United States
Department of
Agriculture

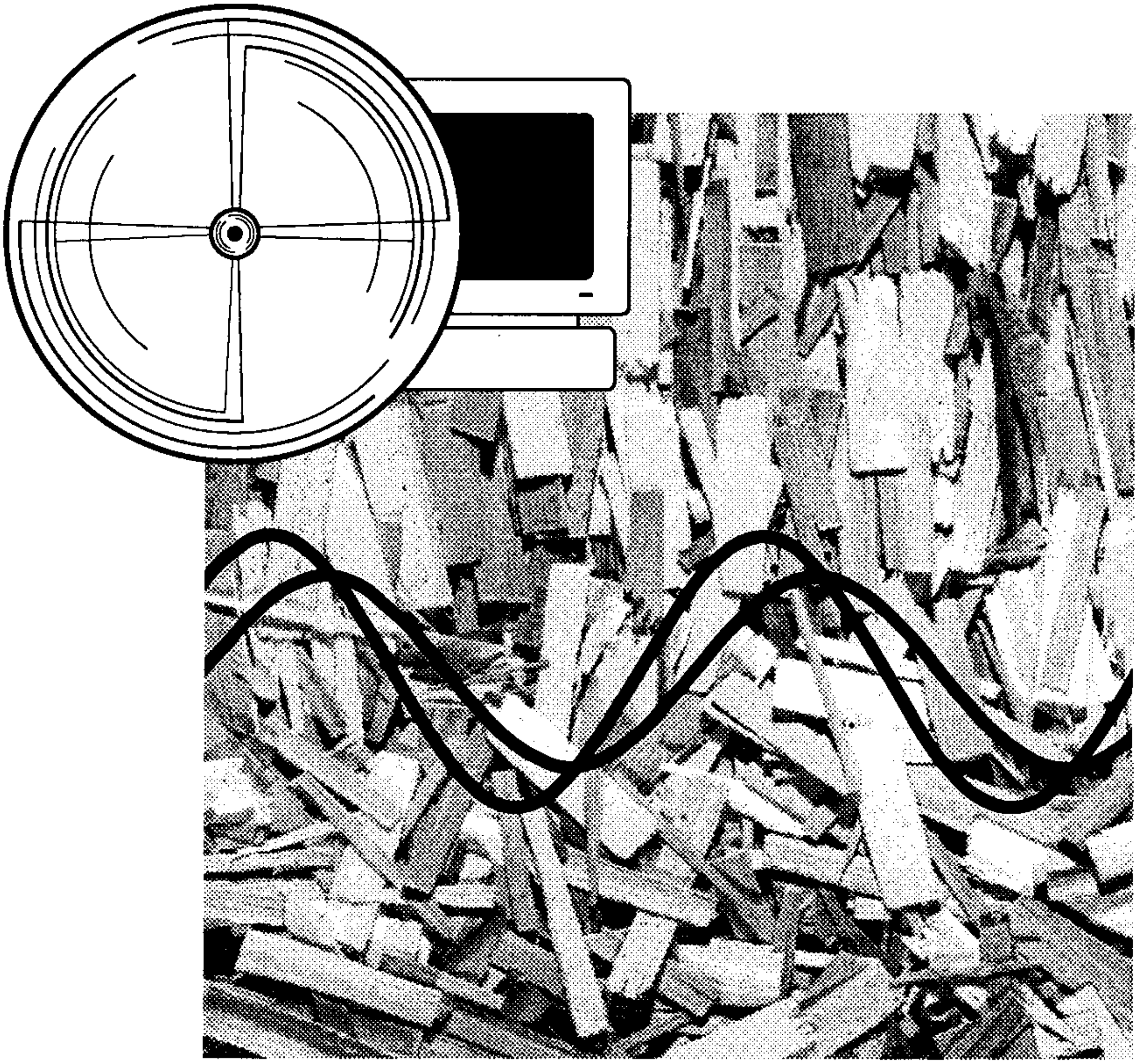
Forest Service

Forest
Products
Laboratory

Research
Paper
FPL-RP-518

Measurement of Flake Alignment in Flakeboard with Grain Angle Indicator

Robert L. Geimer
Kent A. McDonald
Friend K. Bechtel
James E. Wood



Abstract

Flake alignment in face layers of oriented structural flakeboard is considered one of the most important variables for control of panel stiffness. On-line measurement of flake alignment, imperative for production quality control of structural flakeboard, is not possible with existing methods. This study showed that a Grain Angle Indicator (GAI), developed for measuring grain angle in lumber, can be used to distinguish flake alignment in the faces of structural three-layer flakeboard. The GAI measurements were compared to alignment estimates obtained from direct surface measurements, modulus of elasticity ratios, and sonic velocity ratios. Mathematical equations were developed to calculate direction and level of alignment independently. Specific gravity and board moisture content did not appreciably alter flake angle measurements. The GAI used in this experiment was sensitive to flake alignment of 0.64 and 0.84 specific gravity aspen hoards at depths to 3.2 mm (0.125 in.). The GAI has the potential to he developed for direct on-line monitoring of flake alignment in three-layer flakeboard production.

Keywords: Flake alignment, Grain Angle Indicator, layered boards, alignment measurement, density, theory of operation

March 1993

Geimer, Robert L.; McDonald, Kent A.; Bechtel, Friend K.; Wood, James E. 1993. Measurement of flake alignment in flakeboard with Grain Angle Indicator. Res. Pap. FPL-RP-518. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive. Madison, WI 53705-2398. Laboratory publications are sent to more than 1,000 libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Measurement of Flake Alignment in Flakeboard With Grain Angle Indicator

Robert L. Geimer, Research Wood Scientist
Kent A. McDonald, Research Wood Scientist
Forest Products Laboratory, Madison, Wisconsin

Friend K. Bechtel, Vice President and Director of Research
Metriguard Inc., Pullman, Washington

James E. Wood, Physical Science Technician
Forest Products Laboratory, Madison, Wisconsin

Introduction

Flake alignment results from a process used in the composite wood industry where wood flakes or strands are intentionally oriented in specific directions relative to the edge of a panel. The alignment process is useful in fabricating layered structural panels with bidirectional properties comparable to those made with peeled veneer. Flake alignment of the face layers is an important, if not the most important, variable in controlling the bending stiffness of oriented structural flakeboard. In this report, a Metriguard Model 510 Grain Angle Indicator[1] was used to measure flake alignment in the surface layers of such panels.

Presently, an indication of flake alignment can be obtained from the ratios of either bending modulus of elasticity (MOE) or bending modulus of rupture (MOR) in the two planar panel directions (Geimer 1986). Sonic velocity ratio (SVR) is a measure of alignment using the ratio of the velocity of sound waves along the panel length to that across the width (Geimer 1979). Sonic velocity, MOE, and MOR ratios are affected by the alignment of flakes throughout the thickness of a board but are not able to discriminate changes in alignment throughout the depth. Commercially produced aligned panels, for the most part, are not homogeneous hut are constructed with multiple cross-aligned layers. The MOE and MOR ratios can serve as a post-fabrication quality control tool for three-layer panel production but do not meet industry needs for on-line measuring of flake alignment in the critical face layers.

The only known method of providing adequate information on the alignment of the face layer of a three-layer board involves the very tedious manual direct measurement of flake angles on the board surface (Geimer 1979). Although the use of image analysis reduces the time it takes to directly measure flake angles, the equipment has not yet been developed for commercial use. The reliability of direct measurement of surface flakes is based on the supposition that exposed flakes accurately reflect the average flake alignment distribution throughout the thickness of the face. layer.

For more direct quality control purposes, a measurement method is needed that will indicate average flake alignment through a depth of the face layer under production conditions. Recently, an electrical capacitance-type device, the Grain Angle Indicator (GAI), was found suitable for determining localized slope of grain in lumber (McDonald and Bendtsen 1986). The GAI sensor, consisting of a plane array of capacitor electrodes mounted on a circular disk, is positioned parallel and adjacent to the wood surface to be measured. An electric field caused by a radio-frequency potential applied to a first pair of sensor electrodes is affected by the dielectric properties of the wood adjacent to the sensor. The effect is monitored by measuring the voltage across a second pair of sensor electrodes. Because the dielectric constant of wood is greater along the grain than across the grain, the sensed voltage signal changes as the sensor is rotated relative to the wood (McLauchlan and others 1973). The phase of the signal relative to the position of the sensor permits the detection and measurement of grain angle.

Because the electric field generated by the GAI is not constrained to the surface of the material being measured, we

---

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

believed the GAI would be useful in obtaining information about flake alignment for flakes beneath the surface of flakeboard, as well as for those flakes on the surface. Thus, GAI measurement of flake alignment in flakeboard would be more realistic than any measurements restricted to the visible surface. In addition, if the depth of penetration can be determined and controlled, the GAI would be potentially useful for measuring flake alignment in the face layers of a multilayered board. The noncontact features and recent advances in speed of measurement using a stationary sensor (Bechtel and others 1990) make this general type of technology readily adaptable to on-line monitoring of board fabrication. However, the equipment may not be sensitive to the dispersion of flake alignment in flakeboard resulting from multiple, overlapping layers of nonparallel flakes. Other factors of the board that may affect flake alignment measurement and must be considered in the evaluation of the GAI are (1) face-layer depth, (2) core-layer flake alignment, (3) moisture content, and (4) density.

The objective of this study was to explore the ability of the rotating capacitance-type GAI to quantify flake alignment in homogeneous flakeboard and in the surface layers of three-layer flakeboard.

Background

Geimer (1976) introduced a measure for the level of flake alignment, which he called percent flake alignment, given by

$$\text{percent flake alignment} - [(45 - A)/45]\ 100 \qquad (1)$$

where A in degrees is the average of the absolute values of the flake angles measured relative to the machine direction. Unless otherwise stated, the angles are measured relative to a reference direction, which is parallel to the trimmed panel edge, which in turn is parallel to the machine or preferred direction of alignment (also known as the cardinal direction).

Other measures of the level of alignment have been studied. Using the same surface flake angle measurements, alignment can also be defined by (1) the percentage of flake angles within a specified angle relative to the machine direction and (2) the standard deviation of the absolute value of flake angles measured relative to the machine direction (Geimer 1976).

The angle obtained by averaging the directionally described (plus or minus) deviations that individual flakes make with the machine direction will tend toward zero if the alignment process is performing as designed. If the direction of alignment agrees with the machine direction, it is clear that percent flake alignment defined by Equation (1) will progress smoothly from 0 to 100 percent inversely as *A* progresses from 45° to 0°. If the direction of alignment does not agree with the machine direction, a reduced level of alignment is indicated. For example, if the flakes are perfectly aligned at 10° relative to the machine direction, Equation (1) yields 100((45 - 10)/45) = 78 percent. The sensitivity of A to direction of alignment may be desirable because misalignment can seriously degrade product quality as can poor aligument level. In some cases, misalignment can be calculated by averaging the directionally defined (plus or minus) flake angles. Averaging the absolute values of the flake angles that have been adjusted by this offset provides a corrected measure of alignment level. However, situations exist where this method does not work For example, flakes clustering about +90° and -90° average to 0°, giving a false indication of alignment along the machine direction when in fact the alignment is perpendicular to the machine direction. The method described here properly deals with these situations.

Flake angles tit the description of axial data (Mardia 1972) because when swapped end-for-end, the angles of flakes in a given position are indistinguishable in their effect on flakeboard. This fact has been recognized by others who have used shape factor and concentration parameter for specific parametric distributions as measures of alignment (Johnson and Harris 1976; Shaler 1991). Shaler discussed comparison of the two measures, concentration parameter and percent alignment of Equation (1), for the von Mises distribution.

In this study, we developed, from the concept of axial data, methods that provide independent measures of alignment dispersion and direction and that can be implemented using GAI measurements.

There are two methods for obtaining measures of alignment from the GAI angle measurement and signal strength. We identified areas of uncertainty in determining alignment measures with both methods. The first method is based on GAI measurements of grain angle. The second method is based on GAI signal strength. Signal strength is incompletely documented in our experiments because the instrument was not provided with a readout of signal strength. However, an indicator that the signal strength was above or below a preset threshold was available and was used to indicate the potential of the signal strength method.

Calculating Flake Alignment Using Grain Angle Indicator

With clear lumber, the signal developed in the GAI resembles a sinusoidal waveform that attains its maximum value when the sensor is aligned along the fiber direction (Fig. 1). Because the sensor is aligned with the grain twice. per revolution (fiber directions different by 180° are indistinguishable), the GAI signal progresses through two periods, or 720° of the sinusoidal waveform, while the GAI sensor rotates through 360°. The maximum value of the

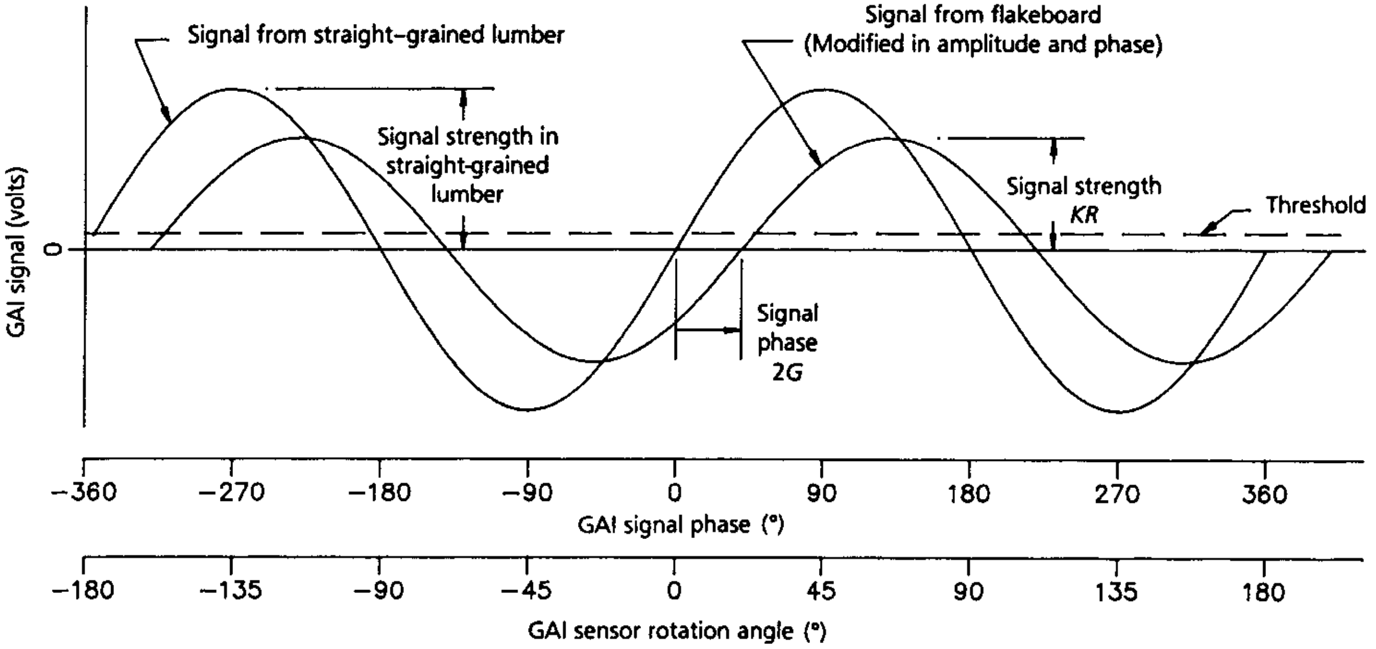


Figure 1—Signal phase and strength variation in response to effective flake angular change.

sinusoidal waveform is its amplitude; we call this signal strength. The angular position of the sensor at the time when a maximum signal occurs, relative to a fixed angular reference. point, defines the signal phase. The GAI is calibrated to read grain angle (rotational angle, Fig. 1) as half the phase of the GAI signal. For practical reasons, the GAI determines phase from the "sine wave zero crossings," which are midway between the maxima and minima.

With clear lumber, the GAI signal phase responds to changes in grain angle. With flakeboard, the phase responds to the weighted average. direction of those flakes contributing to the GAI signal. The contribution of each flake can be thought of as a tiny sinusoid with phase corresponding to flake alignment and a frequency fixed by the rotational speed of the GAI. Because the superposition of sinusoids with a common frequency is a sinusoid with the same frequency, the signal remains a sinusoidal waveform, even though many flakes positioned at different angles contribute to the signal. The amount or weight that each individual flake contributes to the signal is a function of its size and proximity to the sensor.

We elected to use the theory of axial data (Mardia 1972) to relate alignment level to the GAI measurements. The model we used for the GAI signal *S(t),* which was developed by analysis of the GAI hardware and which fit the observations, is the sinusoid given by

$$S(t) - KR\sin(2G - 2wt) \qquad (2)$$

Amplitude of the sinusoid (signal strength) is given by the product of the factors K and R, which will be further defined. The signal phase is the double angle $2G$, w is the angular rotational speed of the GAI sensor in radians per second, and t is a running time variable in seconds.

The contribution of each individual flake to the GAI signal can be modeled as a vector r_i with a length w_i, which is the amount or weight of the contribution of the i^{th} flake and angle $2\theta_i$, which is twice the angle of the i^{th} flake relative to the machine direction. We assumed that the machine direction was aligned with the reference direction of calibration for the GAI. Without loss of generality, we assumed that the weights w_i add to 1:

$$\sum_i w_i = 1 \qquad (3)$$

Double angles are necessary to account for the 720° of the sinusoid generated as the sensor rotates through 360° (Fig. 1). The flake angles tit Mardia's definition of axial data wherein angles different by 180° are indistinguishable (Mardia 1972). The angles θ_i, of the individual flakes may be either positive or negative relative to the machine direction.

Let us now define the resultant vector **R** as the vector sum of all the vectors r_i for flakes contributing to the measurement (Fig. 2):

$$\mathbf{R} = \sum_i \mathbf{r}_i \qquad (4)$$

The vector **R** can also be thought of as a weighted average of unit length vectors, with the i^{th} vector being oriented at angle

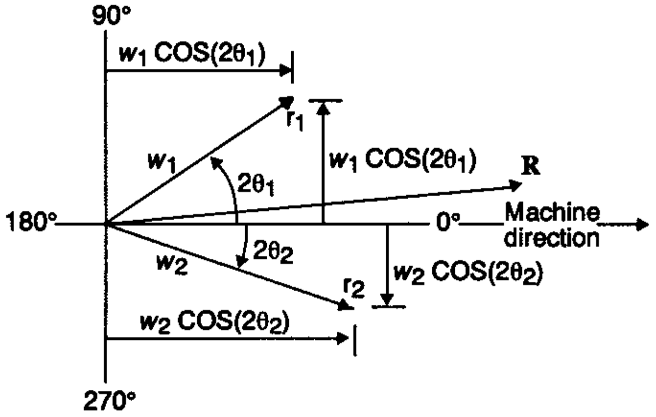


Figure 2—Determination of resultant vector **R.**

$2\theta_i$ and having weight (length) w_i. The weighted average magnitude $\boldsymbol{R}$ and angle. $2G$ of the resultant vector **R** are given by

$$R = (c^2 + s^2)^{1/2} \qquad (5)$$

$$2G = \tan^{-1}(s/c) \qquad (6)$$

in terms of the vector components c and s where

$$c = \sum_i w_i \cos(2\theta_i) \qquad (7)$$

$$s = \sum_i w_i \sin(2\theta_i) \qquad (8)$$

Equations (5) and (6) are the defining equations for $\boldsymbol{R}$ and $2G$ of Equation (2).

The factor $\boldsymbol{K}$ is a calibration factor accounting for species, flake moisture content, amplification of the GAI system, and the distance of the sensor from the flakeboard. This will become. clear later in an example dealing with the determination of $\boldsymbol{K}$.

The previous definitions are similar to Mardia's formulation for axial data with the exception that we included weights w_i to account for the extent to which individual flakes (vectors) affect the signal. Following Mardia's example, we can define circular variance $\boldsymbol{V}$ as

$$V = 1 - R \qquad (9)$$

The minimum value of $\boldsymbol{V}$ is zero, corresponding to a maximum value of $\boldsymbol{R} = 1$ when all angles θ_i are the same, as would occur with perfect alignment, that is, all flakes oriented in the same direction. This can be seen by direct substitution of $\theta_i = \theta$, a common angle, into Equations (7) and (8), applying Equation (3), and then recognizing in Equation (5) that $\cos^2(2\theta) + \sin^2(2\theta) = 1$ for any angle θ. When the vectors r_i are distributed with truly random angles $2\theta_i$ (that is, a uniform distribution of flake angles θ_i ranging from -90° to +90°), $\boldsymbol{R}$ tends toward 0 and $V = 1 - \boldsymbol{R}$ tends toward 1.

Mardia (1972) suggested a transformation of circular variance $\boldsymbol{V}$ to a value that we denoted **VAR,** which can be any positive real number. The transformation is

$$\mathrm{VAR} = -0.5\log_e(1 - V) \qquad (10)$$

where $\boldsymbol{V}$ is the circular variance defined for the double angles $2\theta_i$, and **VAR** is similar to an ordinary variance of $2\theta_i$ on the red line. We will show that the value VAR is useful in undoing the confounding effect that multiple flakes have in determining the new measure of flake alignment level.

For axial data, Mardia defines circular variance. $\boldsymbol{V}_o$ for single angles θ_i in terms of circular variance $\boldsymbol{V}$ for the double angles $2\theta_i$ by

$$V_o = 1 - (1 - V)^{1/4} \qquad (11)$$

Defining $\boldsymbol{R}_o = 1 - \boldsymbol{V}_o$ and substituting from Equations (11) and (9). we obtain $\boldsymbol{R}_o = R^{1/4}$. We suggest using $100\boldsymbol{R}_o$ as a new measure of alignment level. The factor 100 expresses the new measure as a percentage in the same context as Equation (1). consequently,

$$\text{percent flake alignment} = 100\boldsymbol{R}_o = 100\boldsymbol{R}^{1/4} \qquad (12)$$

The value $100\boldsymbol{R}_o$ increases as alignment dispersion decreases and varies between 0 for random flake distribution and 100 for perfect alignment. The value $100\boldsymbol{R}_o$ is independent of the direction of alignment obtained by the GAI as angle G.

To evaluate $100\boldsymbol{R}_o$ of Equation (12), we obtained the quantity $\boldsymbol{R}$ by first measuring the signal strength $\boldsymbol{KR}$ and then removing the factor $\boldsymbol{K}$ by division. One proposed method of obtaining $\boldsymbol{K}$ is to measure a piece of clear straight-grained wood with the GAI. As shown previously, if the grain is all in the same direction, then $\boldsymbol{R} = 1$. In that case, a measure of signal strength is a measure of $\boldsymbol{K}$. Assuming that the flakeboard is of the same species and moisture content as the straight-grained wood, that the distance between the sensor and the measured wood surface is the same as that for the flakeboard, and that the resin, interstitial voids, and compaction of the flakeboard affect the result in a known way or only negligibly, then $\boldsymbol{K}$ for the straight-grained wood can be substituted for $\boldsymbol{K}$ of the flakeboard.

The previous discussion refers to the measurement of alignment at any one spot on a flakeboard. However, when measuring the alignment of a flakeboard, a series of measurements are normally taken at many positions on the board. This provides another method for obtaining the measure of alignment level $100\boldsymbol{R}_0$ that does not depend on the factor ***K***. This method replaces the uncertainty in the determination of ***K*** with uncertainty in the effective number of flakes contributing to each measurement. Also, an implicit assumption is made that the distribution of flake angles is homogeneous over the board area.

In statistical theory, the variance of the average of *n* independent and identically distributed observations decreases with sample size as 1/*n*. Likewise, when *n* is considered as an effective number of flakes contributing to each GAI measurement, the variability of the signal phase and signal strength about their respective mean values will decrease as *n* increases (Fig. 3). The number of flakes affecting the GAI signal is determined by the shape and size of the sensor, the distance between the sensor and the flakeboard surface, and the. size distribution of the flake furnish. The term effective number is applied to *n* because some flakes near the periphery of the sensed area minimally affect the result, and some flakes have a major effect. We assumed that there is an effective number *n* of equally weighted flakes with flake angles independent and identically distributed that would cause the same effect in reducing variability as would the actual situation where the weights are unequal. Then, we expected the variance. of signal phase 2*G* to be reduced from the variance of $2\theta_i$ by the factor *n*. Similarly, we expected the variance of signal strength ***KR*** to be. proportional to 1/*n*. If the assumption of statistical independence among the flake. angles is not valid, the effective number *n* of flakes will be smaller and the variability in signal strength will be larger.

Now let us take several measurements of grain angle G_k, $k = 1,..,n'$, using the GAI at n' different locations. Following Mardia (1972) for axial data, we defined the sample. mean vector $\boldsymbol{R}'$ in terms of its magnitude $\boldsymbol{R}'$ and the double angle $2G'$ by

$$R' = (c'^2 + s'^2)^{1/2} \qquad (13)$$

$$2G' = \tan^{-1}(s'/c') \qquad (14)$$

where

$$c' = \frac{1}{n'}\sum_{k=1}^{n'}\cos(2G_k) \qquad (15)$$

and

$$s' = \frac{1}{n'}\sum_{k=1}^{n'}\sin(2G_k) \qquad (16)$$

are the components of the vector $\mathbf{R}'$.

The circular variance ***V*** of the angles $2G_k$ is given by

$$V' = 1 - R' \qquad (17)$$

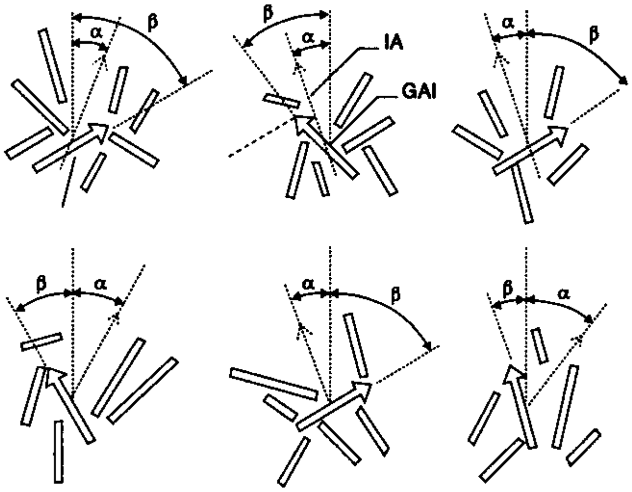


Figure 3—Six hypothetical observations showing that angular variance is dependent on number of flakes. Variation between single flake angles (β) measured by image analyzer is greater than variation between angles (α), which are calculated as average of *n* flakes sensed by Grain Angle Indicator (GAI) at each observation.

Mardia’s transformation can be used again to convert circular variance to a positive real number VAR′ that is similar to the ordinary variance of the double angles $2G_k$.

$$\mathrm{VAR}' = -0.5\log_e(1 - V') \qquad (18)$$

Because the constituents $2G_k$ of VAR′ each have an effective number *n* of contributing flakes, we reasoned that VAR′ is reduced from VAR by the factor *n*. Consequently,

$$\mathrm{VAR} = n(\mathrm{VAR}') \qquad (19)$$

Equivalently, by substituting Equations (10) and (18) and then (9) and (17) into Equation (19),

$$R = R'^n \qquad (20)$$

Finally, by substituting $\boldsymbol{R}'^{\,n}$ from Equation (20) for ***R*** *in* Equation (12), we write our new measure of alignment level as

$$\text{percent flake alignment} = 100\boldsymbol{R}_0 = 100\boldsymbol{R}'^{\,n/4} \qquad (21)$$

When *n* is 4, percent alignment varies directly with $\boldsymbol{R}'$. As *n* values vary, the relation is changed as shown in Figure 4.

Percent flake alignment as defined by Equation (1) is affected by the alignment direction, that is, any difference between the machine. direction and the actual alignment direction. Consequently, percent flake alignment serves as a good indicator of the alignment level in the machine

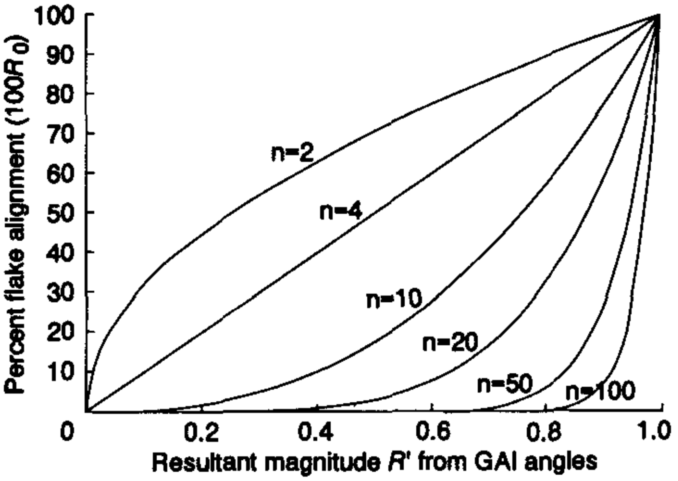


Figure 4—Calculation of axial flake alignment descriptor $100\boldsymbol{R}_0$ is dependent on effective number of flakes n sensed by Grain Angle Indicator (GAI).

direction, but it does not give the correct value of alignment level when there is a difference between the machine direction and actual alignment direction (Shaler 1991). On the other hand, the measure of alignment $100\boldsymbol{R}_0$ is independent of the actual alignment direction. As discussed previously, $\boldsymbol{R} = 1$ for any situation where the flakes are all aligned at the same angle (whatever that may be). Thus, for the situation where all flakes are aligned in the same direction, the percent alignment from Equation (12) is 100 percent regardless of the alignment direction.

To summarize, assuming homogeneity of a panel, the value G' obtained from Equation (14) is an estimate of the actual direction of flake alignment relative to the machine direction or GAI zero reference direction. The value G' is derived from a series of n' individual GAI measurements, each of which is a composite of contributions from an effective number n of individual flakes. The value $100\boldsymbol{R}_0$, a level of alignment, is also derived from the n' GAI measurements. The value $100\boldsymbol{R}_0$ is expressed as a percentage in the range 0 to 100 percent with 0 percent meaning complete random distribution and 100 percent meaning perfect aliment with all flakes oriented in the same direction. Equation (21) expresses the value $100\boldsymbol{R}_0$ as a function of $\boldsymbol{R}'$, which is obtained from grain angle measurements and does not require evaluation of signal strength. However, this equation does include an adjustment to compensate for the averaging effect caused by the contributions of an effective number of flakes n. In the absence of definite knowledge of n, it can be treated as a calibrating parameter.

Because of the inherent averaging of the contributing flake angles by the GAI in each single measurement of the angle G, the distribution of $2G$ obtained from a series of measurements is narrower than the distribution of the individual double flake angles $2\theta_i$. This suggests that there should be a difference. between direct use of GAI and image analyzer (IA) data defining percent alignment. The calculation methods described compensate for this difference. when the actual alignment direction is the same as the machine direction, calibration can be accomplished by comparing measurements on boards fabricated to different alignment levels and obtaining regressions in the usual manner.

Experimental Design

The procedures followed four research goals to meet the objective. They were to (1) establish how well the manufacturing process aligned the flakes in the test boards, that is, met the target levels as measured by known methods, (2) establish the GAI results on homogeneous boards and determine the relationship of the GAI measurements to the other methods, (3) evaluate the depth sensitivity of the GAI, and (4) evaluate the performance of the GAI on manufactured three-layer boards.

Homogeneous aspen boards at specific gravity (SG) levels of 0.64 and 0.85 were constructed to learn the basic respome of the GAI to a random flake distribution and four levels of flake alignment. Specimens cut parallel to the machine direction were successively reduced in thickness and measured for alignment, first while backed by a randomly aligned specimen and then while tacked by an aligned specimen cut perpendicular to the machine direction. This allowed us to evaluate the depth of GAI penetration and the effect of flakeboard core alignment. Three-layer cross-aligned boards were constructed and measured for alignment before and after removal of a thin face layer so we could determine the effect of normal variations of layer thickness in the vertical direction and the effect of the flake alignment level within layers.

Flake alignment measurements obtained with the GAI were averaged and compared to measurements obtained using bending (MOE and MOR) ratios, sonic velocity ratios (SVR), and surface image (image analysis (IA)) measurements. Equations relating to the measures of alignment used previously are given for specific board types elsewhere (Geimer 1979, 1981).

Using the measure of alignment given by Equation (1), the target alignment levels from this study were random and 30, 50, and 70 percent, corresponding respectively to average absolute alignment angles of 45°, 31.5°. 22.5°, and 13.5°. This notation indicates the relative progression of alignment from 0 percent for a random board with an average absolute alignment angle (A) of 45° to 100 percent for a perfectly aligned board with a” average absolute alignment angle of 0°.

Table 1—Board fabrication

Board type	Target align- ment (percent)	Target face-layer alignment (percent)	Target core alignment[a] (percent)	Target specific gravity
Homogen- eous[b]	0			0.64, 0.85
	30			
	50			
	70			
Three-layer[c]		30	0, 30	0.721
		50	0, 50	
		70	0, 70	

[a] Perpendicular to face layer.

[b] Target thickness was 12.7 mm (0.5 in.) for all boards. Specific gravity was on an ovendry basis. Two board replications ware made for each condition.

[c] Target thickness was 12.7 mm 0.5 in.) for all boards. Specific gravity was on an ovendry basis. One board was made for each condition.

Board Fabrication

All boards were fabricated using an established technique to reduce the density gradient (Geimer 1979). The boards were pressed to a thickness of 12.7 nun (0.5 in.) in a cold press and then heated under restraint until the core temperature had passed 104°C (220°F) for 10 min. An equal mixture of 12.7-and 6.35-mm- (0.5- and 0.25-in.-) wide aspen disk-flakes was used. Target flake thickness and length were 0.51 and 89 nun (0.020 and 3.5 in.), respectively. The boards were bonded with 5 percent phenolic resin (ovendry wood basis, no wax) and cold pressed at a mat moisture content of 10 percent.

The boards fabricated for this study are outlined in Table 1. To fabricate the homogeneous boards, two replications of 12.7-by 610- by 711-mm (0.5- by 24- by 28-in.) boards were constructed to target SG levels of 0.64 and 0.85 based on ovendry (OD) weight and at target alignment levels of random and 30, 50, and 70 percent (45°, 31.5°, 22.5°, and 13.5° average absolute flake angle alignments) for a total of 16 boards.

In addition, six three-layer boards were pressed to a target SG of 0.721 (OD weight). Three pair of these 12.7- by 610-by 610-mm (0.5-by 24-by 24-in.) boards were fabricated, one pair at each face-layer target alignment of 30, 50, and 70 percent. One board of each pair was constructed with a random core, and the other board was constructed with a core cross-aligned to the same degree of alignment as the face. Layer proportions were 20:60:20 by weight.

Specimen Preparation and Measurements

After trimming the fabricated boards (Fig. 5a, b) but prior to cutting individual specimens from each board, SVR were determined and direct image measurements were made. from the board surfaces.

Direct measurement of the flake alignment on the surfaces of all 22 boards was facilitated by a clear plastic overlay marked with a 51-by 51-mm (2-by 2-in.) dot grid placed on the top surface of each board (Geimer 1979). The grain direction of these flakes occurring at the intersections of the grid was traced onto the overlay. The overlay was then observed with an IA to determine the individual flake angles. Average alignments were calculated using Equation (1).

Sonic velocity ratios were determined for the 16 homogeneous boards using a James V-Meter (Geimer 1979). After the SVR and IA flake alignment values were obtained, the. boards were cut into specimens (Fig. 5a, b) and conditioned at 30 percent relative humidity (RH) and 27°C (80°F) to an average measured moisture content of 5 percent (OD basis).

The 121-by 432-mm (4.75-by 17-in.) specimens (No. 1, 2, and 3) (Fig. 5a) cut from both replications of the homogeneous boards were measured for flake alignment using the. GAI equipment shown in Figure 6. The Model 510 GAI, manufactured by Metriguard, Pullman, WA, consists of a capacitor electrode array in the shape. of a 19-mm- (0.75-in.-) diameter disk mounted flush in a sensing surface and rotated at 3,600 rpm. Sensor electrodes are excited with radio frequency energy at 500 kHz. The machine was calibrated to establish its reference direction by using a straight-grained block of Douglas-fir.

The specimen to be measured was held in the GAI material transport assembly by rollers under pressure. The position of the specimen was controlled by a stepping motor connected directly to the specimen with a cable chain. During operation, the specimen moved longitudinally at a constant rate of 610 mm/min (24 in/min). Readings were taken every 6.3 mm (0.25 in.) of specimen travel. The motion of the specimen was halted after travelling 406 mm (16 in.). The sensor was shifted transversely 6.3 mm (0.25 in.), and the longitudinal motion of the specimen was reversed. Scanning over an 89-by 406-mm (3.5-by 16-in.) area resulted in a 14 x 64 data matrix. A special jig (Fig. 7), built to carry the 432-mm-(17-in.-) long specimens over the 406-mm (16-in.) gap between pressure rollers, allowed us to maintain the scanned surface of each specimen at a constant distance of 1.6 mm (0.063 in.) from the GAI head sensor surface.

The eight No. 1 specimens from one replication of each SG and alignment combination of the homogeneous boards were scanned to determine the effect of layer thickness and core

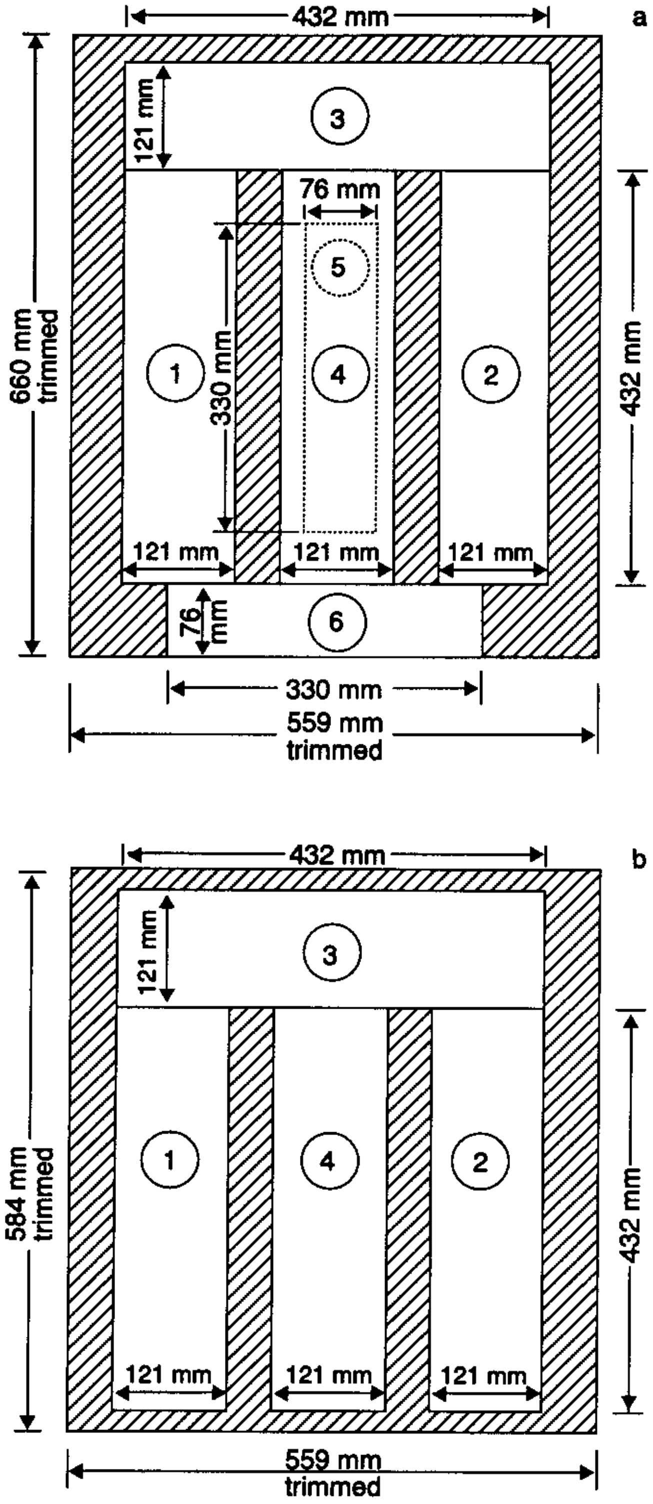


Figure 5 —Cut up diagram of (a) homogeneous and (b) three-layer boards (1 mm - 0.04 in.).

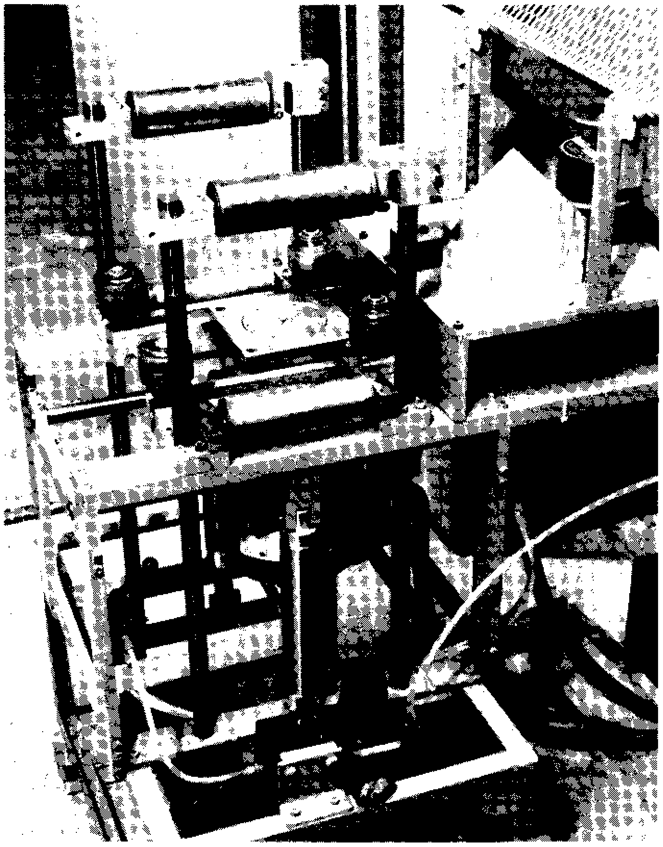


Figure 6—Grain Angle Indicator in transport assembly (M90 0013-17).

alignment. A 0.38-mm (0.015-in.) layer was removed from the bottom face (as pressed) of the eight specimens to optimize contact with the backers. The six homogeneous No. 1 aligned specimens were backed by the 0.64 SG random specimen, and GAI angle measurements were obtained. The backer was then replaced with a 0.64 SG cross-aligned specimen (No. 3, Fig. 5a), where the alignment level was the same as the surface specimen, and GAI measurements were retaken. Both the random and the aligned backers had a 0.38-mm (0.015-in.) layer removed from the top face (as pressed) to ensure good contact with the surface specimen. The GAI measurements were repeated for the-se six No. 1 aligned specimens, with the various backers, after the aligned specimens were successively reduced in thickness to 6.3, 3.2, and 1.6 mm (0.25, 0.125, and 0.063 in.) by removing material from the top face (as pressed). The two No. 1 random specimens were also successively reduced in thickness to 6.3, 3.2, and 1.6mm (0.25, 0.125, and 0.063 in.) for additional GAI measurements. In this case, measurements were conducted with the random specimens backed by the 0.64 SG, 70-percent cross-aligned specimen.

The 12.7-mm- (0.5-in.-) thick No. 1, 2, and 3 specimens from the remaining replications of the three 0.64 SG homogeneous aligned boards were successively equilibrated and remeasured at 65 percent RH (approximately 8 percent moisture content) and again at OD conditions using the GAI equipment to evaluate the effect of moisture content.

The No. 1, 2, and 4 specimens from the six three-layer boards (Fig. 5b) were measured using the GAI after conditioning at 30 percent RH. Measurements were taken on both the top and bottom faces. Top and bottom faces were

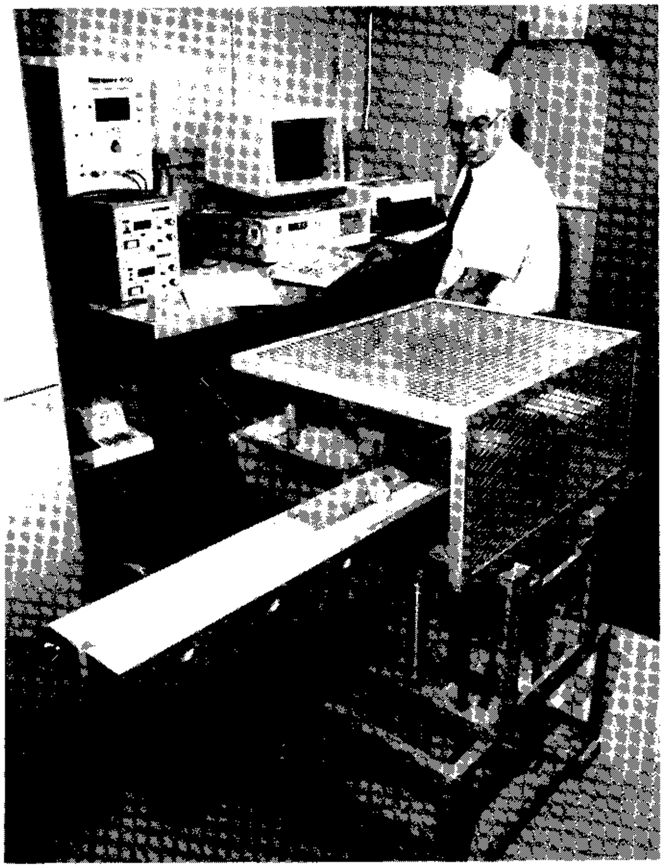


Figure 7—Specimen holding jig (M90 0013-7).

remeasured after a 0.76-mm (0.03-in.) layer was removed from each surface to evaluate the effect of the core alignment.

The MOE and MOR values were determined from each homogeneous No. 5 and 6 specimen according to ASTM Standard D-1037 (ASTM 1987). These data were used to compute the ratios of bending properties, which served as another measure of flake angle. Specimens No. 5 and 6 were also used to compute average SG for the board.

Density gradients were measured on both homogeneous and three-layer 51- by 51-mm (2- by 2-in.) specimens using a nuclear densitometer (Laufenberg 1986). The three-layer density gradient specimens were cut from the six No. 3 specimens. The homogeneous density gradient specimens were cut from the unbroken ends of the 16 No. 5 bending test specimens.

Results and Discussion

A primary consideration in using the Model 510 GAI was whether this model, or for that matter any other available instrument of this type, was capable of distinguishing flake alignment level. To be effective, the measuring instrument must provide a usable reading when it simultaneously encounters adjacent wood elements, horizontally and vertically, which are arranged in different directions. The data for the alignment of the 12.7-mm- (0.5-in.-) thick homogeneous boards (Tables 2 and 3) show that the GAI does respond readily to differences in alignment level. Grain Angle Indicator absolute angle level (Table 3), calculated according to Equation (1), was 5 percent for the random boards and ranged from 81 to 88 percent for the aligned boards. The results are presented and discussed in the order outlined in Experimental Design.

Accuracy of Target Alignment

Average results obtained by direct measurements of the surface flake angles, using the IA, were close to targeted values, with the exception of boards targeted for the 70-percent alignment level (Table 2). Alignment direction varied between +7° and 4° relative to the machine direction, a deviation that is well within limits experienced in previous work The boards were fabricated using alignment procedures expected to produce a certain alignment level as measured by the IA (Geimer 1976). Consequently, IA and target values should be close.

Alignment percentages estimated from average MOE ratios (MOE:R) (Geimer 1986) and SVR also deviated from target values (Table 2). Alignment levels estimated from MOE:R were similar to the IA values in that they were below target values. However, alignment levels estimated from the SVR data were higher than target values. Differences between results obtained with the IA, MOE:R, and SVR methods used in this study are likely due to differences in species and furnish of boards used to compute the relations. The regression equations relating SVR and MOE:R to IA measure of alignment were developed using Douglas-fir and oak flakes of various sizes (Geimer 1979, 1981, 1986). However, all three methods were consistent in showing that the difference. in alignment between those boards targeted for 50 and 70 percent alignment was less than the desired 20 percent.

Expressing MOE values as a percentage increase from random board values permitted us to combine data from the two SG levels in comparing the different alignment measurement methods (Table 2, Fig. 8). There is no evidence available at this time indicating that any measurement method provides more accurate or useful information than another.

Actual board SG averaged slightly below target values (Table 2). Densitometer measurements indicated a uniform density throughout the thickness of the boards made at 0.64 SG (maximum variation of +5 or -5 percent around the average). Maximum density of the surface of those boards made to an average SG of 0.85 was approximately 10 percent greater than the interior density. We found no consistent evidence that SG had an effect on alignment.

Table 2—Comparative alignment measures in homogeneous boards

Target align-ment (%)	Specific gravity		Image analyzer alignment		MOE				MOR		Sonic velocity		
	Target	Measured	Direc-tion (deg.)	Level (%)	Parallel stiffness (MPa (x10^3 lb/in^2))	Ratio parallel/perpen-dicular	Ratio parallel/random[a]	Level[b] (%)	Parallel strength (MPa (lb/in^2))	Ratio	Parallel velocity (mm/µs)[c]	Ratio	Level[d] (%)
0	0.64	0.587	3	-7	3,778 (548)	0.832	0.91	-6	33.813 (4,904)	0.879	3.365	1.045	3
0	0.85	0.812	7	2	6,536 (948)	1.101	1.05	3	57.304 (8,311)	1.12	3.619	1.048	3
		Average	**5**	**-3**		**0.967**	**0.98**	**-1**		**0.999**	**3.492**	**1.046**	**3**
30	0.64	0.583	2	32	6,095 (884)	2.120	1.63	23	45,024 (6,530)	1.685	4.077	1.632	37
30	0.85	0.789	6	26	8,943 (1,297)	2.029	1.44	22	71,363 (10,350)	1.769	4.259	1.616	36
		Average	**4**	**29**		**2.074**	**1.53**	**22**		**1.727**	**4.168**	**1.642**	**37**
50	0.64	0.599	4	48	7,005 (1,016)	3.616	1.79	40	52.057 (7,550)	3.312	4.301	2.529	70
50	0.85	0.830	-4	52	11,825 (1,715)	4.309	1.73	45	84.119 (12,200)	3.489	4.595	1.965	51
		Average	**-4**	**50**		**3.963**	**1.76**	**43**		**3.400**	**4.468**	**2.247**	**61**
70	0.64	0.593	4	54	8,239 (1,195)	5.382	2.15	52	53.574 (7,770)	4.010	4.757	2.961	82
70	0.85	0.844	4	56	12,383 (1,796)	7.214	1.78	60	106.528 (15,450)	7.270	4.894	2.457	68
		Average	**4**	**55**		**6.298**	**1.96**	**57**		**5.640**	**4.826**	**2.709**	**75**

[a] Random MOE values adjusted to the same specific gravity as aligned MOE (Geimer 1966).

[b] Percent = 30.7 (In MOE:R) (Geimer 1986).

[c] 1 mm/µs = 3.284 x 10^3 ft/s.

[d] Percent = 75.8 (In SVR) (Geimer 1986).

Table 3—Grain Angle Indicator alignment measuments in homogeneous boards

			Parallel							Perpendicular						
				Signal phase							Signal phase					
					By axial data method[a]							By axial data method[a]				
							100R_0 (%)							100R_0 (%)		
Target alignment (%)	Specific gravity Target	Specific gravity Measured	Signal strength (no data)[b]	Absolute angle level (%)	G' (deg.)	R'	n=5	n=24	n=60	Signal strength (no data)[b]	Absolute angle level[c] (%)	G' (deg.)	R'	n=5	n=24	n=60
0	0.64	0.587	663	+13	-26.7	0.171	11	0	0	694	7	-63.1	0.187	12	0	0
0	0.85	0.812	776	-4	-54.0	0.237	17	0	0	813	11	66.9	0.311	23	0	0
		Average	**720**	**5**	**-37.6**	**0.173**	**11**	**0**	**0**	**753**	**9**	-81.8	0.147	9	0	0
30	0.64	0.583	214	80	-0.4	0.925	91	63	31	274	71	86.8	0.881	85	47	15
30	0.85	0.789	262	81	-0.3	0.925	91	63	31	409	75	89.4	0.883	86	47	15
		Average	**238**	**81**	**-0.3**	**0.925**	**91**	**63**	**31**	**341**	**73**	**87.9**	**0.881**	**85**	**47**	**15**
50	0.64	0.599	72	84	0.8	0.945	93	71	43	104	79	89.0	0.899	88	53	20
50	0.85	0.830	84	88	0.6	0.974	97	86	67	78	81	-87.5	0.920	90	61	29
		Average	**78**	**86**	**0.7**	**0.960**	**95**	**78**	**54**	**91**	**80**	**-89.2**	**0.908**	**89**	**56**	**24**
70	0.64	0.593	12	87	1.4	0.966	96	81	59	15	81	89.5	0.910	89	57	24
70	0.85	0.844	4	90	1.2	0.981	98	89	75	61	82	89.7	0.910	89	57	24
		Average	**8**	**88**	**1.3**	**0.973**	**97**	**85**	**67**	**38**	**82**	**89.6**	**0.910**	**89**	**57**	**24**

[a] All averages for axial data computed by circular mean (Mardia 1972).

[b] Number of occurrences when signal strength was too low to obtain an angle recording.

[c] Computed from complements of measured angles.

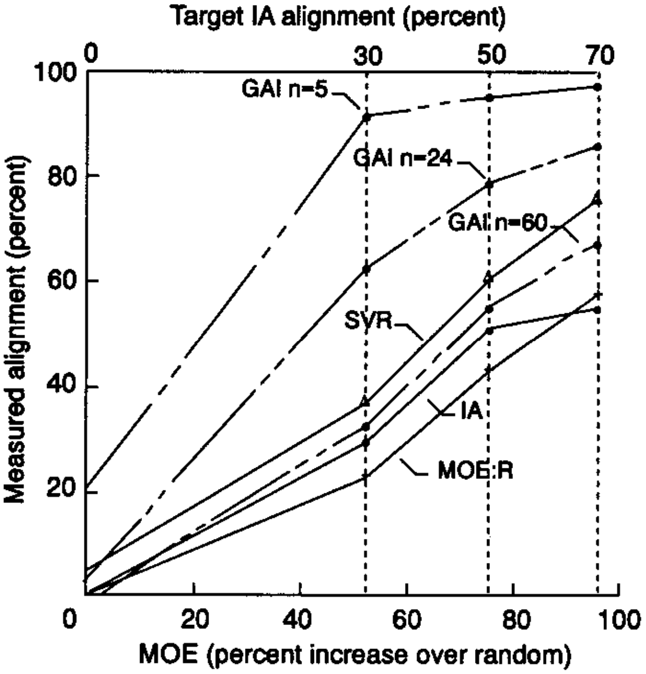


Figure 8—Flake alignment as measured by image analysis (IA), sonic velocity ratio (SVR), MOE ratio (MOE:R), and Grain Angle Indicator (GAI) measurements compared to MOE increase. over random alignment.

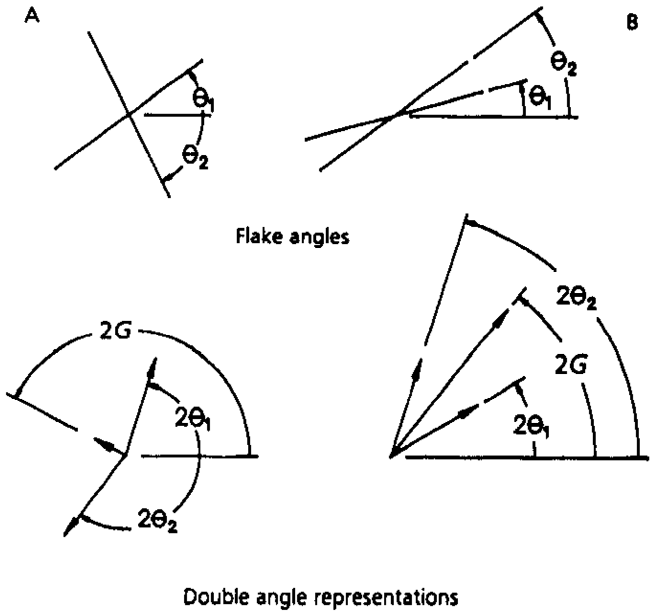


Figure 9—Resultant vector computation; (A) two flakes randomly aligned, (B) two flakes somewhat aligned.

GAI Measurements Compared to Target Alignment and Other Measurement Methods

When the GAI encounters a distribution of flakes as occurs in flakeboard, the signal strength varies considerably. Signal strength decreases with increasing variability in alignment of simultaneously sensed flakes. If all flakes are aligned in the same direction, then the signal strength is large. On the other hand, if the flakes contributing to the measurement are disbursed uniformly in all directions as in a truly random fashion, the signal strength will be low. This relation is depicted in Figure 9, which represents two flakes each contributing equally to the GAI signal. The flake directions, their vector representations in a double-angle space, and the resultant vector also in the double-angle space are shown. For a randomly oriented board (Fig. 9A), the resultant of the double-angle vectors is equally likely to occur in any direction but tends to have a small amplitude. In a partially aligned board (Fig. 9B), the direction of the resultant double-angle vector is influenced by the alignment direction and tends to be large in magnitude.

As indicated earlier, the Model 510 GAI can be adjusted to prevent angle calculation when the signal strength is below a threshold limit. This level was arbitrarily set during this study to eliminate very low-strength signals. Output for those measurement locations where signal strength was below the threshold was presented as a no data symbol. The low-strength or no data responses occurred randomly throughout the range of angles measured and thus have little effect on the calculation of alignment level. Useable data are presented as angles (between +89° and -89° from the reference direction). Tote $G´$ and R´ values for the parallel data in Table 3 are the averages of four specimens (two from each of two boards). The $G´$ and $R´$ values for the perpendicular data are the averages of two specimens (one from each of two boards). These averages were computed by the same method as presented in Equations (14) to (17) (circular mean (Mardia 1972)). The $c´$ and $s´$ values for individual specimens were weighted by the correspunding numbers $n´$ to derive the averages $c´$ and s' for the set. The set averages c' and s' were used in Equations (14) and (15) to compute G' and R' for the set. All multiple specimen average values of G' and R' given throughout this paper were computed in this manner.

Because of the averaging effect cawed by contribution of multiple flakes (Fig. 3), percent alignments calculated as the averages of the absolute GAI angles (Equation (1). Table 3) were higher than those obtained with the IA, MOE:R, or SVR methods for the aligned boards (Table 2). Percent alignments calculated using the axial methods described previously (Equation (22)) are shown for values of n equal to 5, 24, and 60 in Table 3 and Figure 8. The predicted alignments obtained with n = 60 are closer to values from other methods than when n = 5. For the purpose of comparing the effect of process variables on the GAI measurements, we chose a value of n = 24. We believe that n is related to an effective number of flakes contributing to each measurement; however, more experiments and comparisons are required to learn how process variables such as flake geometry affect the result. The sensitivity of *n* to changes in process variables will determine the reliability of the GAI instrument for process control.

The GAI showed increased alignment of high-density boards in the 50- and 70-percent target alignment groups compared with measurements from low-density boards (Table 3). This trend was also present in the IA and MOE:R data, indicating that the alignment difference was real and not a function of signal alteration. In addition, we determined that specimen moisture content, in the range tested, does not affect the GAI reading. The GAI values determined for those specimens conditioned at 65 percent RH and at OD conditions were identical to those obtained from specimens conditioned at 30 percent RH. These data are not shown.

Calculations of alignment angle *G'* showed very little deviation from the preferred alignment direction with the exception of those boards with random flake distribution (Table 3). The alignment directional angle calculated for individual boards with random flake distribution varied from -76° to +84°, which is simply an indication of the random flake distribution. With truly random alignment, one would expect the angles *G'* to be uniformly distributed over the entire range of -90° to +90°. This is consistent with the small *R'* values observed for boards with random flake distribution

Differences between alignment measurements made in the two sample directions were evident. The GAI percent alignment was calculated using Equations (1) and (22) for both the average of No. 3 specimens (flake alignment perpendicular to the longitudinal direction of GAI travel) and the average of No. 1 and 2 specimens (flake alignment parallel to the direction of GAI travel) (Table 3). Alignment measured from the perpendicular cut samples was less than the alignment measured from the parallel cut samples. The reason for this is not folly understood, but the reduced alignment is thought to be partially caused by forming techniques. The board was formed by passing a deckle box back and forth under a mechanical aligner. Both the interference of the box and the change in motion at the end of a pass tended to reduce alignment in the area of the board from which the perpendicular sample was cot. Discrepancies between parallel and perpendicular data may also relate to instrument calibration. The Model 510 GAI was designed to optimize the measurement of grain angles around 0°. Calibration for the equipment becomes quite sensitive for angles around +90° and -90°. Newer technology, using a nonrotating sensor, does not have the same calibration sensitivity around +90° or -90°. In fact, signals proportional to cos(2θ) and sin(2θ) are directly available as outputs.

Although it did not provide a high-resolution measurement of signal strength, the Model 510 GAI did provide the binary result that the signal was either above or below a preset threshold. The average number of no-data (below threshold) recordings varied inversely with the IA alignment level, from 724 (out of a possible 896 for the 14 x 64 matrix) for the random specimens to just 8 for the boards targeted to a 70-percent flake alignment (Table 3). Figure 10 shows the regression of IA alignment of the boards against the number of no-data recordings for 32 parallel-aligned specimens, two from each of 16 boards. The relationship between number of no-data responses to alignment level is a clear indication of the potential for using GAI signal strength to indicate alignment level. Variables such as moisture content, density, species, and sensor proximity may have a greater effect on signal strength than on signal phase and must be considered in using signal strength to obtain an alignment measurement.

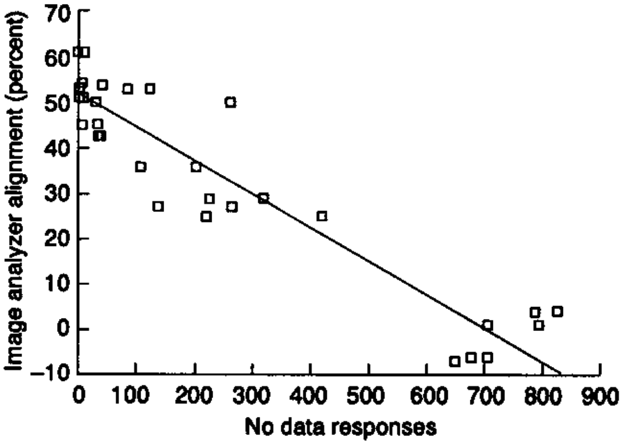


Figure 10—Flake alignment is related to number of no-data responses. Regression is described using no-data count for two specimens each from 16 boards. Image analysis data was obtained on each board. Image analysis percent alignment = 51.5 - 0.0726 (number of misses), r^2 = 0.877.

Measurement Penetration of GAI

Homogeneous aligned specimens backed by both random and cross-aligned specimens were reduced in thickness to determine the extent of GAI penetration and the effect of core alignment on flake alignment measurements. The data indicate that penetration is between 1.6 and 3.2 mm (0.063 and 0.125 in.) in either a random or aligned board (Table 4). For example, at a target alignment of 30 percent, the GAI reading of 86 percent obtained with a 3.2-mm (0.125-in.) hoard thickness decreased to 44 percent when the board thickness was reduced to 1.6 mm (0.063 in.). This reduction shows that the backer contributes significantly to the measurement through the 1.6-mm (0.063-in.) surface boards but not significantly through the 3.2-mm (0.125-in.) surface boards.

Table 4—Grain Angle indicator flake alignment measurements as affected by board thickness[a]

Target alignment (%)	Target specific gravity	Flake alignment measurements (%)									
		Board thickness (mm (in.))[b]				Board thickness (mm (in.))[c]				Board thickness (mm (in.))[d]	Board thickness (mm (in.))[e]
		12.7 (0.50)	6.3 (0.25)	3.2 (0.125)	1.6 (0.063)	12.7 (0.50)	6.3 (0.25)	3.2 (0.125)	1.6 (0.063)	1.6 (0.063)	1.6 (0.063)
0	0.64	–	–	–	–	0	0	0	4		0
0	0.85	–	–	–	–	0	0	0	5		0
30	0.64	63	51	86	44	62	49	46	29	65	43
30	0.85	52	66	65	40	52	65	59	24	63	46
50	0.64	70	82	88	74	70	82	85	54	85	78
50	0.85	81	88	87	80	81	88	84	58	88	82
70	0.64	90	91	93	82	90	91	89	60	90	84
70	0.85	88	93	96	92	87	92	95	85	95	93

[a] Percentages calculated using axial data (*n* = 24).

[b] Random backer.

[c] Cross-aligned backer.

[d] Aligned backer.

[e] No backer.

Successive reductions in specimen thickness indicated in most cases that the inner portions of the homogeneous boards were more aligned than was the surface. This could account for some differences between GAI and IA values. Measurements taken on the 1.6-mm- (0.063-in.-) thick specimens with a parallel-aligned backer, and again without any backer, indicated only slight differences in alignment of this layer and the central portion of the board. For the same specimen thickness (1.6 mm (0.063 in.)), the cross-aligned backer influenced the readings to a greater degree than did the random backer.

Density had a slight effect on penetration of the electric field of the sensor. When the specimen thickness was reduced from 3.2 mm (0.125 in.) to 1.6 mm (0.063 in.), there. was a greater change in the calculated average alignment percent for the low SG random-backed samples than for the high SG random-backed samples.

Sensors can be designed with different geometries to achieve different sensed areas and depths of reading (Bechtel and others 1990). The sensor used for these experiments was sensitive over a circular area with a diameter of 19 mm **(0.75** in.) and had gaps between electrodes of about 2.3 mm (0.090 in.). No experiments with different sensor geometries were perfomed.

GAI Performance on Three-Layer Boards

Face-layer thickness has been shown to vary within thick red oak three-layer board by as much as 3.05 mm (0.120 in.) (Geimer and others 1982). Three-layer boards were fabricated to ascertain the effect that these normal variations in vertical layer thickness have on the GAI alignment measurements. Average alignment percentages for specimens from the three-layer boards are given in Table 5.

Random Core

Within the constraints of this study, the random core had no effect on percent alignment as calculated from GAI measurements of the face layer. The GAI measurements of three-layer random core specimens (Table 5) showed only small (3 to 9 percent) differences in alignment between the top and bottom surfaces. Planing 0.762 mm (0.030 in.) off the faces bad little effect on measurement of surface alignment. The GAI measurements of the unplaned random core boards were similar to those measurements taken on homogeneous specimens, which indicated that fabrication techniques provided the same degree of alignment in both types of boards. Image analyzer values obtained in both cases were also similar.

Cross-Aligned Core

The cross-aligned core influenced the GAI measurements at a greater depth than did the random core. (Table. 5). This is contrary to what was experienced with the reduced thickness homogeneous boards where both the random and the cross-aligned backers were detected between 1.6 and 2.54 mm (0.063 and 0.100 in.). The effect of the core was further emphasized after removing a 0.762-mm- (0.030-in.-) thick layer and was more noticeable on the bottom than on the top layer.

These 12.7-mm- (0.5-in.-) thick three-layer boards were. made with a layer distribution of 20:60:20 (by weight) and have a theoretical face-layer thickness of 2.54 mm (0.100 in.). The three-layer boards were constructed to an average SG of 0.721. Maximum density of the face layers on these boards was only 5 percent greater than the average board density because of the cold pressing technique used to consolidate the mats. Considering the possible variations in layer thickness caused by uneven mat formation and a slight face-layer thickness reduction caused by the vertical density gradient, cross-aligned core flakes were probably sensed by the GAI at some measured positions. Variation in the alignment values of the three specimen replications measured for each reported value was approximately four times larger for the boards with cross-aligned cores than for the boards with random cores.

Removing 0.762 mm (0.030 in.) of thickness could easily produce areas of face thickness less than the 1.600 mm (0.063 in.) where GAI depth penetration was observed in the homogeneous boards. To further investigate the internal construction of these boards, an additional 1.52 mm (0.060 in.) of face material was removed. At this level, numerous core-layer flakes were exposed. The fact material was completely eliminated in some cases after removing a total of 3.05 mm (0.120 in.) and in all cases after removing 3.81 mm (0.150 in.).

From a product performance aspect, knowing the effect of face-layer variations on bending strength of a board is vital. The sensitivity of the GAI to face-layer depth may be equally important to the ability of the GAI to distinguish flake alignment.

Conclusions

Flake. alignment in face layers of oriented structural flakeboard is an important variable for control of panel stiffness. The Grain Angle Indicator (GAI) device used in this study is capable of quantifying the alignment of flakes and indicates the potential as an on-line means to determine the alignment in the surface layers of three-layer board. Our investigations were primarily directed at using the GAI-generated angular (phase) measurements to determine

Table 5—Average flake alignment of three-layer boards.

Face target alignment	Core target alignment	Grain Angle Indicator alignment measurement[b]								IA alignment measurement[c]
		Top layer				Bottom layer				
		Before		After		Before		After		
		R'	$100R_o$ (%)	R'	$100R_o$ (%)	R'	$100R_o$ (%)	R'	$100R_o$ (%)	
30	0	0.902	54	0.898	52	0.911	57	0.896	52	32
30	30	0.810	28	0.188	0	0.608	5	0.211	0	32
50	0	0.962	79	0.962	79	0.943	71	0.923	62	50
50	50	0.825	32	0.355	0	0.842	36	0.674	9	36
70	0	0.960	78	0.958	78	0.969	83	0.966	81	52
70	70	0.884	48	0.530	2	0.859	40	0.195	0	50

[a] Calculated from axial data (n = 24).

[b] Before and after designate removal of 0.76 mm (0.030 in.) of surface layer.

[c] Image analysis (IA) data taken on top surface before cutting specimen or removing any material.

average alignment levels. Mathematical relations were developed that allow the direction and level of alignment to be calculated independently. Calculations must be adjusted by a factor *n* that represents an effective number of flakes contributing to the sensor signal at any one measuring point. If a definite means is developed for determining *n*, that value can be. used to determine percent alignment along with a claim to being calibrated against a fixed standard. In the absence of perfect knowledge of *n*, a convenient value can be selected. With constant furnish distribution and fixed sensor, we believe the resulting percent alignment values can be used to accurately compare. the alignment of one board with that of another. Alternatively, the value *n* can be adjusted to make the percent alignment agree with some other measure of percent alignment (for example, Equation (1)) for known situations. Thus, *n* can be used as a calibrating parameter.

This study showed that specific gravity only slightly influences the depth of the GAI reading below the surface of flakeboard. No effect was observed from moisture. content in the range from ovendry to 8 percent. Sensitivity of the GAI signal to flake alignment at depths to about 3.2 mm (0.125 in.) was observed. No evidence is available at this time that indicates that the GAI measure for alignment level is more or less accurate than previously used methods, which arc based on individual flake angle, sonic velocity ratio, or bending ratio measurements. However, the GAI methods described have an advantage in their potential for practical implementation.

Recommendations

The ability of the GAI to measure signal amplitude may provide a second method of measuring alignment. However, this feature may be more sensitive to board density, moisture content, and sensor proximity to the board than arc angular measurements. Further investigations should expand the collection of data to include lower amplitude signals and determine the feasibility of using signal strength as a measure of alignment. The design of sensor geometry needs to be optimized.

Further experiments would more accurately determine and verify the effect of different flake geometries and sizes on alignment measures computed from the GAI signal. Information is needed concerning GAI sensitivity of depth variations in multilayered boards with cross-aligned cores.

Acknowledgment

The authors thank Dr. Steven M. Cramer, Assistant Professor, Department of Civil Engineering, University of Wisconsin-Madison, Madison, Wisconsin 53706, for the use of the Metriguard Model 510 Grain Angle Indicator.

References

ASTM. 1987. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D-1037. Philadelphia, PA: American Society for Testing and Materials.

Bechtel, F.K.; Allen, J.R.; Uskoski, D.A. 1990. Advances in grain angle measurement, In: Proceedings, process control symposium; 1990 November 1; Athens, GA.

Geimer, R. 1976. Flake alignment in particleboard as affected by machine variables and particle geometry. Res. Pap. FPL-275. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Geimer, R. 1979. Data basic to the engineering design of reconstituted flakeboard. In: Proceedings, 13th International particleboard symposium; 1979 April 3-5; Pullman, WA. Pullman, WA: Wood Technology Section and Engineering Extension Service, Washington State University.

Geimer, R. 1981. Predicting shear and internal bond properties of flakeboard. Holz als Roh-und Werkstoff. 39: 409-415.

Geimer, R. 1986. Mechanical property ratios—a measure of flake alignment. Res. Pap. FPL-468. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Geimer, R.; Hoover, W.L.; Hunt, M.O. 1982. Design and construction of large scale reconstituted wood roof decking. Research Bull. RB 973. West Lafayette, IN: Department of Forestry and Natural Resources, Agricultural Experiment Station, Purdue University.

Johnson, J. A.; Harris, R.A. 1976. Characterizing particle orientation in particleboard with directional probability distribution functions and predicting the tensile elastic modulus. #VPIWST-76-6. Blacksburg, VA: Virginia Polytechnic Institute and State University.

Laufenberg, T.L. 1986. Using gamma radiation to measure density gradients in reconstituted wood products. Forest Products Journal. 36:(2): 59-62.

Mardia, K.V. 1972. Statistics of directional data. London, England: Academic Press.

McDonald, K.A.; Bendtsen, B.A. 1986. Measuring localized slope of grain by electrical capacitance. Forest Products Journal. 36(10): 75-78.

McLauchlan, T.A.; Norton, J.A.; Kusec, D.J. 1973. Slope of grain indicator. Forest Products Journal. 23(8): 50-55.

Shaler, S.M. 1991. Comparing two measures of flake alignment. Wood Science and Technology. 26: 53-61.