RING FLAKED MAXI-CHIPS: THE MANUFACTURE, TESTING AND EVALUATION OF COMPOSITE BOARD MADE FROM ALBERTA WOODS

Morrison-Knudsen
Forest Products Co., Ltd.[1]

April 30, 1987
(Rev. May 19, 1987)

This is a joint publication of the Canadian Forestry Service and the Alberta Forest Service pursuant to the Canada-Alberta Forest Resource Development Agreement

[1]Boise, Idaho - U.S.A.

DISCLAIMER

The study on which this report is based was funded under the Canada-Alberta Forest Resource Development Agreement.

The views, conclusions, and recommendations are those of the authors. The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by the Canadian Forestry Service or the Alberta Forest Service.

ISBN 0-662-16051-7

Catalogue No. Fo 42-91/33 - 1988E

Additional copies of this publication are available at no charge from:

Regional Development
Canadian Forestry Service
5320 - 122 Street
Edmonton, Alberta
T6H 3S5

Government of Alberta
Forestry, Lands & Wildlife
Forest Industry Development Division
Ste. 930, 9942 - 108 Street
Edmonton, Alberta, Canada T5K 2J5
403/422-7011

TABLE OF CONTENTS

INTRODUCTION

Jager Industries of Calgary, Alberta and the Forest Industry Development Division (FIDD) of the Government of Alberta have shown substantial interest in the feasibility of utilizing ring-cut maxi-chips to produce three-layer structural panels. It is believed that this technology could greatly benefit the utilization of Alberta's timber resources. Alberta FIDD asked Morrison-Knudsen Forest Products (M-K FPC) to direct the project because of its prior involvement in such studies. Also, M-K FPC's FORCELINE electrostatic orientation process adds a great deal to the technical and economic feasibility of this overall concept.

M-K FPC would establish the scope of work, the tasks and schedules working closely with the Alberta Research Council (ARC). The ARC would select and obtain the wood materials, fabricate the random panels and perform all testing. M-K FPC would produce the aligned single layer panels, 3 layer panels and assemble the final reports.

The wood species used would be those abundant in the Province: aspen, black poplar, and spruce/pine. The spruce/pine would come from sawmill residuals, whereas the aspen and black poplar would be utilized as round wood. In order to maximize utilization and minimize costs, the plant must have economy of scale and manufacture a panel that is structurally efficient and marketable as an effective substitute for plywood and waferboard in major end-use applications. This work discusses a method by which significant quantities of Alberta wood species can be used in a technically and economically viable manner.

The oriented three-layer panel (OSB) would be used in load bearing applications such as roofing and flooring. The top and bottom face layers would consist of in-line oriented flakes while the core would have cross-oriented flakes.

If the wood raw material is in the form of a maxi chip produced from sawmill or plywood mill residues or roundwood, ring flakers may be used to convert chips into flakes and Forceline orientation will be needed for panel manufacturing. This approach can provide lower capital requirements and a higher return on investment compared to a structural panel plant utilizing whole log flaking.

The objectives of the oriented three-layer panel study were as follows:

1. Determine size classification of chips used for this study.

2. Establish panel modulus of elasticity and linear expansion properties on a separate face and core layer basis.

3. Based on engineering calculations appropriate to sandwich

panels, determine estimations of modulus of elasticity parallel to the major axis and cross panel linear expansion for 7/16 and 1/2-inch panels. Compare these properties to the American Plywood Association (APA) requirements for uniform load and oven dry vacuum pressure soak linear expansion.

4. Manufacture five oriented 7/16-inch three-layer panels at 38 lb. per cu. ft. density, to be submitted to ARC for evaluation.

5. Compile final study report and submit to Jager Industries and the Government of Alberta FIDD.

6. Review project results with Jager Industries and the Government of Alberta FIDD.

The following sections present discussions on the procedure, chip and flake geometry and screen analyses, single layer panel actual results, three layer panel estimations, and three layer panel actual results.

Since it was not a specified requirement, this study did not examine the minimum panel density or resin content that would be needed to pass the APA or CSA 0437 requirements. We believe these factors would be worthy of further study.

CONCLUSIONS

1. This study demonstrates that a structurally efficient panel made with ring-cut maxi-chips and FORCELINE orientation can be designed to equal or exceed the flexural stiffness and linear expansion performance of many OSB panels now on the market.

2. These oriented panels, from a variety of wood species, can be designed to meet American Plywood Association requirements for uniform loading and cross panel linear expansion. The designer must efficiently arrange various factors such as densities, chip forms, classification of face and core flakes, resin/content, face/core ratios and thickness in order to meet performance standards. Market strategy and economics will further define objectives.

3. Oriented single layer panels made from each species or admixtures of species investigated produce high MOE's, high panel stiffness, and low linear expansions. Black poplar panels exhibited the highest orientation index while aspen produced the highest modulus of elasticity and lowest linear expansion.

4. Of considerable importance to the economies of the process is the fact that FORCELINE orientation effectively utilizes 96% to 98% of the ring flaked wood.

5. The Canadian wood industry has had difficulty in flaking black poplar. Initial trials of ring flaking black poplar indicated the wet flakes folded over the knife cutting edge and plugged the slot between the knife and pressure lip. Drying the wood below the fiber saturation point (25 to 30% moisture content, ODW) eliminated the problem and produced an acceptable flake for FORCELINE orientation.

6. Three layer panel estimations revealed at 41 lb./ft.^{3} densities, revealed 7/16-inch and 1/2-inch oriented panels should easily pass the A.P.A. 24/16 and 32/16 roof/floor uniform load span ratings, respectively. Oven-dry vacuum pressure soak linear expansion should be less than the 0.5% requirement for the A.P.A. and the 0.4% requirement for CAN3-O437. The panel can be satisfactorily made with 100% of each species or various admixtures of the three species.

7. High flake length/thickness ratios yield high panel bending properties. High flake length/width ratios improve orientation efficiencies. To increase the flake length/width ratios, all face flakes were tumbled in a rotary-tumble drum blender. Without this processing step, MOE orientation ratios would be below 4/1 and panel MOE would have been below the requirement for 24/16 and 32/16 roof/floor span rating.

8. At 41 lb./ft.^{3}, random panels made from the available wood species met the CSA 0437 R-1 grade requirement for modulus of rupture, modulus of rupture bond durability, MOE, internal bond, and oven-dry to saturated linear expansion.

9. Estimations of 41 lb./ft.^{3} three layer oriented panels, made with Alberta species maxi-chip face flakes and Douglas-fir or lodgepole pine pulp chip core flakes, indicated these panels should pass the A.P.A. uniform load span rating and linear expansion requirements.

10. Because the estimated properties comfortably exceeded A.P.A. requirements, it was decided that a target density of 38 lb./ft.^{3} should be used in making the oriented 3-layer test panels.

Test results of these panels in 7/16" thickness indicated that they met the CAN 3-0437 requirements for modulus of rupture, modulus of elasticity, and linear expansion. Also, these panels passed the A.P.A. 24/16 uniform load span rating and linear expansion requirements.

ORIENTED SINGLE LAYER PANELS

PROCEDURE

ARC collected and shipped the needed raw material to H. C. Moore & Sons, Marion, Alabama. The aspen and black poplar was obtained in round wood form while the pine/spruce mixture were obtained from sawmill slabs and edgings. H. C. Moore used a 5-knife 60" horizontal feed chipper to convert the raw material into maxi-chips.

Samples of maxi-chips from each species were sent to Acrowood Corporation, Everett, Washington for chip length analysis. Table 1 shows test results.

The maxi-chips were sent to the Wood Technology Section, Washington State University (WSU), Pullman, Washington for conversion into ring-cut flakes and separation into face and core flakes. A Pallmann PZ-8 was used to produce 0.015 to 0.020-inch thick flakes at a relative cutting speed of 6,000 ft./min.

Green black poplar is difficult to flake because it tends to coat the knives and plug the knife slot. Drying the black poplar below the fiber saturation point prior to flaking eliminated the problem.

After drying to about 10% moisture content, the flakes were classified with a Black Clawson screen shaker into a face and core flake mix for each species. Aspen face flakes were those retained on a 3/4-inch screen. Aspen core flakes were those that passed through the 3/4-inch screen and were retained on a 20 mesh screen. Black poplar and spruce/pine face flakes consisted of the +1/2-inch screen size while the core flakes were the -1/2 + 20 mesh screen size. During screening, wood flow rate and screening area were varied in order to arrive at a yield of 47.5% face flakes, 47.5% core flakes, and 5% fines loss. Screening results are listed in Table 2. The actual amount of -20 mesh fines loss was only 2 to 4%.

M-K FPC determined the flake geometry and screen analyses of all flakes. Results are listed in Table 3.

Manufacturing procedures for single layer panels are displayed in Figure 1. Prior to blending, all face flakes were tumbled in a rotary tumble drum blender to improve the aspect ratio (length/width). Higher length/width ratios improve orientation efficiency. Thirty single layer panels were produced: five in-line oriented aspen face panels, five black poplar in-line oriented face panels, five spruce/pine in-line oriented face panels, five cross-oriented aspen core panels, five cross-oriented black poplar core panels, five cross-oriented spruce/pine core panels. Closing pressure was varied slightly to maintain similar close time to stops for all panels. Press cycle was established on the basis of time to 225°F core line temperature plus about one minute.

After manufacturing, single layer panels were cut according to the pattern in Figure 2 to obtain test samples. M-K FPC used the Metriguard stress wave timer to determine orientation index. ARC determined density and modulus of elasticity (MOE) by ASTM D-1037, except samples were not humidified to 65% relative humidity. ARC also tested for oven-dry vacuum pressure soak linear expansion (LE) by American Plywood Association Test Method P-1, except sample size was 12-in. X 3-in.

Single layer test results are listed in Tables 4 to 13. Table 4 lists the Metriguard orientation index. Tables 5 to 8 and 13 list MOE's. MOE's were corrected to 41 lb./ft.^{3} density for comparison purposes. Tables 9 to 13 list percent linear expansion. Table 13 summarizes properties of each chip type.

Estimations of three layer panel properties focused upon various combinations of the three wood species. These were as follows:

1. <u>Aspen Face</u> with aspen or black poplar and spruce/pine or admixture of all species for the core.

2. <u>Black poplar Face</u> with aspen or black poplar or spruce/pine or admixture of all species for the core.

3. <u>Spruce/pine Face</u> with aspen or black poplar or spruce/pine or admixture of all species for the core.

4. Admixture of all species for the face and aspen or black poplar or spruce/pine or admixture of all species for the core.

Tables 14 and 15 show the estimated properties of the panel type for 7/16 and 1/2-inch panels at 41 lb./ft.^{3} density. Estimated properties included apparent modulus of elasticity parallel to face orientation, flexural stiffness parallel to face orientation, APA uniform load roof/span rating and cross panel linear expansion. Graphical illustrations of the relationships between species and properties are shown in Figures 3 and 4.

PARTICLE SCREEN ANALYSES AND GEOMETRY

Particle geometry refers to the size and shape of the particle. Measurements reveal distribution of particle size by screen analyses, length/width ratios, and length/thickness ratios (slenderness ratio).

Maxi-chip analyses were done by Acrowood Corporation, who used the Williams Screen Classification for determining chip length. Table 1 lists test results. The spruce/pine chips were the longest; the aspen and black poplar chips were about the same average length.

M-K FPC determined screen analyses and geometry of the ring-cut flakes. The average length, width and thickness of the screen fractions was determined by measuring twenty flakes of each screen fraction. These measurements were then weighted according to the retained percentage on each screen, to compute the average length/width and length/thickness ratios.

Screen analyses and flake geometry are shown in Table 3. Generally speaking, as the flake length/width ratio increases but maintaining the same flake thickness, flakes orient more efficiently. Black poplar flakes had the highest length/width ratio (aspect ratio). Aspen and spruce/pine had similar ratios. In addition, as the length/thickness ratio (slenderness ratio) increases, panel MOE increases. The slenderness ratio of all face flakes was significantly higher than the core flakes. All core flakes had similar slenderness ratios. Aspen and spruce/pine face flakes had higher ratios that black poplar face flakes.

ORIENTED SINGLE LAYER PANEL TEST RESULTS

Orientation Index

Orientation index is a measure of the efficiency of alignment. Wood flakes aligned within a wood panel exhibit a grain and cross-grain direction similar to plywood or lumber. Because of alignment, anisotropic properties exist parallel and perpendicular to alignment. Random panels, those without alignment, have isotropic properties. Orientation index is expressed as the ratio of the bending MOE parallel to alignment divided by the bending MOE perpendicular to alignment, at a specific density. Random panels have a 1.0 MOE orientation index because MOE's are the same in both panel directions. An MOE orientation index of 4.0 means the MOE parallel to alignment is four times greater than perpendicular to alignment. Also, it means the MOE of an oriented panel, parallel to alignment, is about two times ($\sqrt{4} = 2$) greater than the same type of random panel.

Two methods were used to measure MOE orientation. The Metriguard stress wave timer was used to measure orientation on the entire panel (26-inches X 22-inches) before samples were cut for testing. This unit measures the relative time it takes for stress waves to travel parallel and perpendicular to alignment. Then, mathematical relationships are used to determine orientation. The second method used the results from the ARC tests on the flexure samples cut from within the whole panel.

Table 4 lists Metriguard results. Table 13 lists results from ARC flexure tests. Generally, black poplar panels had higher orientation efficiencies than aspen or spruce/pine.

Modulus of Elasticity (MOE)

MOE's are found in Tables 5 to 8 and 13. Aspen panels exhibited higher MOE's, parallel to alignment than black poplar and spruce/pine, which were similar. Perpendicular to alignment, all MOE's were very low.

Percent Linear Expansion (LE)

Linear expansion results are listed in Tables 9 to 13. Aspen had the lowest LE parallel to alignment. Perpendicular to alignment, black poplar had the lowest LE.

ESTIMATIONS OF 7/16-INCH AND 1/2-INCH ORIENTED THREE-LAYER PANELS

Modulus of Elasticity (MOE)

In three-layer oriented panels, core orientation is at 90 degrees to face orientation, and face orientation (top and bottom) is parallel to the major axis (long dimension). Since the major axis is placed across the span supports, the apparent MOE and flexural stiffness, parallel to face orientation, govern the uniform-load span rating of the panel.

The apparent MOE is influenced by the MOE of the individual layers and the face/core ratio. In oriented panels, the MOE along the major axis is governed by the face layer MOE parallel to orientation, core MOE perpendicular to orientation and the face/core ratio. As the percentage of face increases, MOE increases. The formula used for estimating MOE is in Figure 5.

Tables 14 and 15 list the estimated apparent MOE, parallel to face alignment, as affected by panel thickness, type of face and core flakes, and face/core ratios. Panel density is 41 lb./ft.^{3}. Both panel thicknesses will have the same MOE if the MOE's of the individual layers are equal and the face/core ratio is the same.

Figure 3 graphically displays the values in Tables 14 and 15. Panels made with aspen face have the highest MOE's. As the percentage of face increased, MOE increased. The type of core species had no significant effect on MOE.

Flexural Stiffness (EI)

The APA uniform load performance standards are based on the EI of the panel along the major axis. EI is an engineering term and is determined by multiplying the apparent modulus of elasticity by the panel moment of inertia (width X thickness^3 $\div$ 12). Figure 5 shows the formula used for estimating EI. Estimations of 7/16 and 1/2 inch panel EI are found in Tables 14 and 15. Figure 3 shows the required dry panel MOE needed for 7/16-inch 24/16 span rating and 1/2-inch 32/16 span rating. All panel types should meet the 24/16 rating with 7/16-inch and 32/16 rating with 1/2-inch thickness.

Linear Expansion (LE)

Dimensional stability is as important for structural panels as are mechanical properties. The APA Test Method P-1 from oven dry to vacuum pressure soak, limits LE to 0.5%.

Relationships for estimating LE were presented by John Talbott, at the 1979 WSU Particleboard Symposium. LE parallel to the face orientation or major axis is dependent upon the face layer MOE and LE parallel to orientation, the core layer MOE and LE perpendicular to orientation and the face/core ratio. Cross panel LE is influenced by face layer MOE and LE perpendicular to the major axis, the core layer MOE and LE parallel to orientation, and the face/core ratio. Seven-sixteenth and 1/2-inch panels will have similar LE's if the estimates are based on the same single layer data and the layer ratio is identical. Figure 5 shows the formula for estimating cross panel linear expansion.

Tables 13 and 14 estimate the cross panel LE. Figure 4 shows the results graphically. All panels should pass the LE requirement as long as the core percentage is greater than or equal to 30%. As the percentage of core increases, cross panel LE decreases. All panel types should meet the LE requirement as long as the core percentage is equal to or greater than 30%. Panels with aspen core flakes exhibited lower LE's than those with black poplar or spruce/pine core flakes. Panels with black poplar core flakes have the highest LE.

SUMMARY

ORIENTED SINGLE LAYER PANELS

Three wood species were collected in Alberta by ARC. These included aspen and black poplar in the form of logs and spruce/pine in the form of sawmill slabs and edgings. All wood forms were converted to maxi-chips. These chips were ring flaked with a Pallmann PZ-8 flaker. Flakes were screen classified into a separate face and core flake furnish.

Single-layer Forceline aligned panels were made with the face and core flakes from each species. Panels were tested for MOE and LE.

Estimations of 7/16 and 1/2-inch three layer panel modulus of elasticity, flexural stiffness, and cross panel linear expansion were made as related to the single layer properties. These relationships for sandwich panels are well established in the literature. The projections can be made with confidence.

Numerous combinations of wood species and face/core ratios for each panel thickness can be used to meet the requirements of an oriented structural panel. Balancing parameters will be necessary to meet APA approval.

Forceline orientation permits a wide latitude of particle sizes. A Forceline structural panel plant will utilize 96% to 98% of the ring-cut flake furnish.

SUMMARY

RANDOM SINGLE LAYER PANELS

Alberta Research Council manufactured 7/16-inch single layer random panels from the face and core flakes. Manufacturing conditions, test results, and supplemental material is found in the ARC report entitled "Ring Flaked Maxi-Chip: The Manufacture, Testing and Evaluation of Composite Board From Alberta Woods."

A summary of random panel properties is found in Table 16. At 41 lb./ft.^{3} density all panels met the CAN3-0437 R-1 requirements for modulus of rupture, modulus of elasticity, internal bond, and oven-dry to saturated linear expansion.

SUMMARY

ORIENTED PULP CHIP PANELS

This part summarizes information from past M-K FPC investigations in which Pallmann ring-cut pulp chips and FORCELINE orientation were used to manufacture oriented structural panels. The ring cut flakes were made from 7/8-inch lodgepole pine pulp chips, 7/8-inch Douglas fir pulp chips and 5/8-inch Douglas fir pulp chips. The lodgepole pine chips were from Montana, and the Douglas fir chips were from western Oregon.

Pulp chip screen analyses and flake geometry are listed in Table 17. The screen analyses, flake aspect ratios, and flake slenderness ratios were similar to the Alberta species core flakes. (Part I, Table 3.)

Basically, the same procedure was used for manufacturing and testing single-layer panels as reported in Part I, Figure 1. Phenol formaldehyde resin content was 5% O.D.W. FORCELINE III was used to orient the flakes for the face layer while FORCELINE II was used to orient the core layer. Panels were tested for density, modulus of elasticity, and oven dry vacuum pressure soak linear expansion.

Pulp chip single-layer property results are listed in Table 18. All face layer MOE's were significantly lower than those from aspen, black poplar, and spruce/pine. The reasons for this are related to species differences, lower length/thickness ratios, and orientation ratios for the pulp chips. The lodgepole pine pulp chips core panels exhibited MOE's similar to the core panels of the Alberta maxi-chips; the Douglas fir core panels were about 20% lower. Pulp chips and maxi-chips had similar LE's.

Table 19 estimates three layer properties of 7/16-inch, 41 lb./ft.^{3} panels with the Alberta maxi-chips for the face flakes and pulp chips for the core flakes. All panel types should meet the 24/16 APA uniform load span rating and the 0.5% linear expansion requirements.

SUMMARY

ORIENTED THREE LAYER PANELS

On March 19, 1987 M-K FPC reviewed the test results of oriented single-layer panels with the Government of Alberta FIDD and Jager Industries. After considering the results, it was decided that M-K FPC should manufacture four types of 7/16-inch oriented three layer panels at 38 lb./ft.^{3} density. These were as follows:

1. 100% aspen
2. Admixture of 70% aspen and 30% black poplar
3. Admixture of 1/3 aspen, 1/3 black poplar, and 1/3 spruce/pine
4. 100% spruce/pine

Manufacturing procedures for three layer oriented panels are listed in Figure 5. Two panels were made from each of the four panel types; one panel for ARC and one panel for Jager/FIDD. Due to insufficient quantity of flakes, the flakes for three-layer panels were used from previously blended batches left from the production of oriented single layer panels. However, there was enough unblended spruce/pine flakes so that these flakes were blended with new resin.

After manufacturing, all panels were shipped to ARC. One panel from each panel type was tested for modulus of rupture, modulus of elasticity, internal bond, and oven dry vacuum pressure soak linear expansion. Sample size for linear expansion tests was 12-inch X 3-inch.

Test results are in Tables 20, 21 and Figures 6, 7, and 8. Figures 6 to 8 graphically display the average panel properties in comparison to APA and Canadian codes. At 38 lb./ft.^{3}, all 7/16-inch panels met the CAN 3-0437 requirements for modulus of rupture, modulus of elasticity, internal bond, and linear expansion. Also, the panels met the APA 24/16 span rating for uniform load and linear expansion.

ECONOMIC ANALYSIS

The process of producing oriented strandboard using maxi and pulp chips, ring flaking and FORCELINE orientation has several economic advantages compared to the conventional roundwood method:

- Lower capital requirements
- Lower raw material costs
- Lower operating costs

CAPITAL REQUIREMENTS: By receiving all raw material in bulk form as chips, it is, of course, possible to eliminate the green end of an OSB plant. Even though a certain amount of maxi-chipping would have to be accomplished by converting existing sawmill chippers and/or chipping with portable systems in the woods, the net capital cost difference would probably be in the range of C $1,500,000 to C $3,000,000 for a 300,000,000 3/8 per year OSB plant.

RAW MATERIAL COSTS: The FORCELINE orienting system enables significant savings in raw material costs in two ways. First, it is able to effectively use lower valued materials such as lumber trim ends, edgings, etc. Secondly, its ability to use a much greater percentage of the input raw material (at least 95% instead of 75 to 85%) than mechanical OSB forming processes is very significant. Combined, these two factors represent a total saving of several million dollars per year.

OPERATING COSTS: Eliminating the green end of the OSB plant we are considering would eliminate at least 16 employees, which would result in a labor cost saving of approximately C $600,000 per year. In addition, there would be sizeable savings in energy, depreciation, maintenance and other cost factors.

SUMMARY: The overall effect of this reduction in capital investment, plus a reduction in raw material and operating costs, would be a substantial improvement in return on investment for the facility.

Table 1 ACROWOOD CHIP LENGTH ANALYSES OF MAXI-CHIPS

Length Category, In.	Percent of Wood Species		
	Aspen	Black Poplar	Spruce/ Pine
0 – 1.8	15.8	11.9	17.1
1.8 – 2.0	5.2	8.4	8.2
2.0 – 2.2	25.2	25.0	8.6
2.2 – 2.4	32.3	32.5	10.9
2.4 – 2.6	16.9	17.3	11.8
2.6 – 2.8	4.0	2.5	8.4
>2.8	>0.6	>2.2	34.9

#12425a/87

Table 2 WASHINGTON STATE UNIVERSITY SCREENING SEPARATIONS FOR FACE FLAKES, CORE FLAKES, AND FINES LOSS

Wood Species	Face Flakes		Core Flakes		Fines Loss	
	Screen Size	Percent Yield	Screen Size	Percent Yield	Screen Size	Percent Loss
Aspen	+ 3/4	43.4	−3/4 + 20	54.6	−20	2.0
Black Poplar	+ 1/2	49.3	−1/2 + 20	48.2	−20	2.5
Spruce/ Pine	+ 1/2	41.6	−1/2 + 20	54.4	−20	4.0

#124258/87

Table 3 SCREEN ANALYSES AND FLAKE GEOMETRY

Wood Species		Aspen		Black Poplar		Pine/Spruce	
Chip Type		Maxi-Chip		Maxi-Chip		Maxi-Chip	
Layer		Face	Core	Face	Core	Face	Core
Flake Screen Size		+ 3/4	−3/4 + 20	+ 1/2	−1/2 + 20	+ 1/2	−1/2 + 20
Flake Length, in.		1.63	.78	1.29	.55	1.45	.62
Flake Width, in.		.30	.17	.20	.08	.34	.11
Flake Thickness, in.		.017	.018	.018	.014	.016	.017
Length/Width Ratio		5.4	4.6	6.4	6.9	4.3	5.6
Slenderness Ratio		95.9	43.3	71.7	39.3	90.6	36.5
U.S. Standard Sieve Screen Percent By Weight	+ 1/4	79	22	43	2	64	5
	−1/4 + 6	13	22	23	12	17	17
	−6 + 10	5	21	16	29	11	25
	−10 + 20	2	29	14	43	7	41
	−20	1	6	4	14	1	12

#12425c/87

Table 4 METRIGUARD STRESS WAVE MODULUS OF ELASTICITY ORIENTATION INDEX OF ORIENTED SINGLE-LAYER PANELS

Wood Species	Face Layer				Core Layer			
	Flake Screen Size	Panel No.	Density, Lb./Ft.^{3}	Orientation Index	Flake Screen Size	Panel No.	Density, Lb./Ft.^{3}	Orientation Index
Aspen	+3/4	43 44 45 46 47	41.6 40.6 42.1 41.4 41.2	4.8 4.3 4.7 4.4 4.7	−3/4 + 20	58 59 60 61 62	41.2 41.4 40.0 40.7 41.0	4.4 4.5 4.5 4.5 4.2
Black Poplar	+1/2	48 49 50 51 52	40.5 41.4 40.9 39.3 40.7	5.2 4.9 5.4 5.4 5.3	−1/2 + 20	63 64 65 66 67	40.8 41.0 41.1 41.5 41.6	4.8 4.6 5.1 4.6 4.7
Spruce/ Pine	+1/2	53 54 55 56 57	41.9 42.1 39.3 38.8 39.7	4.5 4.6 4.7 4.7 4.5	−1/2 + 20	68 69 70 71 72	40.3 40.6 40.1 40.1 40.1	4.7 4.7 4.5 4.7 4.5

•124254-87

Table 5 SINGLE-LAYER MODULUS OF ELASTICITY PARALLEL TO ORIENTATION

Panel Type	Wood Species	Face Layer: Flake Screen Size	Face Layer: Panel No.	Face Layer: Density, Lb./Ft.³	Face Layer: Modulus of Elasticity PSI x 10³	Face Layer: Modulus of Elasticity At 41 Lb./Ft.³ PSI x 10³	Core Layer: Flake Screen Size	Core Layer: Panel No.	Core Layer: Density, Lb./Ft.³	Core Layer: Modulus of Elasticity PSI x 10³	Core Layer: Modulus of Elasticity At 41 Lb./Ft.³ PSI x 10³
Oriented	Aspen	+ 3/4	43-1	41.6	1640	1619	−3/4 + 20	58-1	40.4	1257	1278
			43-2	40.8	1439	1446		58-2	40.2	1000	1028
			43-3	42.8	1653	1590		58-3	40.7	1290	1300
			44-1	42.7	1723	1663		59-1	42.8	1243	1180
			44-2	39.9	1496	1534		59-2	40.6	885	899
			44-3	40.5	1522	1540		59-3	39.2	1272	1335
			45-1	39.6	1392	1441		60-1	40.2	1240	1268
			45-2	41.7	1699	1674		60-2	40.2	811	839
			45-3	41.1	1598	1594		60-3	39.9	1284	1322
			46-1	40.9	1402	1406		61-1	40.5	1196	1214
			46-2	41.4	1520	1506		61-2	39.8	949	991
			46-3	40.9	1552	1556		61-3	39.5	1198	1250
			47-1	41.9	1535	1503		62-1	42.1	1377	1339
			47-2	41.9	1491	1460		62-2	40.7	971	982
			47-3	38.9	1429	1502		62-3	40.3	1260	1284
	Black Poplar	+ 1/2	48-1	40.0	1286	1321	−1/2 + 20	63-1	40.2	967	995
			48-2	41.0	1335	1335		63-2	40.9	967	970
			48-3	41.6	1359	1338		63-3	41.0	1001	1001
			49-1	39.4	1345	1401		64-1	42.0	990	955
			49-2	38.9	1287	1360		64-2	41.7	996	972
			49-3	42.4	1507	1458		64-3	39.7	918	964
			50-1	40.8	1334	1341		65-1	41.7	996	972
			50-2	41.4	1435	1421		65-2	42.7	1078	1019
			50-3	40.7	1485	1496		65-3	41.6	1030	1009
			51-1	40.0	1329	1364		66-1	42.6	1113	1057
			51-2	40.6	1392	1406		66-2	41.9	1108	1076
			51-3	41.3	1450	1440		66-3	40.2	1035	1063
			52-1	40.3	1343	1368		67-1	39.3	987	1046
			52-2	41.9	1673	1641		67-2	39.9	1004	1042
			52-3	38.8	1316	1393		67-3	40.3	1033	1056

#12425e/87

Table 6 SINGLE-LAYER MODULUS OF ELASTICITY PARALLEL TO ORIENTATION

Panel Type	Wood Species	Face Layer					Core Layer				
		Flake Screen Size	Panel No.	Density, Lb./Ft.^{3}	Modulus of Elasticity		Flake Screen Size	Panel No.	Density, Lb./Ft.^{3}	Modulus of Elasticity	
					PSI x 10^3	At 41 Lb./Ft.^{3} PSI x 10^3				PSI x 10^3	At 41 Lb./Ft.^{3} PSI x 10^3
Oriented	Spruce/ Pine	+ 1/2	53-1	42.4	1418	1369	−1/2 + 20	68-1	40.8	1009	1016
			53-2	44.5	1529	1406		68-2	41.5	1026	1008
			53-3	39.5	1357	1410		68-3	39.3	978	1038
			54-1	40.7	1420	1430		69-1	43.0	1122	1052
			54-2	41.4	1539	1525		69-2	41.2	1065	1058
			54-3	41.7	1449	1424		69-3	43.1	1145	1072
			55-1	41.9	1376	1344		70-1	41.8	994	966
			55-2	39.2	1382	1445		70-2	39.2	904	967
			55-3	40.1	1404	1436		70-3	39.3	901	960
			56-1	40.8	1380	1387		71-1	41.8	1038	1010
			56-2	37.7	1278	1394		71-2	40.4	1023	1044
			56-3	39.3	1278	1338		71-3	40.3	1020	1044
			57-1	42.7	1459	1400		72-1	41.5	1073	1056
			57-2	39.8	1272	1314		72-2	40.2	991	1019
			57-3	39.3	1306	1365		72-3	41.4	985	971

#124251 87

Table 7 SINGLE-LAYER MODULUS OF ELASTICITY PERPENDICULAR TO ORIENTATION

Panel Type	Wood Species	Face Layer: Flake Screen Size	Face Layer: Panel No.	Face Layer: Density, $Lb./Ft.^3$	Face Layer: Modulus of Elasticity $PSI \times 10^3$	Face Layer: Modulus of Elasticity At 41 $Lb./Ft.^3$ $PSI \times 10^3$	Core Layer: Flake Screen Size	Core Layer: Panel No.	Core Layer: Density, $Lb./Ft.^3$	Core Layer: Modulus of Elasticity $PSI \times 10^3$	Core Layer: Modulus of Elasticity At 41 $Lb./Ft.^3$ $PSI \times 10^3$
Oriented	Aspen	+3/4	43-4	40.6	265	270	−3/4 + 20	58-4	40.3	186	194
			43-5	40.4	253	260		58-5	41.9	227	216
			43-6	40.4	234	242		58-6	42.3	223	206
			44-4	40.7	266	270		59-4	40.2	206	216
			44-5	39.0	282	291		59-5	39.2	204	227
			44-6	39.5	282	300		59-6	42.9	206	182
			45-4	40.0	279	292		60-4	40.5	202	208
			45-5	41.2	286	284		60-5	38.9	213	239
			45-6	41.2	259	255		60-6	40.3	202	211
			46-4	40.5	277	284		61-4	40.3	194	203
			46-5	41.1	296	295		61-5	40.4	209	216
			46-6	40.1	294	304		61-6	41.5	212	206
			47-4	42.4	252	235		62-4	41.8	218	208
			47-5	41.8	301	291		62-5	42.7	238	217
			47-6	41.2	299	297		62-6	40.8	193	196
	Black Poplar	+1/2	48-4	39.8	209	224	−1/2 + 20	63-4	39.7	184	200
			48-5	40.8	228	231		63-5	41.2	211	209
			48-6	40.1	263	274		63-6	40.9	194	195
			49-4	39.0	199	224		64-4	40.8	199	202
			49-5	40.3	192	201		64-5	40.5	182	188
			49-6	43.3	250	221		64-6	39.5	174	193
			50-4	41.1	201	200		65-4	40.6	186	191
			50-5	40.4	251	258		65-5	41.7	195	186
			50-6	40.8	282	285		65-6	40.8	187	200
			51-4	39.9	219	233		66-4	41.4	195	190
			51-5	40.0	201	214		66-5	42.8	218	196
			51-6	39.4	229	249		66-6	40.7	196	200
			52-4	39.6	202	220		67-4	40.7	193	197
			52-5	40.3	202	211		67-5	43.8	236	201
			52-6	41.7	198	189		67-6	43.6	229	196

#12425e/87

Table 8 SINGLE-LAYER MODULUS OF ELASTICITY PERPENDICULAR TO ORIENTATION

Panel Type	Wood Species	Face Layer					Core Layer				
		Flake Screen Size	Panel No.	Density, $Lb./Ft.^3$	Modulus of Elasticity		Flake Screen Size	Panel No.	Density, $Lb./Ft.^3$	Modulus of Elasticity	
					$PSI \times 10^3$	At 41 $Lb./Ft.^3$ $PSI \times 10^3$				$PSI \times 10^3$	At 41 $Lb./Ft.^3$ $PSI \times 10^3$
Oriented	Spruce/Pine	+ 1/2	53-4	38.7	225	254	−1/2 + 20	68-4	39.7	198	214
			53-5	41.3	286	282		68-5	40.8	204	206
			53-6	39.1	264	288		68-6	40.1	205	216
			54-4	41.1	256	255		69-4	41.7	206	197
			54-5	41.1	283	281		69-5	40.6	193	198
			54-6	42.1	284	270		69-6	38.3	191	225
			55-4	38.5	214	245		70-4	41.4	200	195
			55-5	40.6	258	263		70-5	38.6	165	195
			55-6	37.6	213	256		70-6	38.1	204	240
			56-4	40.5	268	274		71-4	41.1	204	203
			56-5	38.9	252	278		71-5	37.9	171	210
			56-6	39.1	228	252		71-6	38.6	180	210
			57-4	39.6	237	254		72-4	39.2	181	204
			57-5	41.6	275	268		72-5	40.6	191	196
			57-6	39.8	259	274		72-6	39.9	204	218

#12425IV87

Table 9 SINGLE LAYER OVEN-DRY VACUUM PRESSURE SOAK LINEAR EXPANSION PARALLEL TO ORIENTATION

Panel Type	Wood Species	Flake Screen Size	Face Layer Panel No.	Face Layer Density, Lb./Ft.^{3}	Face Layer %	Core Layer Flake Screen Size	Core Layer Panel No.	Core Layer Density, Lb./Ft.^{3}	Core Layer %
Oriented	Aspen	+ 3/4	43-1	41.6	.11	−3/4 + 20	58-1	40.4	.06
			43-2	40.8	.11		58-2	40.2	.02
			43-3	42.8	.09		58-3	40.7	.06
			44-1	42.7	.09		59-1	42.8	.11
			44-2	39.9	.17		59-2	40.6	.11
			44-3	40.5	.04		59-3	39.2	.04
			45-1	39.6	.09		60-1	40.2	.02
			45-2	41.7	.06		60-2	40.2	.09
			45-3	41.1	.15		60-3	39.9	.02
			46-1	40.9	.17		61-1	40.5	.06
			46-2	41.4	.06		61-2	39.8	.09
			46-3	40.9	.06		61-3	39.5	.09
			47-1	41.9	.20		62-1	42.1	.09
			47-2	41.9	.06		62-2	40.7	.09
			47-3	38.9	.11		62-3	40.3	.09
	Black Poplar	+ 1/2	48-1	40.0	.11	−1/2 + 20	63-1	40.2	.22
			48-2	41.0	.09		63-2	40.9	.11
			48-3	41.6	.09		63-3	41.0	.13
			49-1	39.4	.04		64-1	42.0	.17
			49-2	38.9	.06		64-2	41.7	.22
			49-3	42.4	.09		64-3	39.7	.11
			50-1	40.8	.06		65-1	41.7	.13
			50-2	41.4	.06		65-2	42.7	.11
			50-3	40.7	.06		65-3	41.6	.09
			51-1	40.0	.06		66-1	42.6	.19
			51-2	40.6	.06		66-2	41.9	.11
			51-3	41.3	.02		66-3	40.2	.09
			52-1	40.3	.06		67-1	39.3	.22
			52-2	41.9	.06		67-2	39.9	.17
			52-3	38.8	.19		67-3	40.3	.13

Table 10 SINGLE LAYER OVEN-DRY VACUUM PRESSURE SOAK LINEAR EXPANSION PARALLEL TO ORIENTATION

Panel Type	Wood Species	Flake Screen Size	Face Layer Panel No.	Face Layer Density, Lb./Ft.³	Face Layer %	Core Layer Flake Screen Size	Core Layer Panel No.	Core Layer Density, Lb./Ft.³	Core Layer %
Oriented	Spruce/ Pine	+ 1/2	53-1	42.4	.04	−1/2 + 20	68-1	40.8	.13
			53-2	44.5	.06		68-2	41.5	.11
			53-3	39.5	.09		68-3	39.3	.09
			54-1	40.7	.11		69-1	43.0	.13
			54-2	41.4	.11		69-2	41.2	.13
			54-3	41.7	.09		69-3	43.1	.11
			55-1	41.9	.06		70-1	41.8	.11
			55-2	39.2	.09		70-2	39.2	.11
			55-3	40.1	.06		70-3	39.3	.13
			56-1	40.8	.13		71-1	41.8	.06
			56-2	37.7	.09		71-2	40.4	.04
			56-3	39.3	.09		71-3	40.3	.09
			57-1	42.7	.02		72-1	41.5	.09
			57-2	39.8	.06		72-2	40.2	.13
			57-3	39.3	.17		72-3	41.4	.04

#12425/87

Table 11 SINGLE LAYER OVEN-DRY VACUUM PRESSURE SOAK LINEAR EXPANSION PERPENDICULAR TO ORIENTATION

Panel Type	Wood Species	Flake Screen Size	Face Layer			Core Layer			
			Panel No.	Density, Lb./Ft.^{3}	%	Flake Screen Size	Panel No.	Density, Lb./Ft.^{3}	%
Oriented	Aspen	+3/4	43-4	40.6	.62	-3/4+20	58-4	40.3	1.08
			43-5	40.4	.65		58-5	41.9	.90
			43-6	40.4	.71		58-6	42.3	1.12
			44-4	40.7	.60		59-4	40.2	.89
			44-5	39.0	.65		59-5	39.2	.97
			44-6	39.5	.52		59-6	42.9	1.14
			45-4	40.0	.60		60-4	40.5	1.10
			45-5	41.2	.56		60-5	38.9	.89
			45-6	41.2	.67		60-6	40.3	.93
			46-4	40.5	.67		61-4	40.3	1.16
			46-5	41.1	.54		61-5	40.4	.95
			46-6	40.1	.69		61-6	41.5	1.02
			47-4	42.4	.78		62-4	41.8	1.10
			47-5	41.8	.80		62-5	42.7	.95
			47-6	41.2	.58		62-6	40.8	1.03
	Black Poplar	+1/2	48-4	39.8	.61	-1/2+20	63-4	39.7	.76
			48-5	40.8	.65		63-5	41.2	.73
			48-6	40.1	.58		63-6	40.9	.84
			49-4	39.0	.54		64-4	40.8	.73
			49-5	40.3	.63		64-5	40.5	.73
			49-6	43.3	.75		64-6	39.5	.84
			50-4	41.1	.62		65-4	40.6	.84
			50-5	40.4	.63		65-5	41.7	.93
			50-6	40.8	.80		65-6	40.8	.93
			51-4	39.9	.65		66-4	41.4	.80
			51-5	40.0	.65		66-5	42.8	.84
			51-6	39.4	.60		66-6	40.7	.78
			52-4	39.6	.73		67-4	40.7	.74
			52-5	40.3	.56		67-5	43.8	.75
			52-6	41.7	.67		67-6	43.6	.82

#124254/87

Table 12 SINGLE LAYER OVEN-DRY VACUUM PRESSURE SOAK LINEAR EXPANSION PERPENDICULAR TO ORIENTATION

Panel Type	Wood Species	Flake Screen Size	Face Layer			Core Layer			
			Panel No.	Density, Lb./Ft.^{3}	%	Flake Screen Size	Panel No.	Density, Lb./Ft.^{3}	%
Oriented	Spruce/ Pine	+ 1/2	53-4 53-5 53-6	38.7 41.3 39.1	.69 .75 .91	−1/2 + 20	68-4 68-5 68-6	39.7 40.8 40.1	1.14 1.17 1.16
			54-4 54-5 54-6	41.1 41.1 42.1	.91 .88 .95		69-4 69-5 69-6	41.7 40.6 38.3	1.06 1.04 1.10
			55-4 55-5 55-6	38.5 40.6 37.6	.82 .82 .88		70-4 70-5 70-6	41.4 38.6 38.1	1.10 1.06 1.10
			56-4 56-5 56-6	40.5 38.9 39.1	.80 .82 .88		71-4 71-5 71-6	41.1 37.9 38.6	1.12 1.10 1.06
			57-4 57-5 57-6	39.6 41.6 39.8	.86 .90 .86		72-4 72-5 72-6	39.2 40.6 39.9	1.12 1.10 1.08

412425U87

Table 13 SUMMARY OF PROPERTIES OF SINGLE LAYER PANELS

Panel Type	Wood Species	Flake Screen Size	Layer	Modulus of Elasticity Corrected to 41 Lb./Ft.^{3} Density			Oven-Dry Vacuum Pressure Soak Linear Expansion	
				Parallel, PSI × 10^3	Perpendicular PSI × 10^3	Orientation Index	Parallel, %	Perpendicular, %
Oriented	Aspen	+ 3/4	Face	1536	278	5.53	.10	.64
		− 3/4 + 20	Core	1167	210	5.56	.07	1.02
	Black Poplar	+ 1/2	Face	1406	229	6.14	.07	.64
		− 1/2 + 20	Core	1013	196	5.17	.15	.80
	Spruce/ Pine	+ 1/2	Face	1399	266	5.26	.08	.84
		− 1/2 + 20	Core	1019	208	4.90	.10	1.10

#12425m/87

Table 14 ESTIMATION OF APPARENT MODULUS OF ELASTICITY, FLEXURAL STIFFNESS, A.P.A. UNIFORM LOAD ROOF/FLOOR SPAN RATING, CROSS PANEL LINEAR EXPANSION OF 41 LB./FT. 7/16 INCH STRUCTURAL PANELS AT VARIOUS FACE/CORE RATIOS

Layer		Apparent MOE Parallel to Face Orientation At Various Face/Core Ratios PSI × 10^3					Flexural Stiffness EI Per 24-In. Width At Various Face/Core Ratios Lb.-In.^{2} × 10^3					A.P.A. Uniform Load Roof/Floor Span Rating At Various Face/Core Ratios Roof/Floor					Cross Panel Linear Expansion At Various Face/Core Ratios %				
Face	Core	80/20	70/30	60/40	50/50	40/60	80/20	70/30	60/40	50/50	40/60	80/20	70/30	60/40	50/50	40/60	80/20	70/30	60/40	50/50	40/60
Aspen	Aspen	1525	1500	1451	1370	1250	255	250	242	229	209	32/16	32/16	24/16	24/16	24/16	.51	.33	.23	.18	.14
	Black Poplar	1525	1500	1450	1369	1247	255	250	242	228	208	32/16	32/16	24/16	24/16	24/16	.57	.40	.31	.26	.22
	Spruce/Pine	1525	1500	1451	1370	1249	255	250	242	229	208	32/16	32/16	24/16	24/16	24/16	.56	.37	.27	.22	.18
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1525	1500	1451	1370	1249	255	250	242	229	208	32/16	32/16	24/16	24/16	24/16	.55	.37	.27	.22	.18
Black Poplar	Aspen	1396	1374	1329	1257	1148	233	229	222	210	192	24/16	24/16	24/16	24/16	24/16	.44	.29	.21	.16	.14
	Black Poplar	1396	1373	1329	1255	1145	233	229	222	209	191	24/16	24/16	24/16	24/16	24/16	.51	.36	.29	.24	.21
	Spruce/Pine	1396	1374	1329	1256	1147	233	229	222	210	191	24/16	24/16	24/16	24/16	24/16	.50	.33	.25	.20	.17
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1396	1374	1329	1256	1147	233	229	222	210	191	24/16	24/16	24/16	24/16	24/16	.48	.33	.25	.20	.17
Spruce/ Pine	Aspen	1389	1367	1323	1250	1142	232	228	221	209	191	24/16	24/16	24/16	24/16	24/16	.64	.40	.28	.21	.17
	Black Poplar	1389	1367	1322	1249	1139	232	228	221	208	190	24/16	24/16	24/16	24/16	24/16	.72	.48	.37	.29	.25
	Spruce/Pine	1389	1367	1323	1250	1142	232	228	221	209	191	24/16	24/16	24/16	24/16	24/16	.71	.46	.33	.25	.20
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1389	1367	1323	1250	1141	232	228	221	209	190	24/16	24/16	24/16	24/16	24/16	.69	.45	.33	.26	.21
1/3 Aspen 1/3 Black Poplar 1/3 Spruce/ Pine	Aspen	1437	1414	1368	1292	1180	240	236	228	216	197	24/16	24/16	24/16	24/16	24/16	.53	.34	.24	.19	.15
	Black Poplar	1437	1413	1367	1291	1177	240	236	228	215	196	24/16	24/16	24/16	24/16	24/16	.60	.42	.32	.26	.23
	Spruce/Pine	1437	1414	1368	1292	1179	240	236	228	216	197	24/16	24/16	24/16	24/16	24/16	.59	.39	.28	.22	.18
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1437	1413	1368	1292	1179	240	236	228	216	197	24/16	24/16	24/16	24/16	24/16	.58	.38	.29	.23	.19

#12425rv87

Table 15 ESTIMATION OF APPARENT MODULUS OF ELASTICITY, FLEXURAL STIFFNESS, A.P.A. UNIFORM LOAD ROOF/FLOOR SPAN RATING, CROSS PANEL LINEAR EXPANSION OF 41 LB./FT. 1/2 INCH STRUCTURAL PANELS AT VARIOUS FACE/CORE RATIOS

Layer		Apparent MOE Parallel to Face Orientation At Various Face/Core Ratios PSI x 10^3					Flexural Stiffness EI Per 24-In. Width At Various Face/Core Ratios Lb.-In.^{2} x 10^3					A.P.A. Uniform Load Roof/Floor Span Rating At Various Face/Core Ratios Roof/Floor					Cross Panel Linear Expansion At Various Face/Core Ratios %				
Face	Core	80/20	70/30	60/40	50/50	40/60	80/20	70/30	60/40	50/50	40/60	80/20	70/30	60/40	50/50	40/60	80/20	70/30	60/40	50/50	40/60
Aspen	Aspen	1525	1500	1451	1370	1250	381	375	363	343	312	32/16	32/16	32/16	32/16	32/16	.51	.33	.23	.18	.14
	Black Poplar	1525	1500	1450	1369	1247	381	375	363	342	312	32/16	32/16	32/16	32/16	32/16	.57	.40	.31	.26	.22
	Spruce/Pine	1525	1500	1451	1370	1249	381	375	363	343	312	32/16	32/16	32/16	32/16	32/16	.56	.37	.27	.22	.18
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1525	1500	1451	1370	1249	381	375	363	342	312	32/16	32/16	32/16	32/16	32/16	.55	.37	.27	.22	.18
Black Poplar	Aspen	1396	1374	1329	1257	1148	349	343	332	314	287	32/16	32/16	32/16	32/16	32/16	.44	.29	.21	.16	.13
	Black Poplar	1396	1373	1329	1255	1145	349	343	332	314	286	32/16	32/16	32/16	32/16	32/16	.51	.36	.29	.24	.21
	Spruce/Pine	1396	1374	1329	1256	1147	349	343	332	314	287	32/16	32/16	32/16	32/16	32/16	.50	.33	.25	.20	.17
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1396	1374	1329	1256	1147	349	343	332	314	287	32/16	32/16	32/16	32/16	32/16	.48	.33	.25	.20	.17
Spruce/ Pine	Aspen	1389	1367	1323	1250	1142	347	342	331	313	286	32/16	32/16	32/16	32/16	32/16	.64	.40	.28	.21	.17
	Black Poplar	1389	1367	1322	1249	1139	347	342	331	312	285	32/16	32/16	32/16	32/16	32/16	.72	.48	.37	.29	.25
	Spruce/Pine	1389	1367	1323	1250	1142	347	342	331	313	285	32/16	32/16	32/16	32/16	32/16	.71	.46	.33	.25	.20
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1389	1367	1323	1250	1141	347	342	331	312	295	32/16	32/16	32/16	32/16	32/16	.69	.45	.33	.26	.21
1/3 Aspen 1/3 Black Poplar 1/3 Spruce/ Pine	Aspen	1437	1414	1368	1292	1180	359	353	342	323	295	32/16	32/16	32/16	32/16	32/16	.53	.34	.24	.19	.15
	Black Poplar	1437	1413	1367	1291	1177	359	353	342	323	294	32/16	32/16	32/16	32/16	32/16	.60	.42	.32	.26	.23
	Spruce/Pine	1437	1414	1368	1292	1179	359	353	342	323	295	32/16	32/16	32/16	32/16	32/16	.59	.39	.28	.22	.18
	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1437	1413	1368	1292	1179	359	353	342	323	295	32/16	32/16	32/16	32/16	32/16	.58	.38	.29	.23	.19

#124250/87

Table 16 SUMMARY OF RANDOM SINGLE LAYER PANEL PROPERTIES

Wood Species	Flake	Density (2) Lb./Ft.^{3}	Modulus of Rupture				Modulus of Elasticity		Internal Bond	Oven Dry To Saturated Linear Expansion	
					After 2 Hr. Boil						
			Parallel (1) Psi	Perpen-dicular Psi	Parallel Psi	Perpen-dicular Psi	Parallel Psi x 10^3	Perpen-dicular Psi x 10^3	Psi	Parallel %	Perpen-dicular %
Aspen	Face	43.5	5200	5400	2990	2900	769	812	116	0.18	0.19
	Core	42.3	3200	3500	1670	1890	522	566	120	0.28	0.29
Black Poplar	Face	42.9	4600	4900	2570	2580	638	725	95	0.17	0.19
	Core	39.9	2600	3100	1460	1640	421	493	102	0.29	0.27
Spruce/ Pine	Face	42.3	4800	4900	2630	2710	711	740	104	0.24	0.23
	Core	40.5	3000	3300	1570	1700	493	522	132	0.32	0.31

(1) Testing Direction

(2) Density based on separate 3-inch × 3-inch samples cut from within panel.

#12787e/87

Table 17 SCREEN ANALYSES AND FLAKE GEOMETRY OF RING-CUT PULP CHIPS

Wood Species		Lodgepole Pine	Douglas-Fir	
Chip Type		7/8-Inch Pulp	7/8-Inch Pulp	5/8-Inch Pulp
Layer		Face & Core	Face & Core	Face & Core
Flake Length, in.		.72	.70	.60
Flake Width, in.		.14	.14	.16
Flake Thickness, in.		.012	.016	.015
Length/Width Ratio		5.1	5.0	3.8
Slenderness Ratio		60.0	43.8	40.0
U.S. Standard Sieve Screen Percent By Weight	+6	25	36	33
	−6 + 10	18	21	21
	−10 + 20	36	33	35
	−20	21	10	11

#127971/87

Table 18 SUMMARY OF PROPERTIES OF SINGLE LAYER PULP CHIP PANELS

Panel Type	Chip Type	Layer	Modulus of Elasticity Corrected to 41 Lb./Ft.^{3} Density			Oven-Dry Vacuum Pressure Soak Linear Expansion	
			Parallel, PSI × 10^3	Perpendicular PSI × 10^3	Orientation Index	Parallel, %	Perpendicular, %
Oriented	7/8-Inch Lodgepole Pine	Face	1056	235	4.5	.10	.78
		Core	1051	204	5.2	.09	1.08
	7/8-Inch Douglas-Fir	Face	956	274	3.5	.12	.90
		Core	807	226	3.6	.16	1.32
	5/8-Inch Douglas-Fir	Face	918	257	3.6	.12	.83
		Core	834	228	3.7	.14	1.17

#12797g/87

Table 19 ESTIMATION OF APPARENT MODULUS OF ELASTICITY, FLEXURAL STIFFNESS, A.P.A. UNIFORM LOAD ROOF/FLOOR SPAN RATING, CROSS PANEL LINEAR EXPANSION OF 41 LB./FT. 7/16 INCH MAXI-CHIP/PULP CHIP STRUCTURAL PANELS AT 50/50 FACE/CORE RATIO

Layer		Apparent MOE Parallel to Face Orientation	Flexural Stiffness EI Per 24-In. Width	A.P.A. Uniform Load Roof/Floor Span Rating	Cross Panel Linear Expansion
Maxi-Chip Face	Pulp-Chip Core	Psi x 10^3	Lb.-In.^{2} x 10^3	Roof/Floor	%
Aspen	7/8-inch Lodgepole Pine	1370	229	24/16	.21
	7/8-inch Douglas-Fir	1372	229	24/16	.28
	5/8-inch Douglas Fir	1373	229	24/16	.27
Black Poplar	7/8-inch Lodgepole Pine	1256	210	24/16	.19
	7/8-inch Lodgepole Pine	1259	210	24/16	.27
	5/8-inch Douglas Fir	1259	210	24/16	.25
Spruce/Pine	7/8-inch Lodgepole Pine	1250	209	24/16	.24
	7/8-inch Douglas-Fir	1252	209	24/16	.33
	5/8-inch Douglas Fir	1253	209	24/16	.31

#127971v87

Table 20 PHYSICAL AND DIMENSION STABILITY PROPERTIES OF 7/16-INCH FORCELINE STRUCTURAL PANELS WITH 50/50 FACE/CORE RATIOS

Layer		Panel No.	Static Bending										Internal Bond			Linear Expansion			
			Parallel					Perpendicular								Parallel		Perpendicular	
				Modulus of Rupture		Modulus of Elasticity			Modulus of Rupture		Modulus of Elasticity								
Face Flake Type	Core Flake Type		Density Lb/Ft³	Psi	Psi Corr. To 38 Lb/Ft³	Psi x 10³	Psi x 10³ Corr. To 38 Lb/Ft³	Density Lb/Ft³	Psi	Psi Corr. To 38 Lb/Ft³	Psi x 10³	Psi x 10³ Corr. To 38 Lb/Ft³	Density Lb/Ft³	Psi	Psi Corr. To 38 Lb/Ft³	Density Lb/Ft³	%	Density Lb/Ft³	%
Aspen		79-1	37.9	4840	4860	1080	1083							83			.17		
		79-2	35.3	4280	4820	940	1034							82			.13		
		79-3	41.1	7560	6940	1380	1271							72					
		79-4						34.3	2190	2634	301	347		75					.39
		79-5						39.5	2970	2790	366	347		74					.39
		79-6						38.9	2700	2592	341	330		68					
70% Aspen, 30% Black Poplar		77-1	40.3	6310	5850	1240	1160							61			.22		
		77-2	37.6	5800	5880	1120	1134							53			.15		
		77-3	39.1	7630	7410	1210	1248							60					
		77-4						37.7	2770	2806	311			54					.26
		77-5						38.4	2900	2852	349			61					.19
		77-6						39.7	2900	2696	349			69					
1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine		73-1	41.7	6650	5910	1400	1270							73			.15		
		73-2	38.9	5910	5730	1150	1118							76			.15		
		73-3	37.9	5670	5690	1130	1134							71					
		73-4						35.3	1760	2084	234	268		83					.36
		73-5						37.3	2400	2484	280	288		93					.22
		73-6						37.7	2620	2656	325	329		70					
Spruce/Pine		75-1	41.5	6810	6110	1180	1060							70			.13		
		75-2	37.3	5470	5610	980	1004							74			.17		
		75-3	37.3	4980	5064	1040	1064							54					
		75-4						35.7	2060	2336	287	316		72					.34
		75-5						39.1	2790	2658	378	364		77					.39
		75-6						38.8	3210	3114	371	361		85					

#12797U87

Table 21 **SUMMARY OF PROPERTIES OF 7/16-INCH, 38 LB./FT.^{3} THREE LAYER FORCELINE STRUCTURAL PANELS WITH 50/50 FACE/CORE RATIOS**

Layer				Modulus of Elasticity			Oven Dry Vacuum Pressure Soak Linear Expansion	
Face	Core	Parallel Psi	Perpen-dicular Psi	Parallel Psi x 10^3	Perpen-dicular Psi x 10^3	Internal Bond (1) Psi	Parallel %	Perpen-dicular %
Aspen	Aspen	5540	2670	1129	336	76	.15	.39
70% Aspen 30% Black Poplar	70% Aspen 30% Black Poplar	6380	2780	1181	336	60	.19	.22
1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	1/3 Aspen 1/3 Black Poplar 1/3 Spruce/Pine	5780	2410	1174	280	78	.15	.29
Spruce/Pine	Spruce/Pine	5590	2700	1043	345	72	.15	.36

#12797/87

(1) Not at 38 Lb./Ft.^{3}. Density not measured on IB Samples.

Figure 1 MANUFACTURING CONDITIONS FOR ORIENTED SINGLE-LAYER PANELS

Panel Type: Oriented Single-Layer Face and Core Panels

Target Panel Density: 40 - 42 lb./Ft.^{3}

Panel Dimensions:
30 in. × 26 in. × 7/16-in. untrimmed
26 in. × 22 in. × 7/16-in. trimmed

Wood Species:
1. Aspen
2. Black Poplar
3. Spruce/Pine

Screening:
–20 Mesh Fines Removed
1. Aspen – 2%
2. Black Poplar – 4%
3. Spruce/Pine – 2.5%

	Face Flakes	Core Flakes
Aspen	+ 3/4	– 3/4 + 20
Black Poplar	+ 1/2	– 1/2 + 20
Spruce/Pine	+ 1/2	– 1/2 + 20

Blending:
Resin Content: 5% O.D.W. (5 parts resin solids to 100 parts dry wood)
Resin Type: Borden W6-12 phenol formaldehyde at 50% resin solids
Resin Flow Rate: 375 gm./min.
Resin Spray Gun: Devilbiss
Resin Temperature: 30° Centigrade
Wax Content: 1% O.D.W. (1 part wax solids to 100 parts dry wood)
Wax Type: Borden EW403 wax emulsion at 47% solids
Wax Flow Rate: 362 gm./min.
Wax Spray Gun: Universal Spraying Systems
Wax Temperature: 25° Centigrade
Blender Tumbling Time: 2.5 min.
Resin & Wax Applied Through Separate Spray Guns and at the Same Time
Blending Batch Size: 10% of blender volume (3 Ft.^{3})
Resin and Wax Atomized Air Pressure: 60 PSI
Bulk Density: Lb./Ft.^{3}

	Unblended		Blended	
	Face	Core	Face	Core
Aspen	4.6	4.8	5.0	6.0
Black Poplar	3.2	4.0	3.8	4.8
Spruce/Pine	4.4	4.8	4.8	5.1

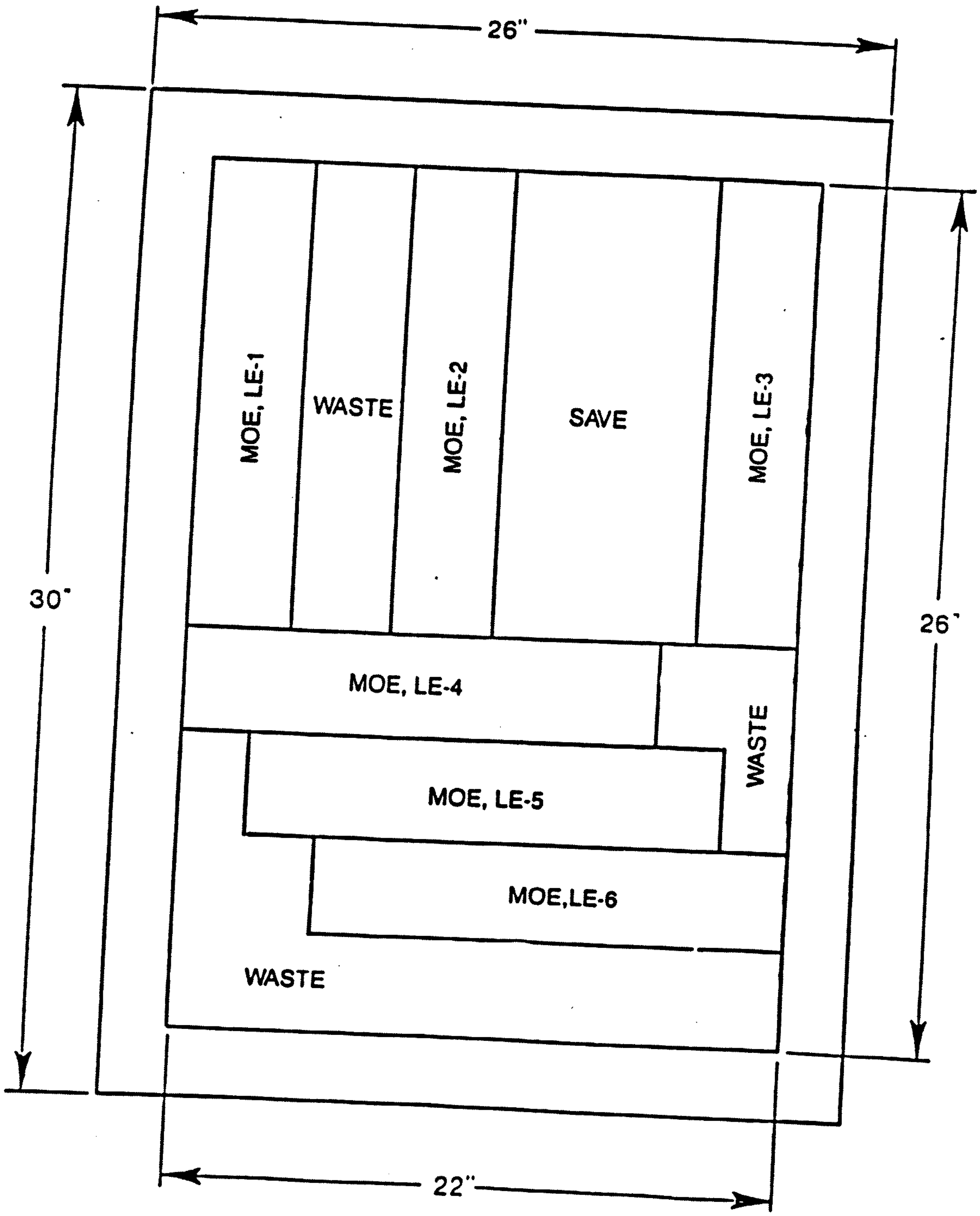
Forming:
Oriented Face: FORCELINE III (In-Line)
Oriented Core: FORCELINE II (Cross-Machine)
FORCELINE Panel Forming Rate: 5 to 7 Lb./Min./Ft.^{2}
Mat Moisture Content: 8.4 to 10.3%, O.D.W.

Pressing:
Press Temperature: 400° Farenheit
Daylight Close Time: 5 to 10 Seconds
Close Time to Stops: 30 to 44 Seconds
Closing Pressure: 470 to 490 PSI
Holding Pressure: 90 to 100 PSI
Cook Cycle: 5 Minutes
Decompress Time: 30 Seconds

Panel Replication:
5 Aspen Face, 5 Aspen Core, 5 Black Poplar Face,
5 Black Poplar Core, 5 Spruce/Pine Face, 5 Spruce/Pine Core

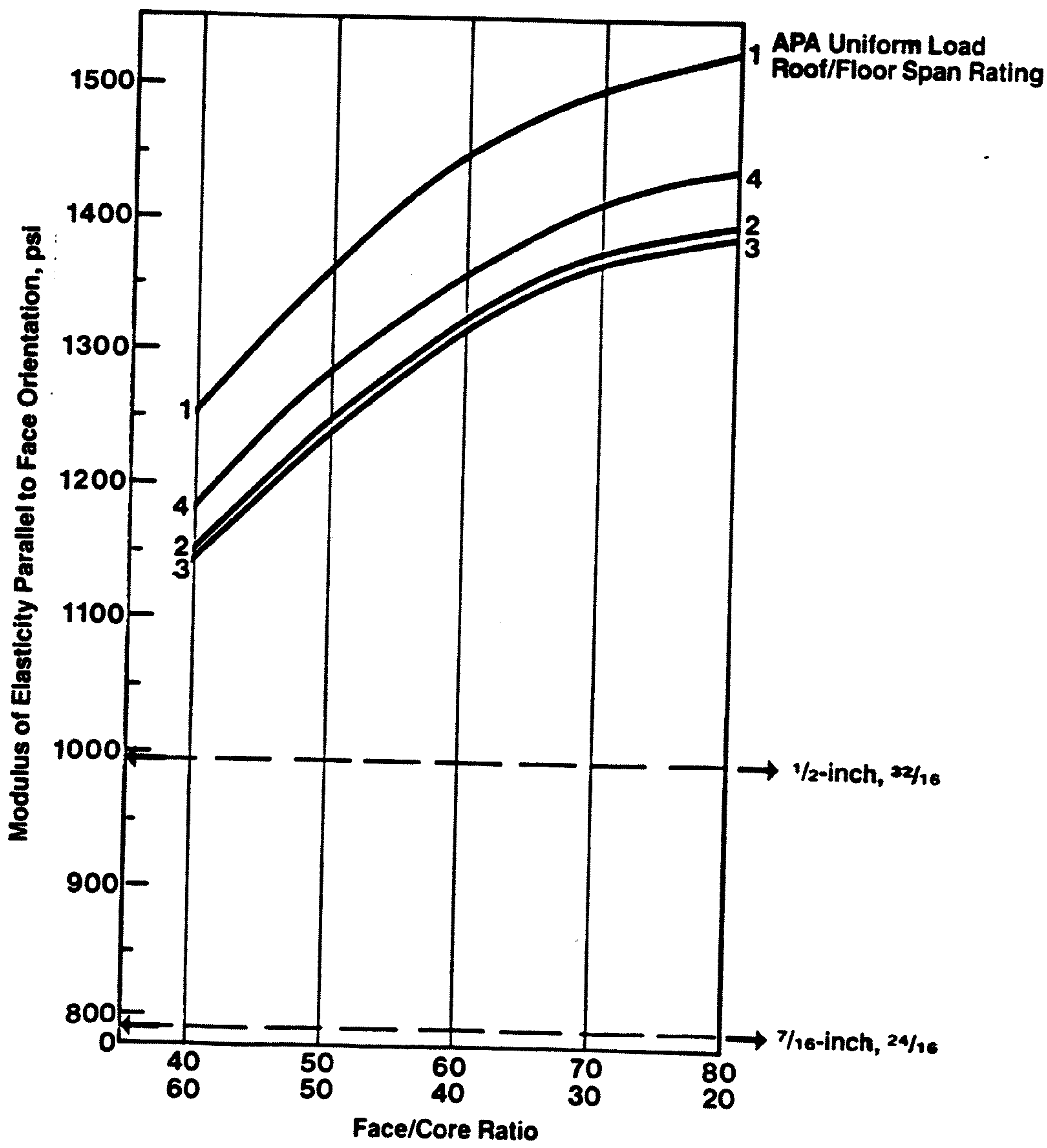
Panel Testing:
Density
Stress Wave Timer Orientation Index
Modulus of Elasticity: A.S.T.M D1037
Oven-Dry Vacuum Pressure Soak Linear Expansion (A.P.A. #1)

Figure 2: PANEL CUT-UP PATTERN OF SINGLE LAYER PANELS



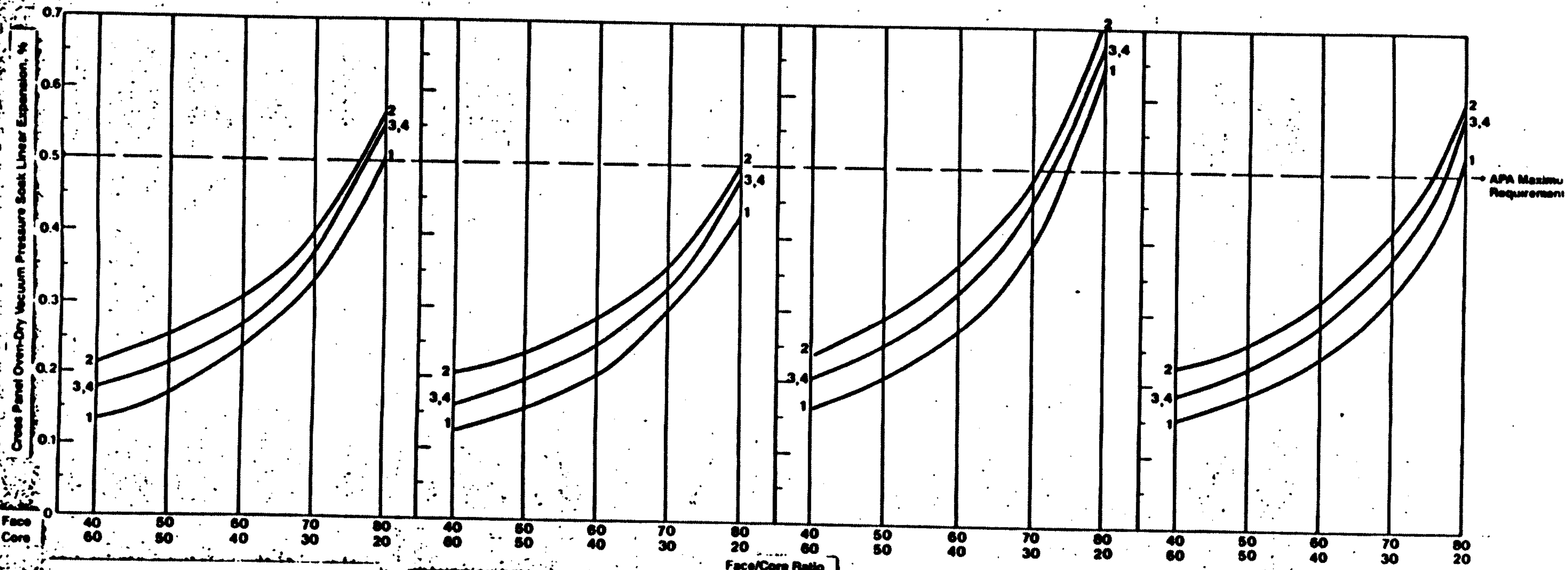
ROUGH PANEL DIMENSIONS: 30 IN. × 26 IN.
TRIMMED PANEL DIMENSIONS: 26 IN. × 22 IN.
MODULUS OF ELASTICITY: 12 IN. × 3 IN.
LINEAR EXPANSION: 12 IN. × 3 IN.

FIGURE 3
APPARENT MODULUS OF ELASTICITY OF 41 LB./FT.^{3} FORCELINE STRUCTURAL PANELS



	Face	Core
1.	Aspen	Any Species
2.	Black Poplar	Any Species
3.	Spruce/Pine	Any Species
4.	⅓ Aspen ⅓ Black Poplar ⅓ Spruce/Pine	Any Species

FIGURE 4
ESTIMATED CROSS PANEL LINEAR EXPANSION OF 41 LB./FT.^{3} FORCELINE STRUCTURAL PANELS



No.	Face	Core
1.	Aspen	Aspen
2.	Aspen	Black Poplar
3.	Aspen	Spruce/Pine
4.	Aspen	Mix*

No.	Face	Core
1.	Black Poplar	Aspen
2.	Black Poplar	Black Poplar
3.	Black Poplar	Spruce/Pine
4.	Black Poplar	Mix*

No.	Face	Core
1.	Spruce/Pine	Aspen
2.	Spruce/Pine	Black Poplar
3.	Spruce/Pine	Spruce/Pine
4.	Spruce/Pine	Mix*

No.	Face	Core
1.	Mix*	Aspen
2.	Mix*	Black Poplar
3.	Mix*	Spruce/Pine
4.	Mix*	Mix*

* Mix = 1/3 Aspen, 1/3 Black Poplar, 1/3 Spruce/Pine

Figure 5 MANUFACTURING CONDITIONS FOR ORIENTED THREE-LAYER PANELS

Panel Type: Oriented Three-Layer Panel

Target Panel Density: 37 - 39 lb./Ft.^{3}

Panel Dimensions:
30 in. × 26 in. × 7/16-in. untrimmed
25 in. × 22 in. × 7/16-in. trimmed

Wood Species: For Each Panel:
1. Aspen
2. Admixture 70% Aspen, 30% Black Poplar
3. Admixture 1/3 Aspen, 1/3 Black Poplar, 1/3 Spruce/Pine
4. Spruce/Pine

Blending:

Resin Content:	5% O.D.W. (5 parts resin solids to 100 parts dry wood)
Resin Type:	Borden W6-12 phenol formaldehyde at 50% resin solids
Resin Flow Rate:	375 gm./min.
Resin Spray Gun:	Devilbiss
Resin Temperature:	30° Centigrade
Wax Content:	1% O.D.W. (1 part wax solids to 100 parts dry wood)
Wax Type:	Borden EW403 wax emulsion at 47% solids
Wax Flow Rate:	362 gm./min.
Wax Spray Gun:	Universal Spraying Systems
Wax Temperature:	25° Centigrade
Blender Tumbling Time:	2.5 min.

Resin & Wax Applied Through Separate Spray Guns and at the Same Time
Blending Batch Size: 10% of blender volume (3 Ft.^{3})
Resin and Wax Atomized Air Pressure: 60 PSI
Bulk Density: Lb./Ft.^{3}

	Blended	
	Face	Core
Aspen	5.0	6.0
Admixture 70% Aspen, 30% Black Poplar	4.5	
Admixture 1/3 Aspen, 1/3 Black Poplar, 1/3 Spruce/Pine	4.5	5.3
Spruce/Pine	4.8	5.1

Forming:
Oriented Face: FORCELINE III (In-Line)
Oriented Core: FORCELINE II (Cross-Machine)
FORCELINE Panel Forming Rate: 5 to 7 Lb./Min./Ft.^{2}
Mat Moisture Content: 9.1 to 10.2%, O.D.W.

Pressing:

Press Temperature:	400° Farenheit
Daylight Close Time:	5 to 10 Seconds
Close Time to Stops:	35 to 45 Seconds
Closing Pressure:	430 to 450 PSI
Holding Pressure:	80 to 100 PSI
Cook Cycle:	5 Minutes
Decompress Time:	30 Seconds

Panel Replication: 2 of each panel type, total of eight

Panel Testing:
Density
Modulus of Rupture: A.S.T.M. D1037
Modulus of Elasticity: A.S.T.M. D1037
Oven-Dry Vacuum Pressure Soak Linear Expansion (A.P.A. #1)
Internal Bond: A.S.T.M. D1037
Bond Durability: CAN 3-0437.1M
(MOR after 2 hour boil)

Figure 6 MODULUS OF RUPTURE OF 7/16-INCH, 38 LB./FT.³ FORCELINE THREE-LAYER STRUCTURAL PANELS

No.	Face and Core, 50/50 Face/Core Ratio
1	Aspen
2	70% Aspen, 30% Black Poplar
3	1/3 Aspen, 1/3 Black Poplar, 1/3 Spruce/Pine
4	Spruce/Pine

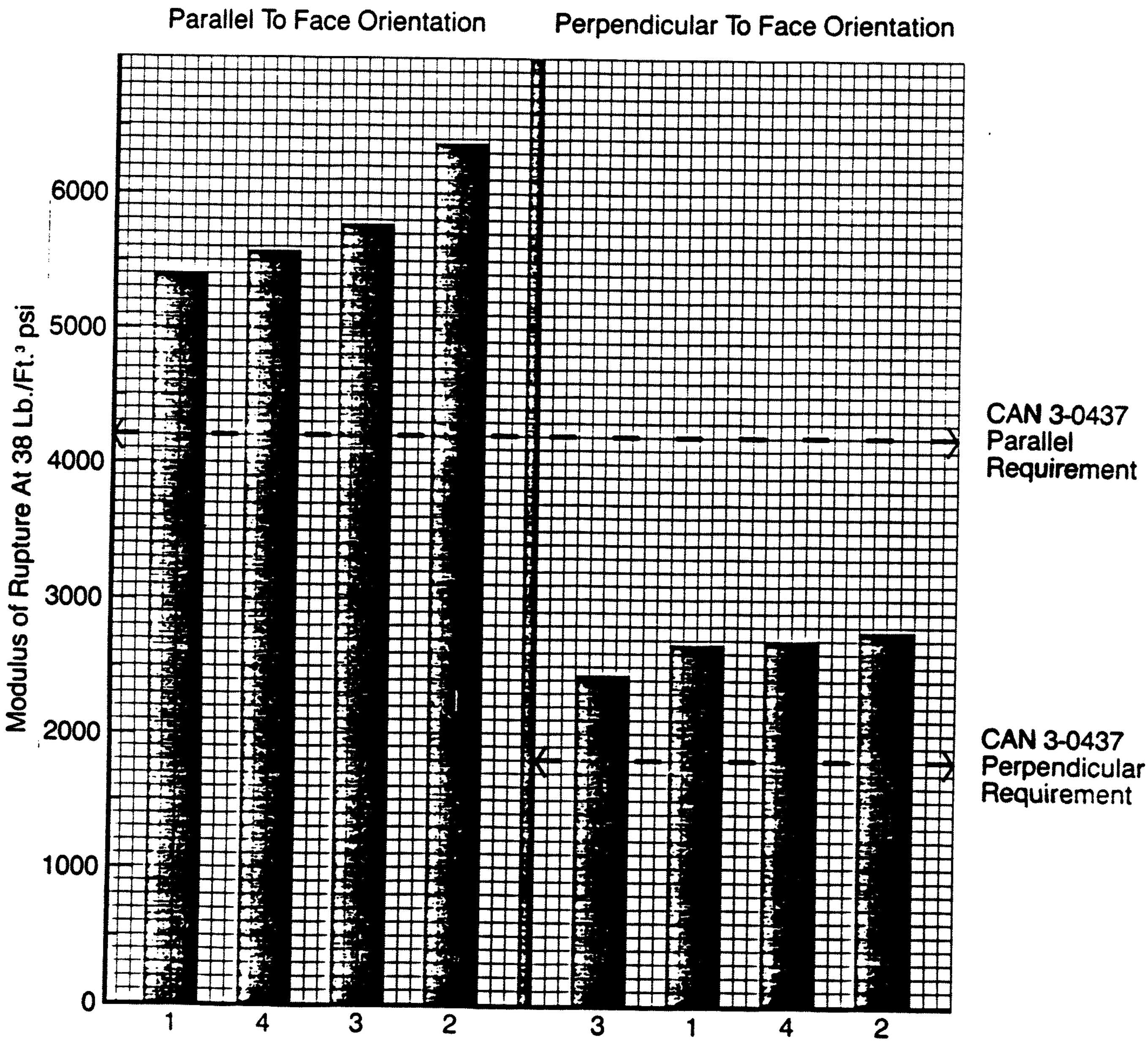


Figure 7 MODULUS OF ELASTICITY OF 7/16-INCH, 38 LB./FT.^{3} FORCELINE THREE-LAYER STRUCTURAL PANELS

No.	Face and Core, 50/50 Face/Core Ratio
1	Aspen
2	70% Aspen, 30% Black Poplar
3	1/3 Aspen, 1/3 Black Poplar, 1/3 Spruce/Pine
4	Spruce/Pine

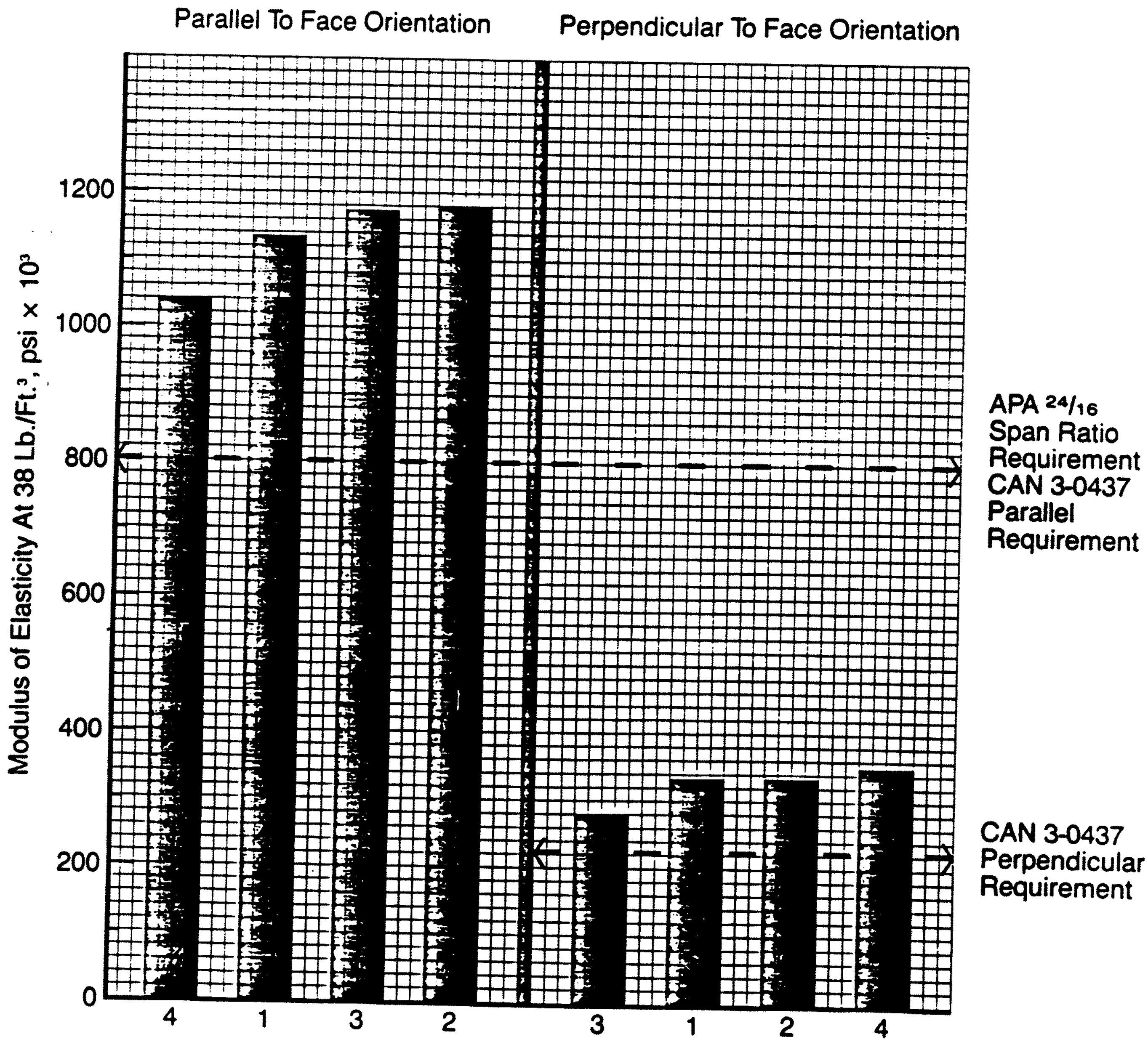
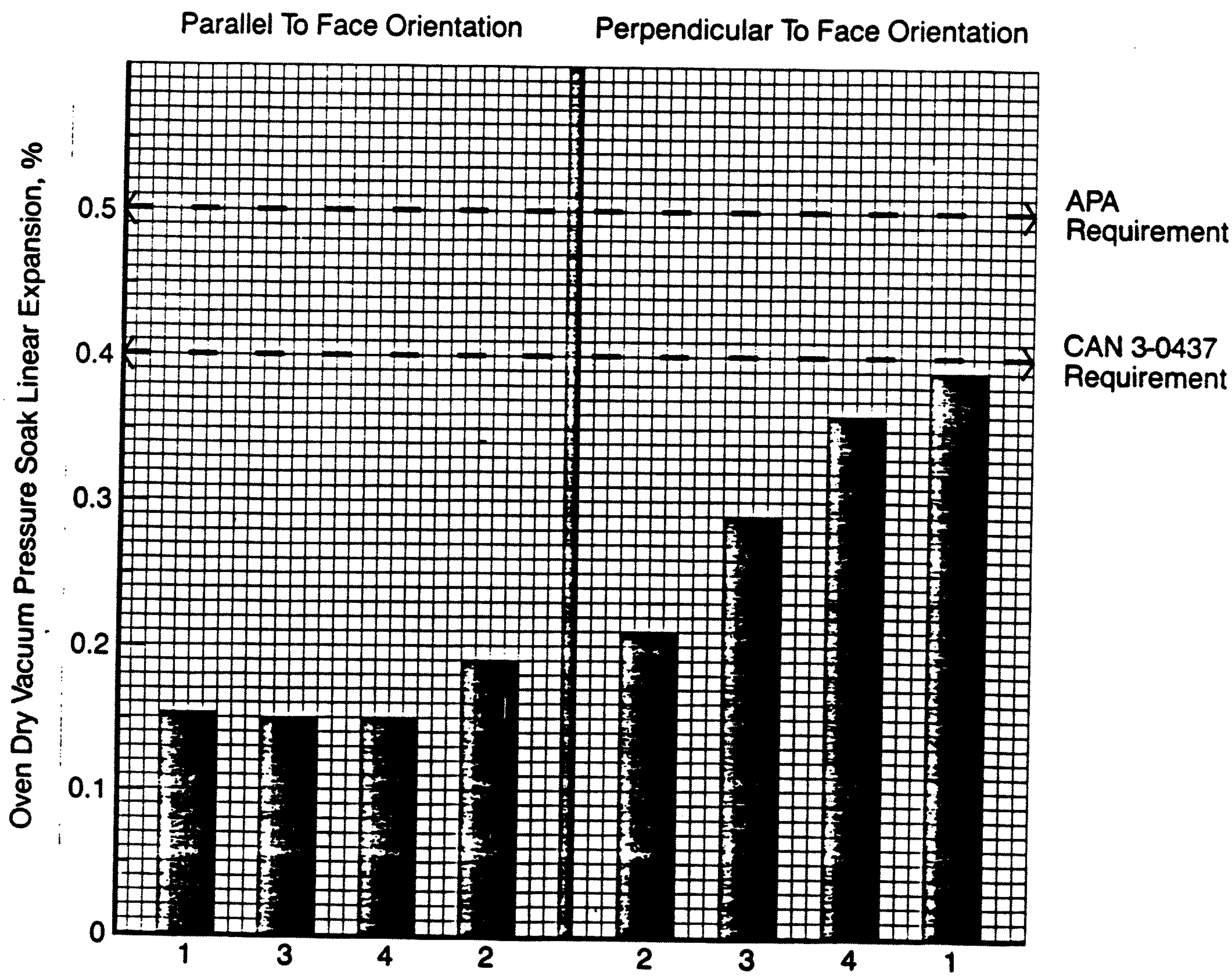
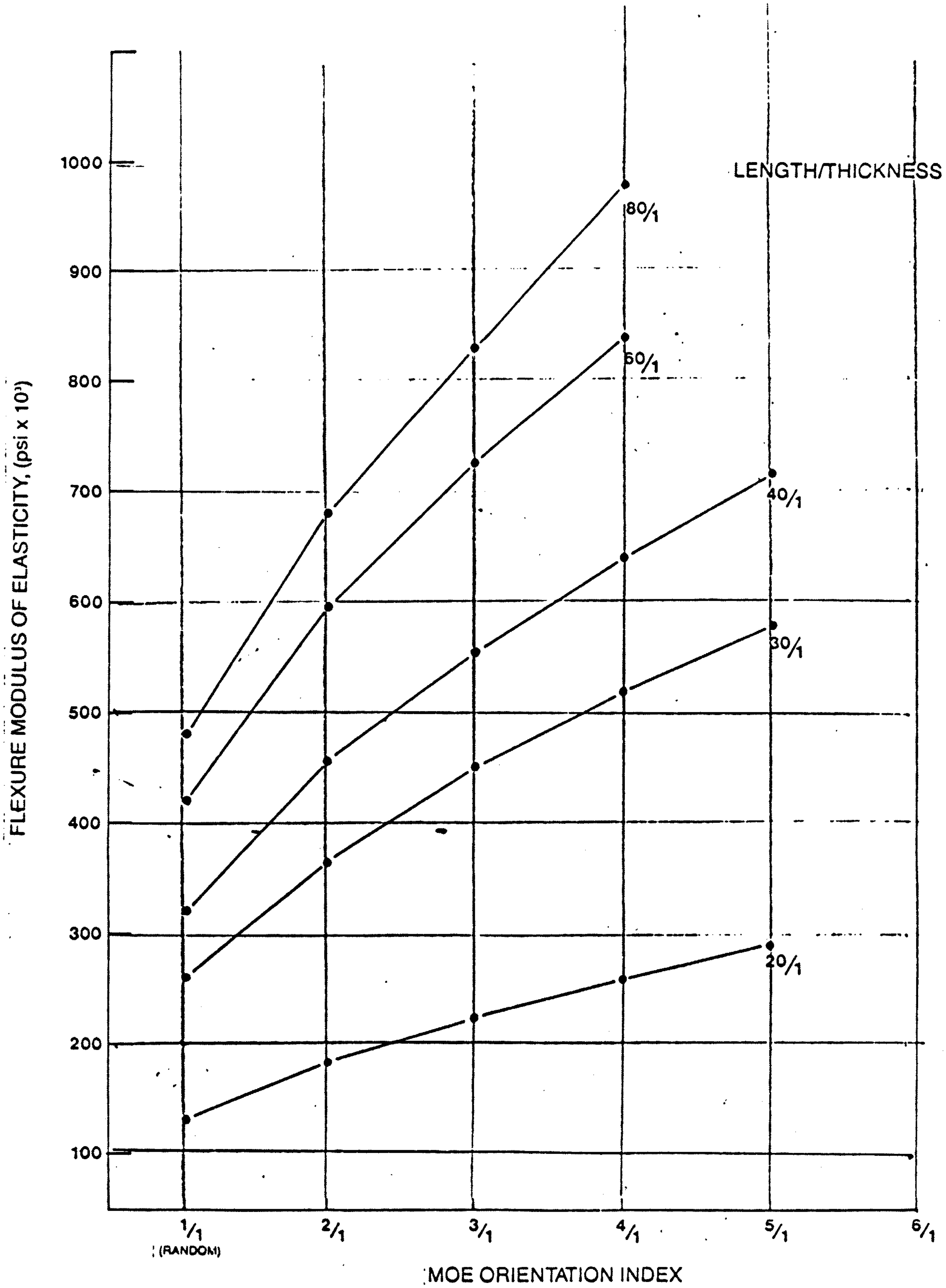


Figure 8 OVEN DRY VACUUM PRESSURE SOAK LINEAR EXPANSION OF 7/16-INCH, 38 LB./FT.^{3} FORCELINE THREE-LAYER STRUCTURAL PANELS

No.	Face and Core, 50/50 Face/Core Ratio
1	Aspen
2	70% Aspen, 30% Black Poplar
3	1/3 Aspen, 1/3 Black Poplar, 1/3 Spruce/Pine
4	Spruce/Pine



EFFECT OF FLAKE LENGTH/THICKNESS RATIO & ORIENTATION ON MOE



M-K FOREST PRODUCTS