COMPARISON OF SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF RED MAPLE (*ACER RUBRUM* L.) AND ASPEN (*POPULUS GRANDIDENTATA* MICHX.) FLAKEBOARD[1]

Kenneth M. Kuklewski

Research Assistant
School of Forest Resources, The Pennsylvania State University
University Park, PA 16802

Paul R. Blankenhorn

Professor of Wood Technology
School of Forest Resources, The Pennsylvania State University
University Park, PA 16802

and

Lester E. Rishel

Research Assistant
School of Forest Resources, The Pennsylvania State University
University Park, PA 16802

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ABSTRACT

Wood from red maple (*Acer rubrum* L.) and aspen (*Populus grandidentata* Michx.) was processed and fabricated into flakeboards with a target density of 50 lb/ft^3. The data collected served as a basis for evaluating red maple as a potential raw material for flakeboard. Within the study parameters, random and aligned flake orientations were compared for both species. Moisture content, density, and flake alignment measurements revealed within- and between-board uniformity. Red maple flakeboards equaled or exceeded the performance of aspen flakeboards in static bending, internal bond, and nail withdrawal tests. In addition, red maple flakeboards containing randomly oriented flakes required higher loads to failure in nail withdrawal and internal bond tests compared to mechanically aligned flakes. Dimensional stability data of the flakeboards were obtained by measuring thickness swell, water absorption, and linear expansion. For both the random and aligned boards, the measured values indicated no substantial difference between the aspen and red maple specimens. In addition, mechanical alignment of the flakes improved some of the properties of the flakeboards compared to the randomly oriented flakeboards.

Keywords: Red maple, aspen, flakeboard.

INTRODUCTION

The particleboard industry has had substantial growth throughout its relatively brief history because particleboard is an efficient means of using small diameter trees and wood processing residues. By consolidating wood particles (i.e., planer shavings, sawdust, mill residues, etc.) into various panel sizes, numerous types of particleboard products have been successfully produced and marketed.

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Research and development studies are in progress to produce a stronger and more stable composite product. Early researchers (Brumbaugh 1960; Post 1958, 1961; Turner 1954) established some of the relationships between particle geometry and strength characteristics of particleboard. Long flakes with a length/width ratio of approximately two have been shown to have superior properties (Post 1958; Geimer 1976; Shuler and Kelly 1976). The optimum width and thickness of particles have also been reported (Brumbaugh 1960; Post 1961; Klauditz et al. 1960). Early work in flake geometry was accompanied by developments in particle orientation and it appeared that a strength advantage was gained when long, narrow flakes were aligned parallel to each other within a panel (Elmendorf 1949). Recently, research has been reported on: 1) resin effects on board properties (Hse et al. 1975; Lehmann and Hefty 1974; Udvardy 1979); 2) layer characteristics on the properties of three-layer particleboards (Brown and Bean 1974; Countryman 1975; Geimer et al. 1975; Lehmann and Geimer 1974; Price and Lehmann 1978); 3) species effects on board properties (Shuler and Kelly 1976; Lehmann and Geimer 1974; Geimer et al. 1974; Heebink and Lehmann 1977; Hse 1978; Hunt et al. 1978; Price and Geimer 1978a; 4) characteristics of aligned particle versus random particle distribution in particleboard (Geimer 1976; Geimer et al. 1974; Price and Geimer 1978a, b); and 5) methods for producing particles (Price and Lehmann 1978; Maloney 1977; Price 1977; Sybertz and Sander 1972; Waller 1979). These research results combined with optimizing the engineering properties of the flakeboards (Lehmann 1974; May 1974; McNatt 1973) have been instrumental in the development of a structural flakeboard industry.

Previous flakeboard research centered on the use of softwoods as furnish because of the properties of softwoods and the desire to efficiently utilize readily available softwood residues. Limited research has been reported on the use of hardwoods for manufacturing acceptable flakeboard products. Availability of acceptable softwood fiber for flakeboard manufacture varies with location in the United States, and certain states have large volumes of hardwoods compared to the total volume of softwoods. Hence, a hardwood species available in large volume and possessing physical and mechanical properties similar to many softwood species may be a viable candidate for the flakeboard industry. Aspen (*Populus grandidentata* Michx.) is a hardwood species that meets these requirements and has been used to produce structural flakeboard. Another species that may meet the basic requirements is red maple (*Acer rubrum* L.). It has physical and mechanical properties similar to many softwood species and is readily available in certain locations.

The purpose of this study was to investigate and report on selected properties of flakeboards fabricated in random and mechanically aligned orientations using red maple flakes. Aspen random and mechanically aligned flakeboards were also fabricated under similar conditions, and the properties of the red maple flakeboards were compared to the properties of the aspen flakeboards. This study was designed to examine the relationships within and between both species in random and aligned flakeboards.

MATERIALS AND METHODS

Particle parameters

Three pole-size trees of red maple and aspen were randomly selected as an indication of the trees available from a typical site in central Pennsylvania. Each tree was cut into 4-ft bolts, manually debarked, and quartered along the length of the bolt. The selected trees exhibited uniform stem taper and lacked the presence of decay. All bolts were then bundled according to species and transported to a Pallmann Pulverizer facility in Clifton, New Jersey, for conversion to flakes. The bolts were chipped at approximately 80% moisture content (oven-dry basis) using a Pallmann drum chipper. Each species of chips was then flaked with a laboratory-scale flaker. Flaking parameters were adjusted to maintain a uniform thickness of 0.02 inches, and a target length-to-width ratio (aspect ratio) of two to one. Particle size selection was based on reports that optimum particle size was an important parameter influencing the degree of alignment in oriented flakeboards (Post 1961; Geimer 1976; Shuler and Kelly 1976).

Flakes were dried in a forced-air oven for 24 hours at a dry bulb temperature of 160 F with no noticeable curling of the flakes. Moisture content (oven-dry basis) of the particles after drying was approximately 8%. The flakes were screened and all material passing a one-inch mesh and retained on a half-inch mesh was used to fabricate the flakeboards. The volume of flakes retained was approximately 50% of the initial unscreened material. All retained material was conditioned to an equilibrium moisture content (EMC) of 6% in an environmental chamber prior to fabrication. Powdered phenolic resin was chosen because it is used in the processing of aspen waferboard. Flakeboards were fabricated with the following design parameters:

1) target density—50 lb/ft^3,
2) adhesive—phenolic powder,
3) resin content (OD basis, by weight)—6%,
4) additives—none,
5) board dimensions (before trim)—0.5 in. × 17.0 in. × 19.0 in.,
6) board mass (OD basis)—2.08 lb,
7) press temperature—410 F, and
8) press cycle—30 sec press closure;
   5 min pressed to stops; and
   30 sec pressure release.

The experiment was designed to investigate the use of red maple as a furnish compared to aspen and as such limited other parameters by reducing the number of board processing variables such as type of adhesive, additives, and so forth. Additional details on board fabrication techniques and the mechanical flake alignment device used in this study can be found in Kuklewski (1982).

The flakes were mixed with the desired quantity of resin in a polyethylene bag. Uniform adhesive distribution on the flakes presented a problem, but frequent shaking of the contents of the bag prior to the forming process helped to improve resin distribution on the flakes. Care was also taken to minimize agitation of the mat before it was placed in the press.

A laboratory-scale hydraulically operated press was used to form the panels. The press incorporated the use of electrically heated platens to maintain a uniform temperature (±5 F) throughout the pressing cycle. Pressing temperature (410 F) and in-press duration (5 min) followed the adhesive manufacturers recommendations. The platens were 24 in. × 24 in. and the board dimensions were 17 in. × 19 in. before trimming. This helped to minimize any edge temperature effects associated with the platen size. The edges of each board were trimmed and dis-

TABLE 1. *Summary of moisture content and density data for random and aligned flakeboards.*

Specimen	Moisture content (%)	Range	Density (lb/ft³)	Range
		Random[1]		
Aspen	3.1	2.8–3.5	52.4	49.9–53.1
Maple	3.5	3.4–3.5	53.7	52.4–54.9
		Aligned[2]		
Aspen	3.1	2.9–3.3	50.6	47.4–53.1
Maple	3.4	3.3–3.6	51.2	48.7–53.7

[1] Values are based on an average of 15 measurements for moisture content and 45 measurements for density.
[2] Values are based on an average of 30 measurements for moisture content and 90 measurements for density.

carded to form a finished dimension of 15 in. by 17 in. All flakeboards after fabrication were stored in a 6% EMC conditioning chamber prior to testing. For each species, ten aligned and five randomly oriented flakeboards were fabricated.

Testing methods

The tests and measurements performed on the panels were: density, moisture content, flake alignment, static bending, internal bond, nail withdrawal, linear expansion, thickness swell, and water absorption. Each test board was machined to provide a minimum of two specimens per physical and mechanical test procedure (Kuklewski 1982). Specimens were obtained from different sections of the boards to account for any density fluctuations. Test specimens were machined to approximately standard test dimensions and stored in 6% EMC conditions prior to testing.

Moisture content and density values were calculated from sections obtained from static bending specimens, as well as from other test specimens in the flakeboard. Three density specimens (oven-dry weight [OD] divided by volume displacement in water) were taken from each section representing the center, middle, and edge portions of the panels, and these specimens were used in calculating density variations within individual boards. Moisture content data (OD basis) was collected from three separate sections in each board.

Flake angle values for the mechanically oriented boards were determined by averaging one hundred individual flake angles on the surfaces of each board. Angles were measured with respect to a reference line parallel to the flake alignment direction in the board. Angles of the underlying surface flakes were measured at fifty randomly selected intersections on the grid and details are given in Kuklewski (1982). Each board face received half of the one hundred measurements. This method did not attempt to characterize the flake angle distribution through the board thickness.

Static bending, internal bond, and nail withdrawal tests were performed according to methods outlined in the American Society for Testing and Materials (ASTM) Standard D 1037-78. All testing was accomplished using a Tinius Olsen Universal Testing Machine with an integrated load-deflection recorder. The static bending specimens were tested at approximately 3% moisture content using a crosshead speed of 0.25 in./min. Specimens prepared for internal bond tests were bonded to aluminum loading blocks with an epoxy adhesive, and the tests were

TABLE 2. *Summary of flake angle data in degrees[1] and percent alignment[2] for aligned aspen and maple flakeboards.*

Specimen[3]	Flake angle	Percent aligned	Flake angle	Percent aligned
	Aspen		*Maple*	
1a	25.56	43.2	28.50	36.7
1b	27.44	39.0	33.02	26.6
2a	24.40	45.8	27.90	38.0
2b	24.88	44.7	28.24	37.2
3a	25.78	42.7	28.76	36.1
3b	27.70	38.4	33.12	26.4
4a	25.72	42.8	31.30	30.4
4b	26.62	40.8	31.80	29.3
5a	26.59	40.9	30.48	32.3
5b	32.00	28.9	33.40	25.8
6a	25.42	43.5	33.16	26.3
6b	34.56	23.2	33.54	25.5
7a	29.14	35.2	31.14	30.8
7b	34.30	23.8	32.08	28.7
8a	27.02	39.9	30.70	31.8
8b	29.14	35.2	30.86	31.4
9a	29.50	34.4	28.70	36.2
9b	31.34	30.1	31.88	29.2
10a	29.44	34.6	29.80	33.8
10b	32.38	28.0	29.86	33.6
Average	28.58	36.7	30.91	31.3

[1] Values are based on an average of 50 measurements.
[2] Values calculated as follows: Percent aligned = 45-A/45 × 100, where A is the average flake angle.
[3] Faces represent the front (a) and back (b) surfaces of the board.

performed using a crosshead speed of 0.05 in./min. Nail withdrawal tests were performed on boards at approximately 3% moisture content and within 24 hours after the nails were driven into the specimens.

The moisture related tests were performed in part according to ASTM Standard D 1037-78. Linear expansion specimens were exposed to 5.5% and 12.5% EMC conditions at 70 F in conditioning chambers. Linear expansion data were reported as a change in the dimension from initial (5.5% EMC) to final (12.5% EMC) conditioned dimensions. Thickness swell and water absorption tests were conducted using 6-in.-square specimens submerged horizontally in deionized water.

Statistical evaluation of the data involved the use of analysis of variance procedures. All testing results were statistically evaluated at a 0.05 level of significance. Use of the general linear models procedure accounted for unequal sample sizes.

RESULTS AND DISCUSSION

The average value and the corresponding range in raw data for the moisture content and density measurements following static bending tests are summarized in Table 1. Moisture content shows considerable uniformity (3.1 to 3.5%) in all species and board designs. Average density measurements for each panel are slightly higher than the target density value of 50 lb/ft^3. Although the random flakeboards (53 lb/ft^3) have a higher average density than the aligned flakeboards (50.9 lb/ft^3), considerable overlap exists in the measured values.

TABLE 3. *Summary of static bending data*[1] *for random and aligned flakeboard.*

Specimen	MOE (10^6 psi)	Range	MOR (10^3 psi)	Range
		Random		
Aspen	0.745	0.612–0.889	4.42	3.33–5.37
Maple	0.815	0.700–0.953	5.56	4.70–6.47
		Aligned		
Aspen (‖)[2]	0.909	0.622–1.240	4.80	3.29–7.08
Aspen (⊥)[3]	0.298	0.244–0.327	2.09	1.51–2.49
Maple (‖)[2]	0.842	0.560–0.964	4.56	3.52–5.55
Maple (⊥)[3]	0.314	0.219–0.413	1.95	1.24–2.84

[1] Values are based on an average of 10 measurements.
[2] The span of the specimen is parallel to the direction of flake alignment.
[3] The span of the specimen is perpendicular to the direction of flake alignment.

The measured board density values exceeded the target density value (50 lb/ft^3). The main factor contributing to higher density values was the thickness of the boards following pressing. Specimen thicknesses averaged 0.4 in. versus the target caliper of 0.5 in. primarily because the boards were pressed between aluminum plates that were permanently deformed during the pressing process. Although densities were somewhat higher than the target density (Table 1), all thirty boards proved statistically similar when compared as a group. One difference observed during pressing was that aligned boards required less hydraulic line pressure to thickness than did the random boards. This difference could be attributed to the packing characteristics of flakes during formation of the random as compared to the aligned boards. In a random board, flakes overlapped each other with a greater frequency, requiring and producing higher flake-to-flake pressure than the aligned boards during pressing to achieve a given thickness. This difference in formation may have contributed to some of the variability in the mechanical and physical property data.

Flake alignment values in degrees and percentages are given in Table 2. For the aligned boards, the average flake angle is not significantly different between species and from the desired alignment direction is 29° and 31° for aspen and maple flakeboards, respectively. The range of flake angles in the aspen boards contributes to a slightly better overall degree of alignment. Measured flake alignment values for individual flakes from both species range from 0° to 90°, with the population being slightly skewed toward larger values.

Flake alignment results obtained for the aligned boards represented a sample of values from a statistically homogeneous population. Percent alignment [Percent aligned = $(\frac{45\text{-}A}{45}) \times 100$, where A is the average flake angle] for all boards was an average of 34%, which was lower than the 70 to 90% range reported by Talbott (1974). Many aligned boards resembled those of the random design on the surface.

Average moisture content at the time of mechanical property testing for both species was approximately 3%. This value was lower than the suggested moisture content for mechanical testing (6% MC), but it should have little effect on the comparative analysis between red maple and aspen test boards. Average moisture content values were low because the boards were conditioned for only a short time in a 6% EMC chamber between fabrication and testing.

TABLE 4. *Summary of internal bond and nail withdrawal data*[1] *for random and aligned flake orientations.*

Specimen	Internal bond (psi)	Range	Nail withdrawal (lb)	Range
		Random		
Aspen	35.5	24.3–43.0	28.6	17.1–44.1
Maple	100.0	89.2–116.2	78.9	49.2–111.3
		Aligned		
Aspen	43.5	30.2–62.7	20.3	10.8–27.2
Maple	80.9	52.5–117.7	38.7	24.6–56.1

[1] Values are based on an average of 10 measurements.

The static bending, internal bond, and nail withdrawal test data are summarized in Tables 3 and 4. As expected, static bending specimens taken from aligned boards with their long axis in the direction of alignment performed considerably better than those machined in the cross-aligned configuration. These observed differences held true in both modulus of elasticity (MOE) and modulus of rupture (MOR) values for both species. Random board values exceeded the performance of cross-aligned board values, and values for parallel-aligned specimens were similar or exceeded bending strength and stiffness values of random boards. Static bending values for specimens fabricated with red maple flakes were not significantly different from aspen specimens in either random or aligned orientations.

Actual measured properties obtained from specimens cut in the perpendicular direction to the alignment revealed the advantages and disadvantages of flake alignment. The static bending test results demonstrated the influence of alignment and species on the modulus of elasticity (MOE) and modulus of rupture (MOR). Random aspen and maple boards were comparable in MOE but not in MOR values. Maple boards were stronger than the aspen boards. With density and amount of adhesive constant, there were fewer maple flakes per unit volume to attain a given board density, which resulted in an increase in the quantity of adhesive distributed on individual flakes. This resin-flake interaction may play an important role in the measured strength values of the test specimens. The situation was different for the aligned boards, where maple boards more closely resembled those of aspen. The most noticeable difference in aligned specimens was the sharp contrast between parallel-aligned values and cross-aligned values. The cross-aligned specimen MOE and MOR values ranged from 30 to 50% of the parallel-aligned specimen values, and were comparable to results reported in other studies (Geimer 1976; Kieser and Steck 1978; Krisnabamrung 1974) on panel products. It is also apparent that the results reported in this paper could be improved with better alignment techniques.

Results for internal bond and nail withdrawal tests followed similar trends in that maple boards achieved higher values than the aspen boards (Table 4). Maximum loads in these tests were not influenced by the flake alignment as was evident in the static bending tests. In both nail withdrawal and internal bond tests, random boards produced specimens requring higher failure loads than did aligned boards with the exception of the internal bond tests for the aligned versus random aspen specimens.

TABLE 5. *Summary of water absorption and thickness swell data for random[1] and aligned[2] flake orientations.*

Specimen	Water absorption (percent change)[3]					
	By weight			By volume		
	After 2 hours	After 24 hours	Range 24 hours	After 2 hours	After 24 hours	Range 24 hours
Aspen random	47.0	62.5	58.5–68.6	34.8	40.8	36.6–43.1
Maple random	35.4	61.0	54.0–79.6	27.6	38.7	29.6–46.1
Aspen aligned	49.2	70.1	64.8–76.8	26.4	35.9	29.8–39.0
Maple aligned	49.7	71.8	64.9–76.8	28.2	36.4	28.5–46.5
	Thickness swell (percent change)					
	After 2 hours	After 24 hours	Range 24 hours			
Aspen random	34.6	39.9	36.5–42.5			
Maple random	26.9	37.8	29.2–45.6			
Aspen aligned	26.2	35.3	29.3–38.6			
Maple aligned	28.0	35.9	28.2–46.1			

[1] Values are based on an average of 10 measurements.
[2] Values are based on an average of 20 measurements.
[3] Values representing percent change from the original measurement.

Internal bond and nail withdrawal tests yielded results with a very distinct pattern. Maple boards required higher loads to failure than aspen specimens, and random board values exceeded those of aligned boards, except for the aspen internal bond tests. A major factor in the strength of the maple boards may be related to the resin-flake interaction. As the density of the flakes increased from 24 lb/ft^3 for aspen to 31 lb/ft^3 for maple, the number of flakes producing a 50 lb/ft^3 board decreased. The increased flake density for the maple caused a decrease in the total flake surface area per board and an increase in the amount of resin available to coat individual flake surfaces, yielding specimens with better adhesive characteristics. In both internal bond and nail withdrawal tests, aligned specimens were generally similar or weaker than random specimens. The higher flake-to-flake pressures in forming random boards compared to aligned boards may have produced better bonds between flakes, which ultimately required higher loads at failure.

Water absorption, thickness swell, and linear expansion were used to evaluate dimensional stability. Water absorption and thickness swell data, by weight or by volume, are summarized in Table 5. Two basic relationships were apparent in the absorption values. Variability between specimens measured after 2 hours of soaking was greater than specimens measured at the completion of the 24-hour test period. In addition, aligned boards absorbed more water with a smaller volumetric change than did the random boards. Thickness swell specimens also showed a similar trend in swelling. Dimensional change was measured by weight or volume in water absorption tests. The results after 2 hours indicated an uneven rate of absorption among specimens. The inherent difference between random and aligned flake orientations was characterized by differences in void volume and structure. These differences were most apparent when absorption was analyzed after a short time interval. After longer periods (24 hours), the specimens approached complete saturation, and the influence of small void areas between flakes

TABLE 6. *Summary of linear expansion data[1] for random and aligned flake orientations in aspen and maple boards.*

Specimen	Percent change	Range
	Random	
Aspen	0.19	0.13–0.23
Maple	0.21	0.17–0.27
	Aligned	
Aspen (‖)[2]	0.09	0.07–0.20
Aspen (⊥)[3]	0.15	0.13–0.26
Maple (‖)[2]	0.10	0.07–0.14
Maple (⊥)[3]	0.19	0.14–0.27

[1] Values representing percent change from initial conditions (5% EMC) to final conditions (12% EMC).
[2] Specimen machined with its long axis parallel to the direction of flake alignment. Measurements taken on the long axis of the specimen.
[3] Specimen machined with its long axis perpendicular to the direction of flake alignment. Measurements taken on the long axis of the specimen.

diminished. Although the aligned board specimens appeared to absorb more water with less volumetric change, all specimens after 24 hours were statistically equal. Thickness swell test results followed the same pattern as water absorption (Table 5).

Average values for the linear expansion (Table 6) measurements of 0.19 and 0.20% change were associated with the random design aspen and maple boards, respectively. These values represented the greatest linear change for both board designs. No statistical difference was evident between random aspen and maple boards. Aligned specimens of the parallel-aligned configuration yielded the lowest expansion values, with cross-aligned specimens more closely resembling random boards. Differences between aligned configurations were attributed to the directional expansion characteristics of fibers in the flakes. Flakes were machined exposing tangential and radial faces. Hence, the transverse direction influenced the linear dimensional change of the random and cross-aligned specimens, and the longitudinal swelling influenced the parallel-aligned specimens. Parallel-aligned specimens of aspen and maple boards were statistically similar. Cross-aligned specimens, on the other hand, yielded statistically significant different means, but the observed range in values was small.

The mechanical and physical property values obtained in this study were lower than properties of commercially produced products. Static bending and internal bond specimens achieved strengths of up to 80% of reported values, and dimensional stability ranged from 60 to 90% of reported values on similar type panels (Geimer et al. 1974; Price and Geimer 1978a; Talbott 1974; Snodgrass et al. 1973). Forming techniques and the resultant flake alignment values may in part explain the differences between values obtained in this study compared to reported values. Improved flake alignment in the test boards should improve the board properties compared to reported values. The boards fabricated in this experiment tended to have lower mechanical properties and were less dimensionally stable compared to other studies. Comparisons between the data of the two species in this study were statistically valid, and indicated that red maple, compared to aspen, may be an acceptable furnish for flakeboard.

SUMMARY

Red maple test panels indicated that red maple may be a potential source of wood for the manufacture of structural flakeboard products. Boards fabricated using red maple were compared to boards fabricated using aspen in both random and aligned orientations. Results in mechanical and physical testing showed similar performance.

Moisture content values averaged 3 ± 1% for all boards at the time of testing. Density measurements revealed a slightly higher fabricated board density than the targeted value. Flake alignment differences were insignificant between species and averaged 29° for aspen and 31° for maple.

Mechanical properties measured included static bending, internal bond, and nail withdrawal. Static bending tests revealed the similarity between aspen and maple boards. Maple boards equaled or exceeded the bending stiffness and strength characteristics of aspen boards. Internal bond and nail withdrawal specimens clearly exhibited a twofold strength advantage in maple versus aspen boards.

Physical parameters investigated included water absorption, thickness swell, and linear expansion. Water absorption and thickness swell tests showed no appreciable difference between aspen and maple boards. Linear expansion data indicated that alignment reduced the dimensional change up to 50% of the values observed in the random design.

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