. Because of OSB's orientation, the LE in the cross direction is greater than the LE in the major panel axis, as evident in Figure 17. Linear expansion was not affected by resin content, as evident by the p-values for LE x resin content in Appendix B, therefore the LE value at the two resin contents were averaged.

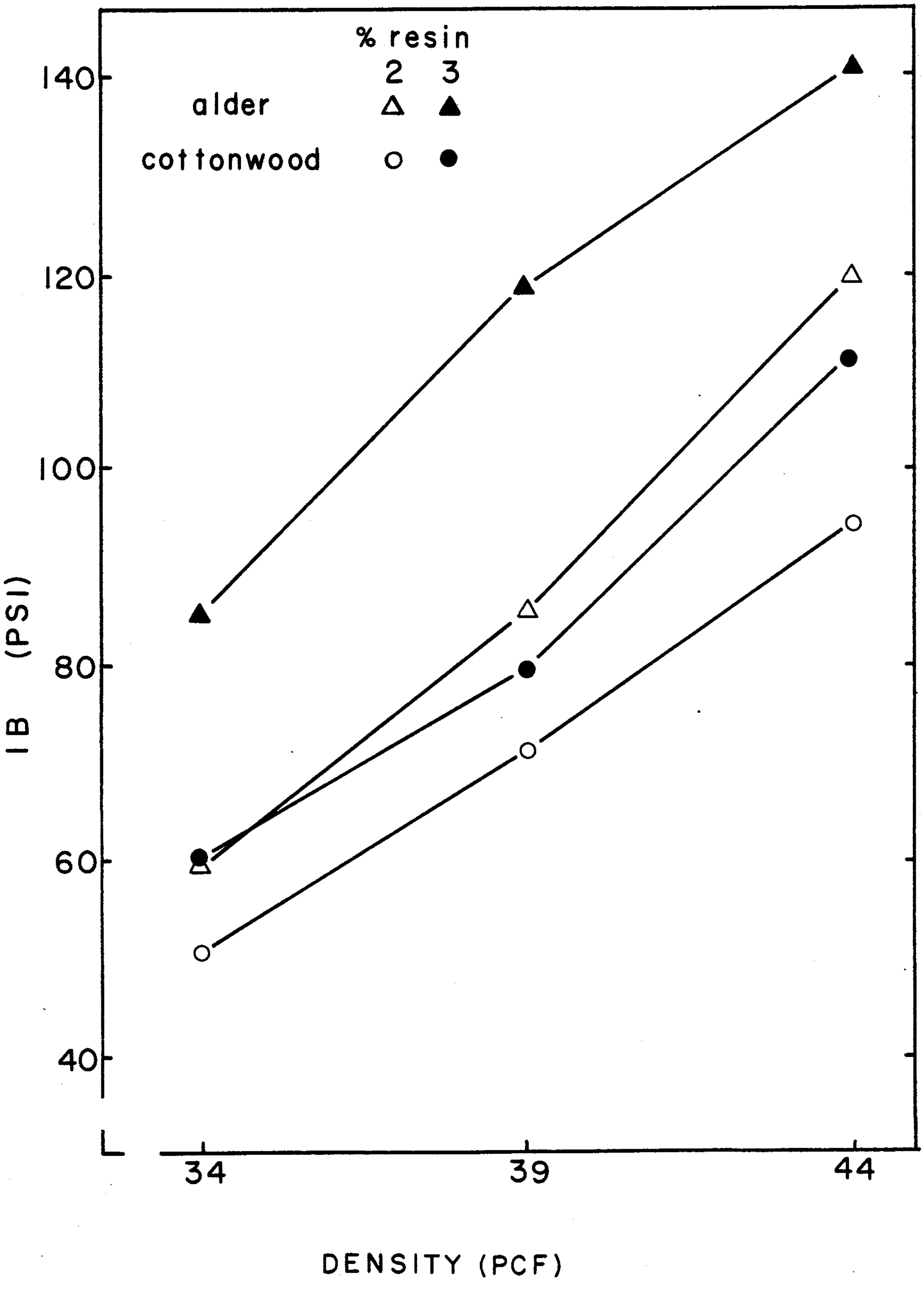

Figure 16 . IB of alder and cottonwood waferboard.

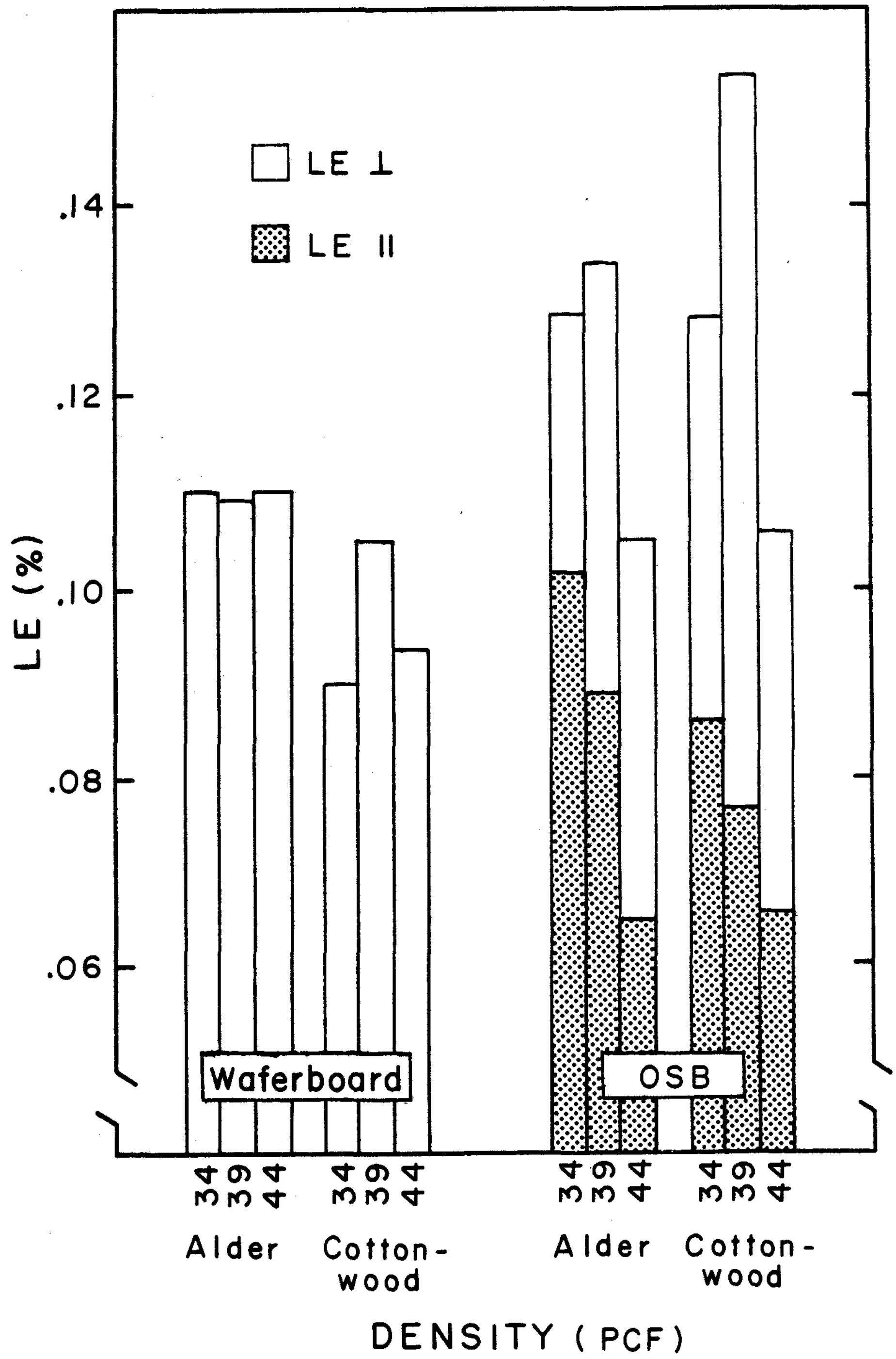

Figure 17. LE of waferboard and OSB manufactured from alder and cottonwood.

Thickness swelling is measured between 50 percent humidity and the wet condition after 2 hours of boiling. This represents exposure to a very severe environment and maximum thickness swelling that will occur. As established by previous research and evident in Figure 18, the thickness swelling depends upon panel density and resin content. Alder and cottonwood boards had TS similar to their commercial counterparts in Lehmann's study. When manufactured at the lower resin content the TS increases about 30 percent for waferboard and about 90% for OSB.

Strength Retention after Aging

Samples of all board types were cycled through two aging cycles, APA's one cycle vacuum-pressure soak and CSA's two hour boil, to determine their strength retention after severe environmental changes. While it is unlikely that waferboard or OSB panels would ever be subjected to the severity of the two-hour boil in actual use, the cycle is useful for determining mismanufacturing of the boards.

All waferboard and OSB types retained at least 50 percent of a dry bending strength when tested wet after the two-hour boil cycle. All waferboard and OSB types retained over 65 percent of their MOR after a one-cycle VPS treatment and the subsequent redrying as presented in Figure 19.

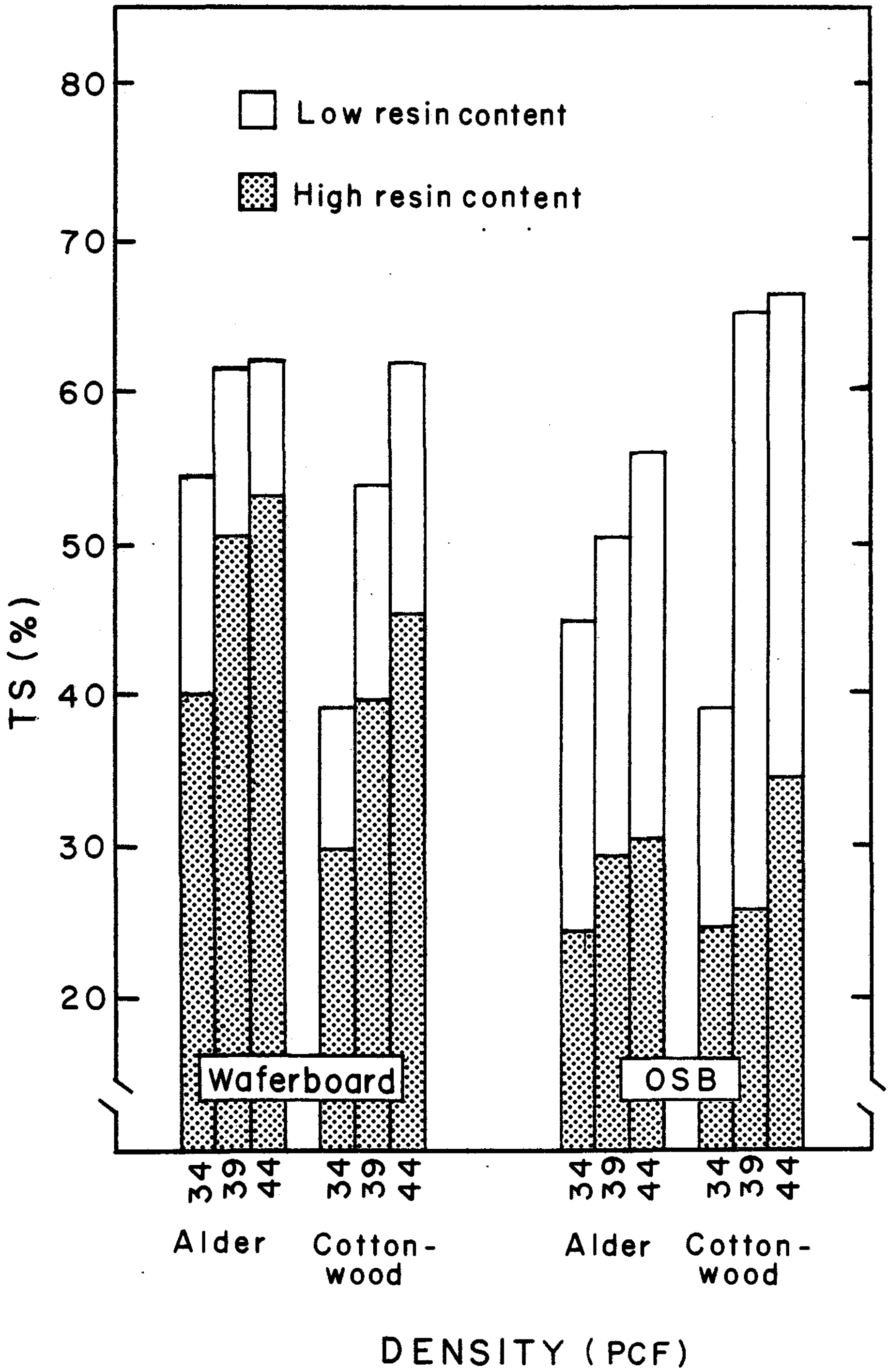

Figure 18. TS of waferboard and OSB manufactured from alder and cottonwood.

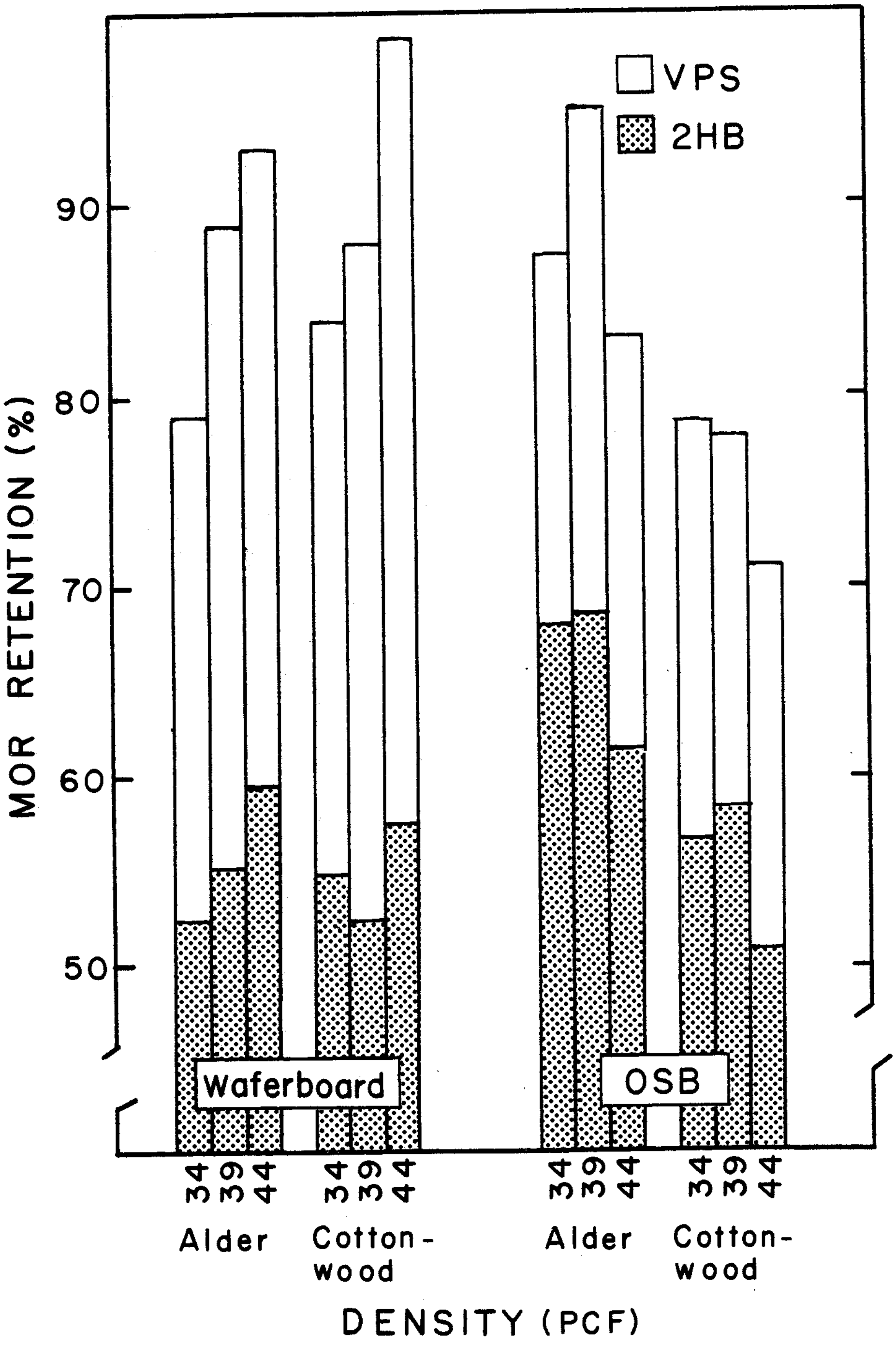

Figure 19. MOR retention of waferboard and OSB made from alder and cottonwood after 2HB and VPS aging cycles.

Both species of waferboard had increased MOR retention after the VPS treatment at the higher density levels. As density increased the TS usually increased also because of greater compression set. This increased TS creates a larger moment of inertia which increased MOR since it's based on the thickness before aging. This explanation is not valid for the OSB panels.

VI. CONCLUSIONS

The findings presented in this study lead to the following conclusions regarding the properties of waferboard and OSB manufactured from alder and cottonwood.

The strength properties of OSB and waferboard increased as either panel density or resin content increased. At equal panel density, cottonwood had more compaction than alder which resulted in slightly higher bending properties at lower and medium densities. Even though cottonwood had a higher compaction ratio at any panel density, alder panels had superior internal bond values. The polyphenol extractives in alder may have acted as a natural binder resulting in improved internal bond strength of both waferboard and OSB.

When manufactured at 39 pcf density and 2 percent resin, alder and cottonwood waferboard had properties which surpassed a commercial aspen waferboard. When manufactured at 39 pcf density and 3 percent resin, alder and cottonwood OSB had properties comparable to a commercial OSB made from a western softwood. These properties improved as density or resin content increased.

Given the distribution of flake angles in an OSB panel, the ratio of (MOE //) to (MOE _/_) could be estimated by calculating the contribution to MOE in each direction, of each flake by using a

Hankinson-type expression. This estimation was confounded by the vertical density gradient which was created during hot pressing.

From the stand point of panel properties, alder and black cottonwood are two species indigenous to the Pacific Northwest which are suitable for waferboard or OSB production.

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APPENDICES

APPENDIX A

List of Abbreviations

ANSI	American National Standards Institute
APA	American Plywood Association
ASTM	American Society of Testing and Materials
CSA	Canadian Standards Associaton
DN_{34-39}	Density increase from 34 to 39 pcf
DN_{39-44}	Density increase from 39 to 44 pcf
IB	Internal bond
LE	Linear expansion
MC	Moisture content
MOE	Modulus of elasticity
MOE //	MOE in direction parallel to orientation
MOE ⊥	MOE in direction perpendicular to orientation
MOR	Modulus of rupture
OD	Ovendry
OSB	Oriented strand board
pcf	Pounds per cubic foot
RC	Resin content affect
RH	Relative humidity
SIPS	Statistical Interactive Programming Systems
SP	Specie affect
TS	Thickness swell
VPS	Vacuum-pressure-soak
2HB	Two hour boil

APPENDIX B

Statistical Results

To determine the statistical significance of the panel production parameters on each of the properties, a multiple linear regression model was used. Indicator variables were used for species, resin content, and density. After regressing the property against the variables, the following hypothesis test is performed on each coefficient.

Ho: coefficient = 0 (variable not significant)
Ha: coefficient ≠ 0 (variable is significant)

Table 16 shows the p-values for each hypothesis test. One minus the p-value is the level at which the variable would be significant. If the p-value is less than .05 the variable is significant at the 95% level.

Table 16. P-values of indicator variables used in regressing properties against production parameters.

PROPERTY			DN	DN
OSB	SP	RC	34-39	39-44
MOE	.234	.011	.000	.000
MOR	.910	.003	.001	.000
IB	.000	.000	.001	.011
%MOR-VPS	.057	.347	.734	.256
%MOR-2HB	.047	.074	.857	.217
LE //	.013	.117	.920	.005
LE /	.882	.709	.562	.150
TS	.427	.044	.056	.362
MOE ratio	.043	.319	.011	.467
waferboard				
MOE	.003	.122	.000	.000
MOR	.061	.019	.000	.000
IB	.000	.001	.000	.000
%MOR-VPS	.141	.352	.025	.019
%MOR-2HB	.627	1.000	.920	.090
LE	.005	1.000	.619	.468
TS	.000	.000	.000	.000

SP Species affect

RC Resin content affect

DN Affect of increasing density of panel