United States
Department of
Agriculture

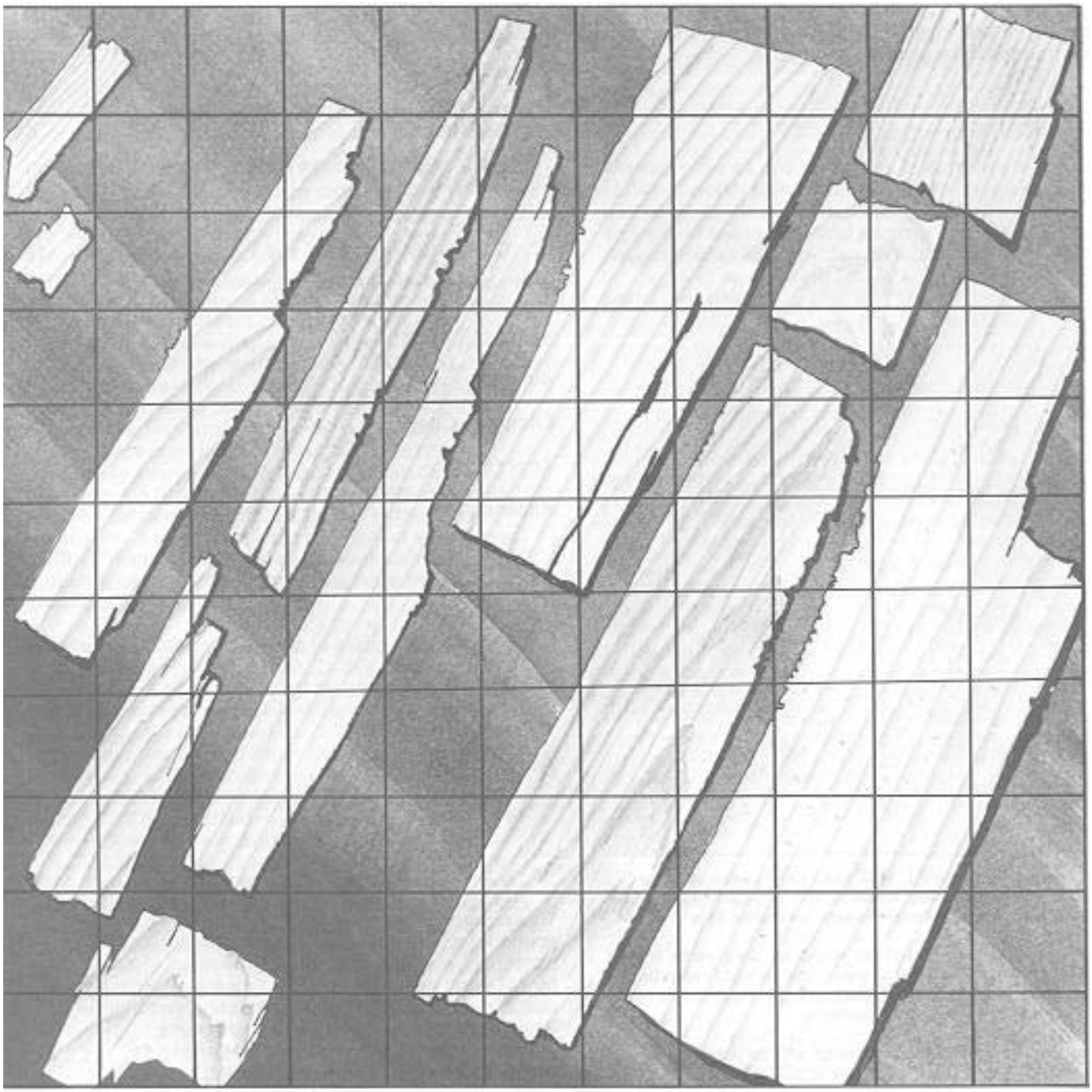
Forest Service

Forest
Products
Laboratory

Research
Paper
FPL-RP-486

Flake Classification by Image Analysis

Robert L. Geimer
Carol L. Link



Abstract

Image analysis is a technique that can be adapted to classify flakes by their geometric dimensions. This system is well suited to the flakeboard industry where flake dimensions, slenderness ratios, and aspect ratios are critical to the design and fabrication of structural material. Our report develops basic relations between image analysis and the more familiar screen fractionation. Analytical methods of presenting the data are discussed, and a cursory look is taken at correlating flake classification data to ultimate board performances.

Keywords: Flakes, classification, image analysis, screen fractionation, particle geometry.

June 1988

Geimer, Robert L.; Link, Carol L. 1988. Flake classification by image analysis. Res. Pap. FPL-RP-486. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 25 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 over 1,000 libraries in the United States and elsewhere.

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

Table of contents

	Page
Introduction	1
Objective	1
Procedure	2
Material Preparation	2
Image Analysis Techniques	5
Board Fabrication	5
Board Testing	5
Results and Discussion	6
Screen Weight and Screen Flake Count Data Sets	6
Image Analysis–Screen Image Analysis	6
Comparison of Screen Fractions	6
Comparison of Type I and Type II Flakes	11
Image Analysis-Main Image Analysis Data Set	11
Board Properties	17
Summary	19
Literature Cited	19
Appendix A	25
Appendix B	25

Acknowledgments

This report results from the efforts of many persons spanning a period of over 5 years. The authors especially wish to acknowledge the input of Xaiver Dop for research design; Copeland Francis, William Rogers, and William Kreul for flake preparation and digitizing; Wench Wlodarczyk for computer programs; J. Kevin Little for initial data analysis; and Richard Kinney for hardware support.

Flake Classification by Image Analysis

Robert L. Geimer, Technologist
Carol L. Link, Mathematical Statistician

Forest Products Laboratory, Madison, WI

Introduction

Characterization and sorting of reconstituted wood furnish is traditionally done by passing the material over a series of screens diminishing in mesh size. This procedure works well with the relatively small, indiscriminate particles used to produce a particleboard, where surface smoothness and laminating quality are of primary importance. Screening is also useful in the production of waferboard, where a major concern is the separation of large flakes from the fines (usually defined as material which passes a 1/16- or 1/32-in mesh screen). Screen fractionation, while serving as an easy method of evaluating a furnish and the only practical means of sorting large quantities of material, does not adequately describe such things as flake dimensions, aspect ratios (length/width), and slenderness ratios (length/thickness), which are critical to the design, fabrication, and performance of oriented strandboard (OSB). The problem of geometrically describing a furnish is confounded if there is a large variation in dimension and form.

A technique that can be used to measure flake dimensions is image analysis. In this method, the perimeter of a flake is defined by a coordinate system; calculated dimensional descriptors, such as length, width, longest chord, area, form factor, etc., are used to compare the flake to other flakes, a set of defined parameters, or population means. The outline of the object in a two-dimensional rectangular coordinate system can be obtained manually through the use of sonic or magnetic x-y digitizers, or can be scanned directly with a video camera (Arnold 1986, McMillen 1982). Coordinate systems have been expanded in some cases to include a z axis. Depth measurements have been made using x rays, optical detectors (in the case of semitranslucent objects), and more recently, laser beams, sonic transducers, and offset lighting techniques (Arnold 1986).

Objective

The objective of this study was to compare two types of flake furnish using both image analysis and screen fractionation classification techniques. The study defines means to view and summarize the image analysis data, and provides an initial look at the problems of associating image analysis data with board properties.

Material Preparation

Ring-cut flakes were chosen as the preferred furnish type for this study to provide greater variation in dimensions than usually occurs with disk-cut flakes. Two grades of aspen ring flakes were fabricated. The high-quality flakes, termed “Type I” flakes in this study, were produced from sawn blocks of aspen measuring 1 by 1 by 2-3/4 inches (fig. 1). The lower quality flakes, termed “Type II” flakes, were flaked from maxichips (fig. 2) produced on a drum chipper. The maxichips were characterized by extreme variability in shape and were often internally shattered parallel to the grain so that the chip could be riffled like a deck of cards. The blocks and the maxichips were each split into three batches of approximately 100-pounds, ovendry (OD) basis. These six batches were then flaked in succession beginning with the sawn blocks (Type I flakes) and alternating with the maxichips (Type II flakes). All six batches were then dried separately to approximately 4 percent moisture content (MC) in a slowly rotating (less than 2 rpm) drum dryer.

During material preparation, five distinct subsets of flakes were set aside for separate purposes. These subsets are referred to as the screen weight data set, the screen flake count data set, the screen image analysis data set, the main image analysis data set, and the board construction data set. A schematic of flake and board preparation procedures is given in figure 3.

Approximately 20 pounds of material from each batch were classified on a 2- by 4-foot laboratory inclined vibrating screening device using 1-, 1/2-, 1/4-,1/8-, 1/16-, and 1/32-inch mesh sizes. The material was screened in three passes using two progressively smaller mesh screens stacked for each pass. After screening, the minus 1/32-inch portion was discarded. The weight of material on each screen was recorded as a percent of the total weight and constituted the screen weight data set. From one batch of each flake type, a small sample from each screen fraction was used to determine a flake count per unit weight. This was called the screen flake count data set. Likewise, 40 to 60 flakes were chosen from each of these screen fractions for image analysis, constituting the screen image analysis data set.

The remaining unscreened portion of each batch was then screened to separate the flakes passing a 1/8-inch screen. In this case, material was screened with a 3- by 5-foot two-deck inclined vibrating screen using 1/4- and 1/8-inch mesh screens. The material not passing through both screens was recombined. This fraction, which contained the largest flakes, was thoroughly mixed in a pile and then successively split vertically and remixed until three small samples per batch could be obtained for the main image analysis work. More priority was given to obtaining a representative sample than to keeping the sample sizes uniform. Sample size varied from 7 to 17 grams. These 18 samples, 3 each from 3 batches of Type I and II flakes, comprised the main image analysis data set.

The flakes remaining after obtaining the samples for image analysis were used to create the board construction data set. The flakes from the second batch of flake furnish were recombined (with the exception of those fines passing a 1/32-in mesh screen) and enough of this material was set aside to make at least four random and four aligned boards from both flake Types I and II (designated Ca and Cr, fig. 3) Material from batches 1 and 3 was mixed and rescreened to provide furnish for making both aligned and random boards from the larger screen fractions (a) retained on or above 1/2 inch (1/2a, 1/2r), (b) passing through 1/2 inch but retained on 1/4 inch (1/4a, 1/4r), and (c) passing through 1/4 inch but retained on 1/8 inch (1/8a, 1/8r) (fig. 3). This procedure was followed for both Type I and Type II flakes.

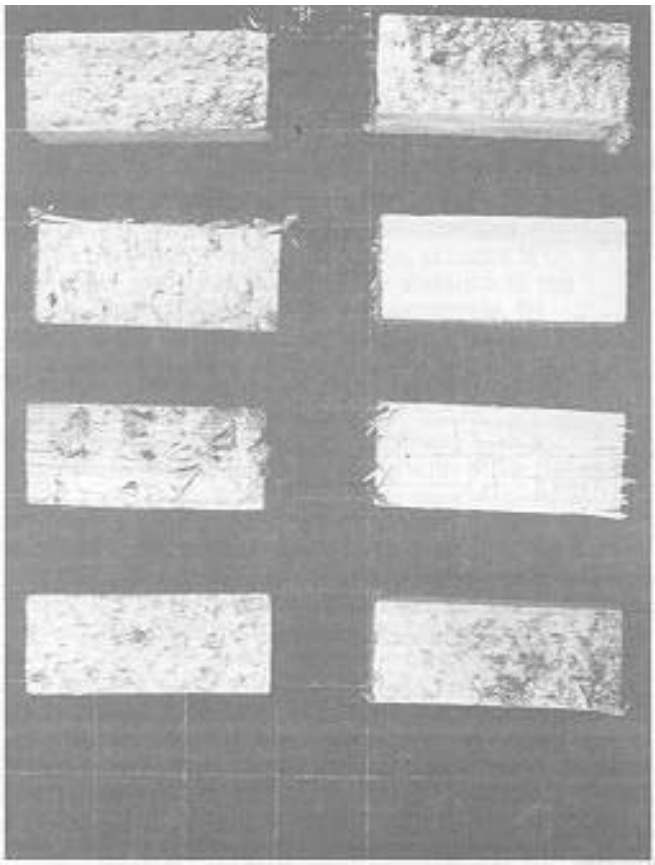


Figure 1 —Type I sawn blocks. (M150 562-1)

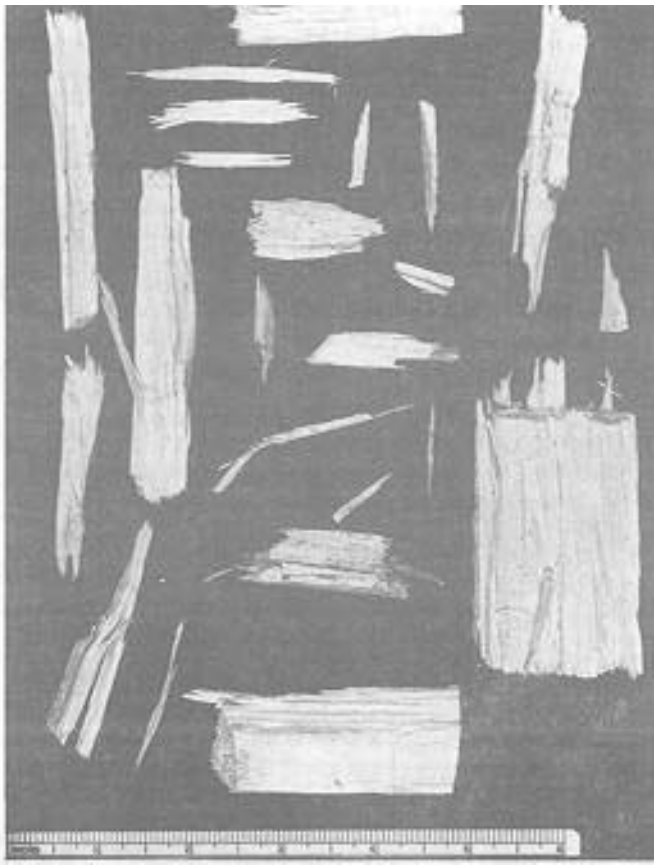


Figure 2—Type II maxi chips. (M150 562-11A)

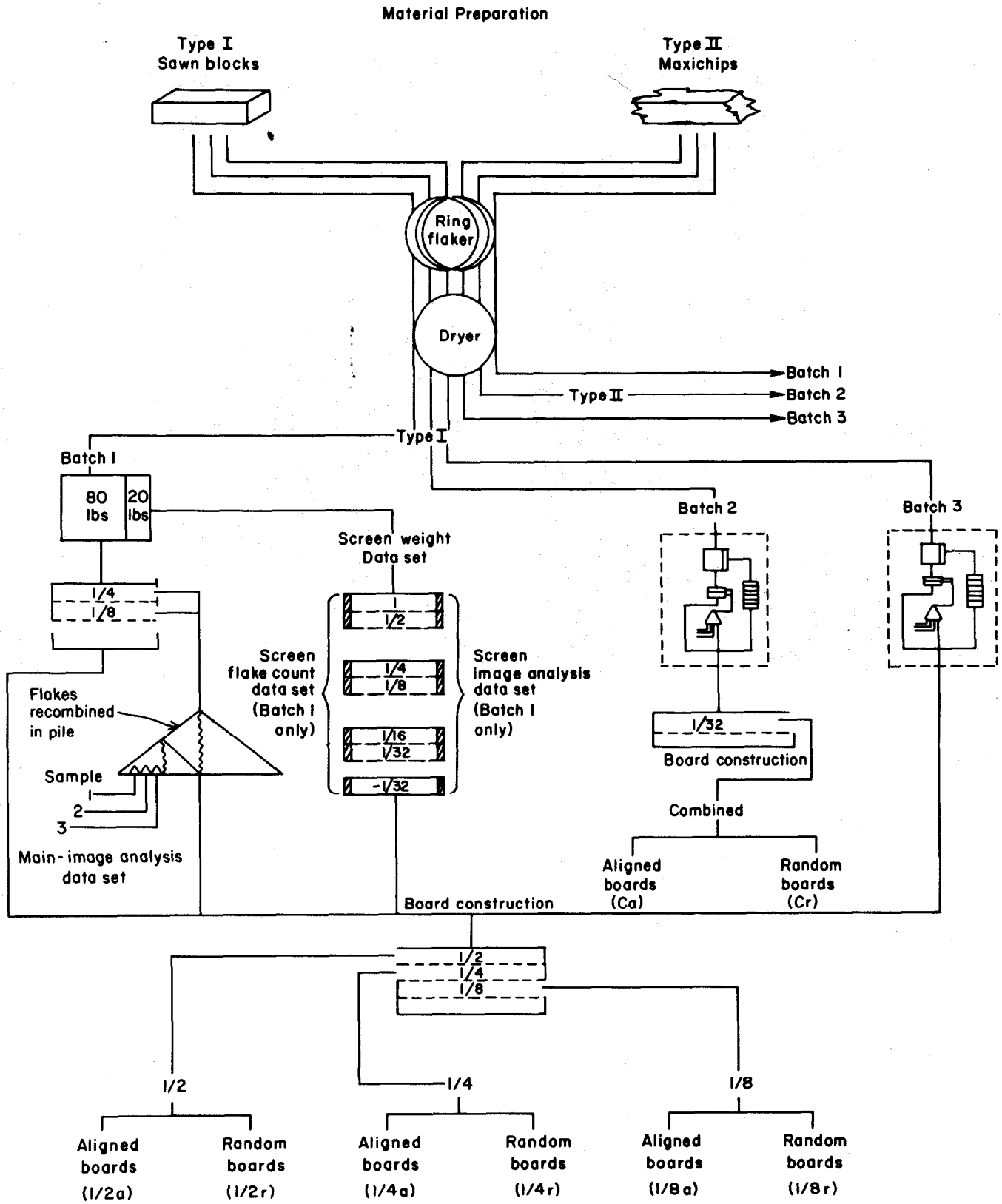


Figure 3—Experimental procedure schematic. (ML87 5509)

Image Analysis Techniques

Image analysis data from both the screen image analysis and main image analysis data sets were obtained using a sonic x-y digitizer. This machine has a linear sonic sensor along each of two adjacent edges of a horizontal table. A stylus used to outline the perimeter of a two-dimensional figure placed on the table emits a spark each time it is pressed to the table. The time lapse between spark initiation and subsequent audio detection by the sensors is measured and used to define the distance to the stylus, thus establishing its x-y coordinate. By successfully raising and lowering-the stylus, a series of coordinates that define the shape of the figure is obtained as the perimeter of the figure is traversed.

Each flake was measured for thickness with a micrometer and then taped, along with other flakes, to a black sheet of paper. The flakes were aligned with the grain direction parallel to the short dimension of the paper. Flake thickness was recorded on the paper alongside the flake and a photocopy made of the entire sheet. The photocopies of the flakes were then placed' on a selected area of the digitizer table, with the short dimension of the paper corresponding to the x axis. The perimeter of the flake was traced using the stylus as outlined above. The periphery of long splits was included in the perimeter measurements. Next, the stylus was used to record the flake thickness and other descriptive data by touching specific areas of the table that had been assigned numeric values. Flake width and the long chord were also defined. Measurement of width perpendicular to the grain direction was sometimes difficult to determine for an irregularly shaped flake. The measurement depended wholly on the technician's visual estimation. The estimated flake width was compared to maximum width by calculating maximum y-axis distance. Long chord, defined as the longest distance between extremities of a flake without crossing checks or splits, was chosen as an estimate of flake length because this distance is readily obtained with video-scanning equipment. Subsequent data analysis showed this dimensional description to be highly correlated with the flake length along the grain (maximum x-axis distance). The data were automatically recorded on magnetic tape and later transferred to a computer for analysis.

The physical size of the measuring stylus prevented obtaining any meaningful image analysis data of very small flakes (minus 1/8-in screen). Another limitation of the sonic digitizer was the time expended to obtain data. Approximately 1 minute was used in measuring and recording ah individual flake. This tedious, repetitious work resulted in errors that later required correction. All these limitations could have been overcome through the use of video-scanning equipment.

Board Fabrication

Using flakes from the board construction data sets, boards were constructed to the following specifications:

Size–0.5 by 24 by 28 inches
Specific gravity (SG)–0.641 OD basis
Resin solids–5 percent phenolic based on OD wood
Emulsified wax solids–1 percent based on OD wood
Mat moisture into press–10 percent based on OD wood, resin, and wax
Press closing time–1 minute
Total press time–10 minutes
Press temperature–347 °F (175 °C)

A flake alignment machine was adjusted to provide approximately 50 percent flake alignment (Geimer 1976) with the combined Type I flake furnish. This setting was then used in fabricating the rest of the aligned boards for both flake types.

Board Testing

After trimming and equilibrating the boards at room temperature and 65 percent relative humidity (RH), the alignment was checked with a sonic velocity meter (Geimer 1979). Sonic velocity measurements were also made on 3- by 13-inch and 13- by 13-inch samples.

The following number of test specimens were cut from each board:

Test	Test direction (to alignment)	
	Parallel	Perpendicular
Bending modulus of elasticity (MOE), modulus of rupture (MOR), SG	2	2
Tension MOE, maximum stress	1	1
Internal bond (IB)	5	—
Dimensional stability	2	2
Bending MOE, MOR (wet)	1	1

All tests were performed to American Society for Testing and Materials (ASTM) D 1037 specifications where applicable. Wet-bending tests were conducted following a vacuum pressure soak (VPS) treatment. Calculations were based on thickness of specimens at time of testing. The dimensional stability properties of MC, thickness swell, and linear expansion were measured after ovendrying and successive exposures to conditions of 65 and 90 percent RH at room temperatures, VPS, and a final ovendrying.

Meaningful flake classification depends on development of both a sorting procedure and a technique to analyze the resultant data (May 1982, May and Keseru 1982, May and Stegmann 1966, Neusser and Krames 1969, Rackwitz 1964, Vorreiter 1964). In addition, it is very important that the parameters used to define the flake furnish are related to actual board performance (Neusser and Krames 1969, Neusser et al. 1969, Rackwitz 1963). Our work was primarily directed at developing techniques for data analysis. As described earlier, the two sets of data used for image analysis were the screen image analysis data set, consisting of 40 to 60 flakes from each screen fraction, and the much larger main image analysis data set of flakes retained on or above a 1/8-inch screen.

Screen Weight and Screen Flake Count Data Sets

Examples of separate screen fractions for Type I flakes passing through 1/32-inch screen and retained on 1/32- through 1/4-inch screens are illustrated in figure 4. No visual differences were discerned between Type I and Type II flakes on these screens. However, Type II flakes retained on 1/2- and 1-inch screens appeared to be narrower and have more ragged edges and less uniformity in length than their Type I counterparts (fig. 5).

The greatest difference between the two flake furnishes, as distinguished by screen fractionation, was the relative quantity of any one flake fraction. The sawn blocks unquestionably resulted in a greater production of large-sized flakes. Screen analysis showed that 40.2 percent by weight of the Type I flakes from sawn blocks were retained on or above a 1/2-inch mesh screen compared to only 5.3 percent for the Type II flakes from maxichips (table 1). Almost 2-1/2 times as many fines (minus 1/32-in mesh) were discarded from the Type II furnish prior to making boards.

A preliminary count using flakes in the screen flake count data set indicated a large difference in flake size between each screen fraction. The number of flakes per 100 grams increased from 330 on the 1-inch mesh screen to 330,000 on the 1/32-inch mesh screen for the Type I furnish and from 740 on the 1-inch mesh screen to 240,000 on the 1/32-inch mesh screen for Type II furnish. These values and means of several other descriptive variables, derived from the screen image analysis, are given in table 1 for each screen fraction and flake type. Note that whereas Type I flakes retained on and above the 1/4-inch mesh screen had a larger mean top surface area and lower flake count than similarly screened Type II flakes, the reverse was true for those flakes passing the 1/4-inch screen.

Image Analysis– Screen Image Analysis Data Set

Comparison of Screen Fractions

Box plots show the range of values for selected variables by screen fraction for Type I flakes (fig. 6a-d). A complete description of box plots can be found in Chambers et al. (1983). Briefly, a box surrounds the central 50 percent of the data. The lower edge of the box denotes the 25th percentile, the upper edge is the 75th percentile, and the line across the box indicates the median (50th percentile) value. Lines from either end of the box show the range of the data, with the exception of outlying data which are denoted by dashes. In figure 6, note the large variation of flake geometry on any one screen and the resulting overlap between screens.

An analysis of variance (ANOVA) was used to test whether the average (mean) values of the geometric descriptors were statistically different between the various screen fractions. The p values from the ANOVAs were all less than 0.0001, with the exception of aspect ratio for the Type II flakes ($p = 0.4$). This implies that the averages of the descriptor variables were not the same at the 0.05 level of significance (except for Type II aspect ratios), and multiple comparisons were used to determine which screens were statistically different. The results of the multiple comparisons are given in table 2. The averages of the geometric descriptors of different screen fractions cannot be considered statistically different if they share a common underline (using Tukey's multiple comparisons). One of the assumptions of ANOVA is that the variability in each screen fraction is the same. This was not the case with many of the variables considered. For example, for unaltered data (fig. 7a), the flake area was quite variable between screen fractions, as depicted by a larger spread in data for the l-inch screen than for the 1/32-inch screen. Transformations of the data, e.g. use of the square root or natural logarithms, can in some cases make the variability between each screen fraction more comparable. For our data, the logarithmic transformation was found to be appropriate for area; i.e., the variability in the logarithm of the areas was approximately the same in each screen fraction (fig. 7b). The transformations used in the ANOVA are given in table 2.

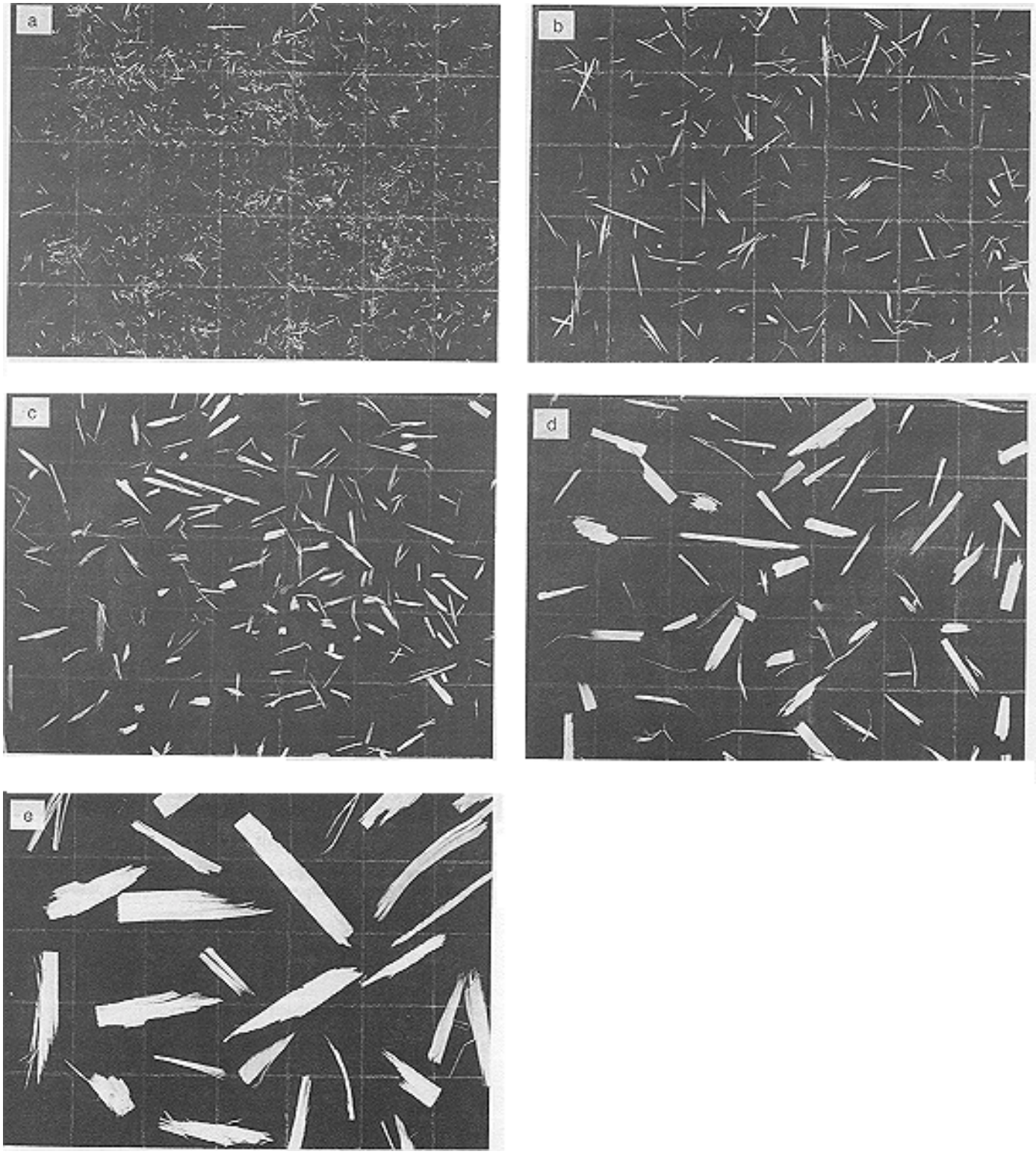


Figure 4—Screen classification of Type I flakes. (a) Flakes passing through 1/32-inch screen (M150 562-8); (b-e) flakes retained on 1/32-, 1/16-, 1/8-, and 1/4-inch screens, respectively (M150 562-7 through 5; M150 562-3).

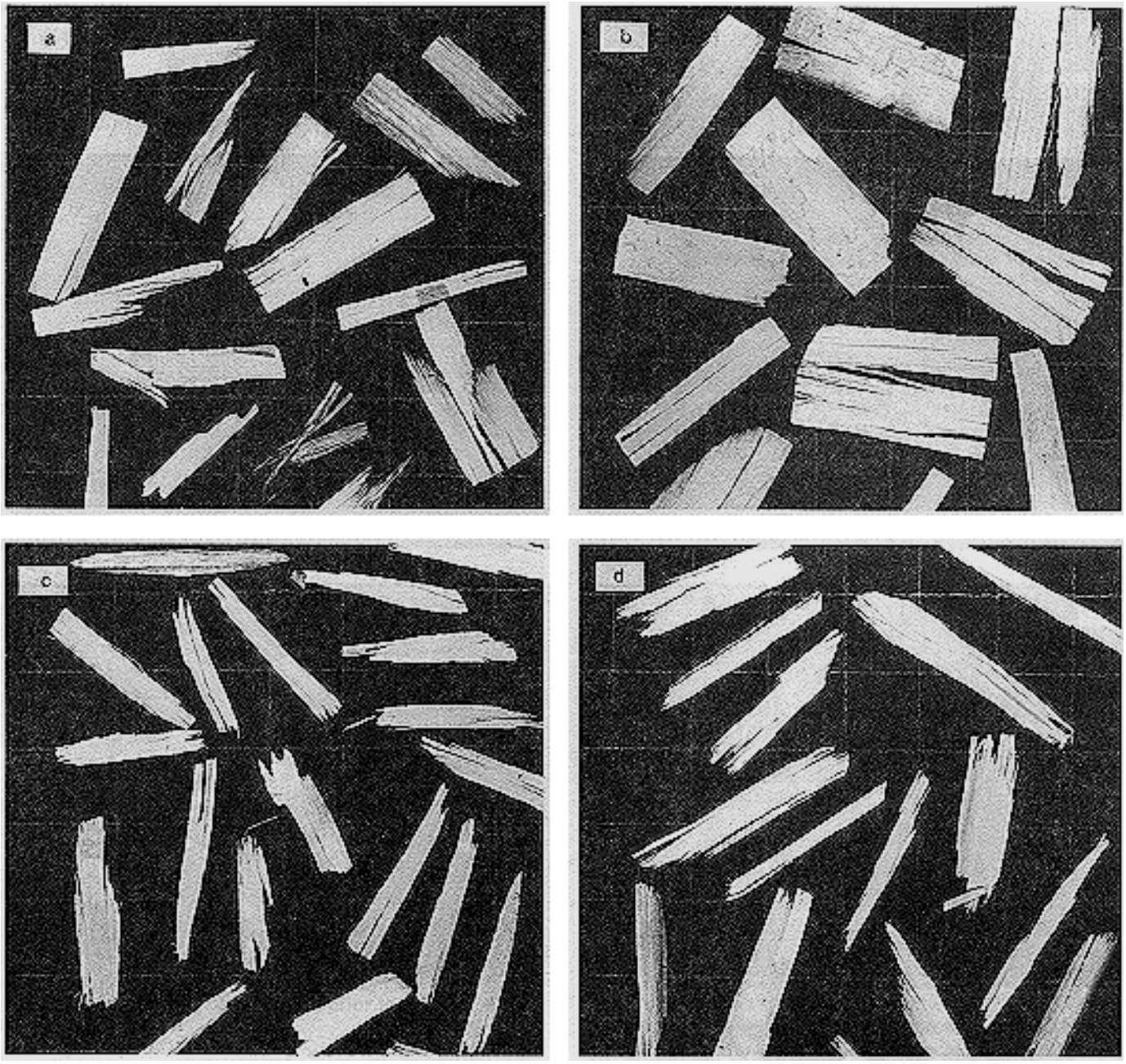


Figure 5—Type I and Type II flakes retained on 1/2- and 1-inch screens. (a) Type I flakes retained on 1/2-inch screen (M150 562-2); (b) Type I flakes retained on l-inch screen (M150 562-2); (c) Type II flakes retained on 1/2-inch screen (M150 562-13); and (d) Type II flakes retained on l-inch screen (M 150 562-12).

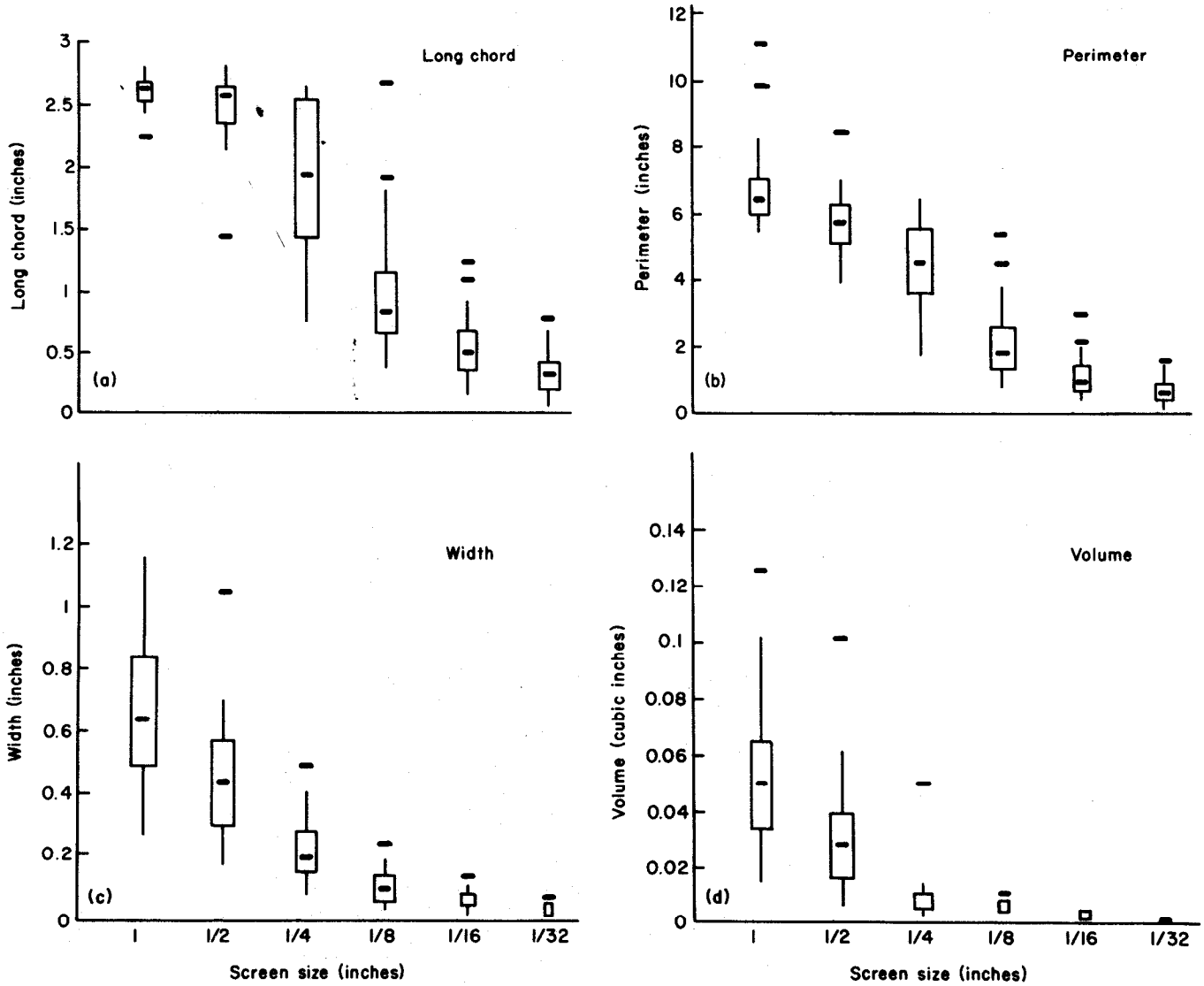


Figure 6—scatter of screen fraction data of Type I flake variables. (a) Long chord, (b) perimeter, (c) width, and (d) volume. (ML87 5510)

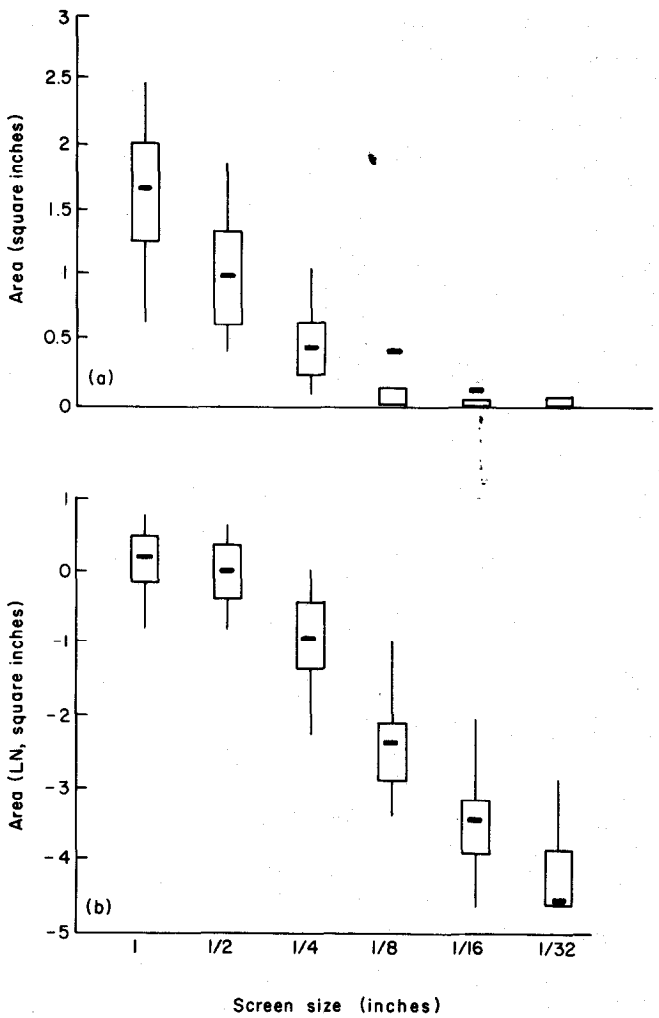


Figure 7—Matching variability in screen fractions of Type I flakes. (a) Flake area unaltered data; (b) flake area logarithmic transformation. (ML87 5511)

Average' flake thickness decreased slightly as the flakes became smaller (table 1). Multiple comparisons, however, indicated that the average flake thickness was not statistically different for all adjacent screens. The decrease in flake thickness was less noticeable with Type II flakes and may have resulted from breakage of the thicker Type II flakes caused by internal damage during chipping. Multiple comparisons indicated that average flake long chords were statistically different between adjacent screens except for the two largest screens of the Type I flakes. Average flake widths and areas were also statistically different between all screens.

Except for very large Type I flakes, the mean aspect ratio (long chord to width) was relatively constant for all flake sizes (table 1). This agrees with findings of Hill and Wilson (1978) and May (1978). The mean slenderness ratio (long chord to thickness), on the other hand, decreased from a high of 84 and 109 for the large Type I and Type II flakes, respectively, to 28 for both types as flakes became smaller.

Except for the fraction retained on the 1/32-inch screen, SG also decreased for both flake types as the surface area became smaller (table 1). A portion of this decrease can be explained by (a) loss of some material (flakes were weighed after being removed from the image analysis sheets) and (b) inaccurate measurement of small flakes due to the diameter of the digitizer stylus. However, it is reasonable to assume that more flaking damage occurred in the lower SG zones of the wood, resulting in smaller flakes from these areas. The difference in areas of SG of screen fractions could not be tested statistically since weights were not determined for individual flakes.

Another statistical procedure, stepwise discriminant analysis, was used to determine the relative importance of the geometric descriptors in classifying the flakes (by type) into screen classes. The variables entered into this analysis were transformed in the same manner as noted in table 2. Because many variables used in this analysis were highly correlated, e.g. long chord, area, and total surface area, no one set of variables could be considered as the "best" set to differentiate the screens. Long chord, width, and area together defined the screen classes as well as any other combination of variables. The accuracy of the prediction using these three variables is shown in table 3. Across all screen sizes, the screen separation prediction accuracy for both flake types was similar, averaging approximately 70 percent. The average prediction accuracy is somewhat misleading because it was favorably influenced by the restricted choices of the top and bottom screens. For example, the analysis predicted a retention of only 50 percent of those Type I flakes actually found on the 1/2-inch screen.

[1]Average refers to the mean of the appropriately transformed variable.

Thirty percent of the flakes actually retained on the 1/2-inch screen were predicted to be retained on the 1-inch screen, whereas the other 20 percent were predicted to pass through the 1/2-inch screen. Addition of more descriptive variables did not appreciably improve the prediction accuracy.

Comparison of Type I and Type II Flakes

As mentioned previously, a difference between the large Type I and Type II flakes was visually discerned. ANOVA corroborated this observation. Average thickness, area, width, volume, total surface area, edge surface area, total surface area-to-volume ratio, and aspect ratio (length to width) were statistically different at the 0.05 level of significance for Type I and Type II flakes retained on the 1- and 1/2-inch screens. In addition, the average long chord, edge ratio, and slenderness ratio (length to thickness) were found to be statistically different at the 0.05 level for those Type I and Type II flakes retained on the 1-inch screen. There were no statistical differences in the average value of any of the descriptors for flakes passing through the 1/2-inch screen.

Because of the numerous splits and ragged edges of the large Type II flakes, we thought that descriptive variables such as perimeter and form factors would be useful in distinguishing the flake types. This was not the case. Neither perimeter nor any of the form factors investigated, including those comparing flake shape to that of a circle, a square, or a rectangle (appendix A), were useful in statistically separating the flake types.

As mentioned earlier, the greatest difference between the two furnishes as distinguished by screen fractionation was the relative quantity of any one fraction of flakes. The average dimensional characteristics of the furnish or portions thereof may be obtained from the screen analysis data set on either a weight or a number basis (appendix B). For example, the mean long chord of the larger Type I flakes (those retained on or above a 1/8-in screen) was estimated at 2.06 inches when weighted by the respective screen weights. However, if numbers are the basis for establishing means, the mean long chord is calculated to be only 1.46 inches (appendix B). These estimates approximate the values obtained directly from the main image analysis data set, as will be shown in the next section.

Image Analysis– Main Image Analysis Data Set

Equipment and time limitations of the sonic digitizing equipment described earlier prohibited measuring dimensions of small flakes. Image analysis of Type I and Type II flakes was limited to representative samples of material retained on or above a 1/8-inch screen. Considering all of the material retained on or above a 1/32-inch screen used in board production, the portion used for image analysis accounted for only 14 percent of the Type I flakes and 8 percent of the Type II flakes, but included 91 and 69 percent, respectively, of the weights of the Type I and Type II furnishes.

Even though the sample sizes were small (a total of 109.267 OD grams of Type I flakes and 89.073 OD grams of Type II flakes), the image analysis still entailed description of 2,748 Type I and 6,664 Type II flakes. The flake count calculated from the above data for the + 1/8-inch furnish was approximately 2,500 flakes per 100 grams for the Type I furnish and 7,500 flakes per 100 grams for the Type II furnish. This agrees reasonably well with those values derived from the screen flake count and screen image analysis data sets adjusted by the fractional weight data. Lack of individual flake weights necessitated the use of volume when calculating weighted means for the large image analysis data set. Means obtained in this fashion may be slightly lower than those obtained if true weight were used because, as noted previously, SG decreases with decreasing flake size. Both numerical (each flake weighted equally) and volume “weighted” means of measured and calculated variables for both flake types are given in table 4. It remains to be seen which of these means is best suited to the development of a flake classification system.

Our research examined the extent of variation not only within a flake population but also the change in variation from batch to batch or from sample to sample within a batch. Analysis and conclusions apply only to the type of flake and flaking process studied and will change with different fabrication techniques. Variations in the area, long chord, and width are presented as box plots of individual samples, grouped by batches, in figures 8-10. Considering the large within-sample variation, no real practical difference was found between samples or batches of a similar flake type. Obviously, the mean values of the Type II flakes were considerably lower than those measured for the Type I flakes. The longest flakes were found in the Type II furnish because no restrictions were put on the maxichips used to manufacture the Type II flakes. The absence of outlying data in the Type I long-chord data was a result of cutting the blocks to a controlled length.

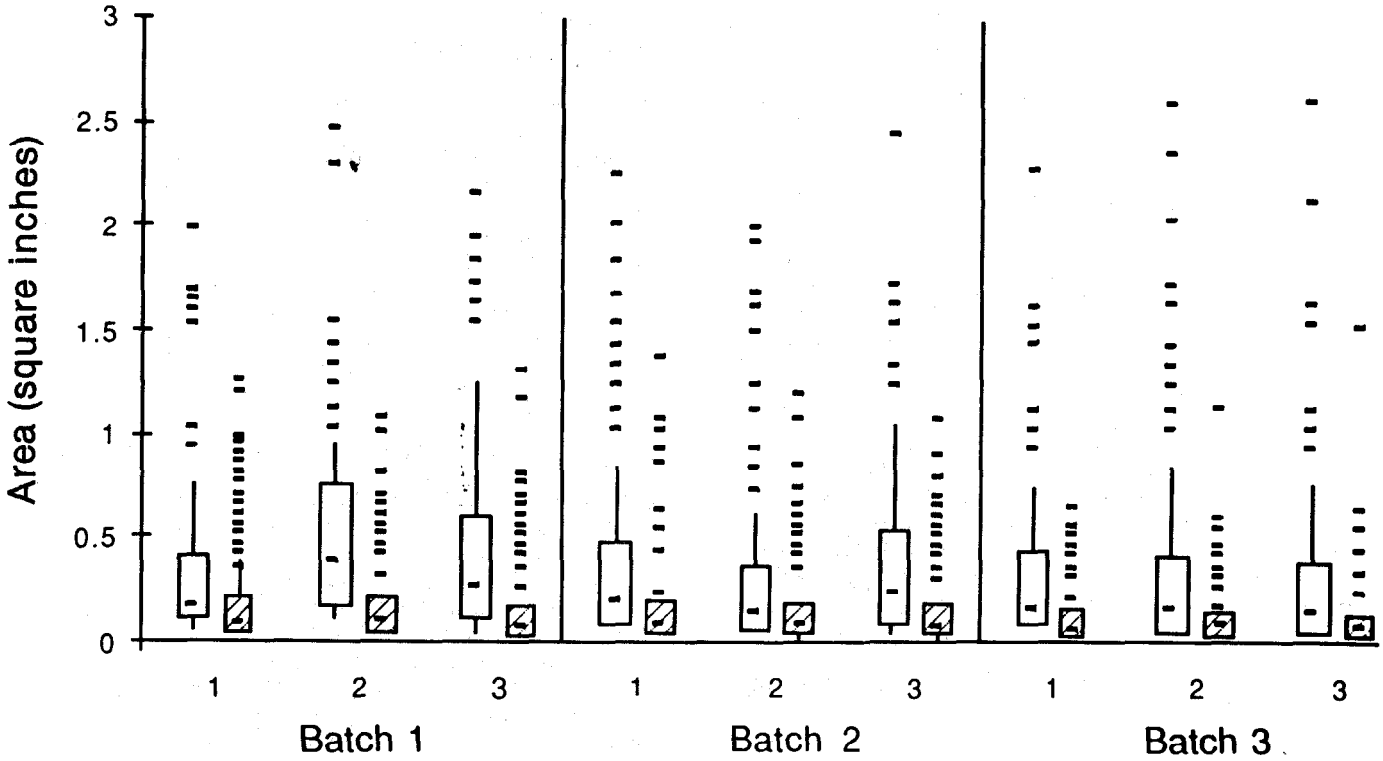


Figure 8—Variability in area; Type I □ and Type II ▨ flakes. (ML87 5406)

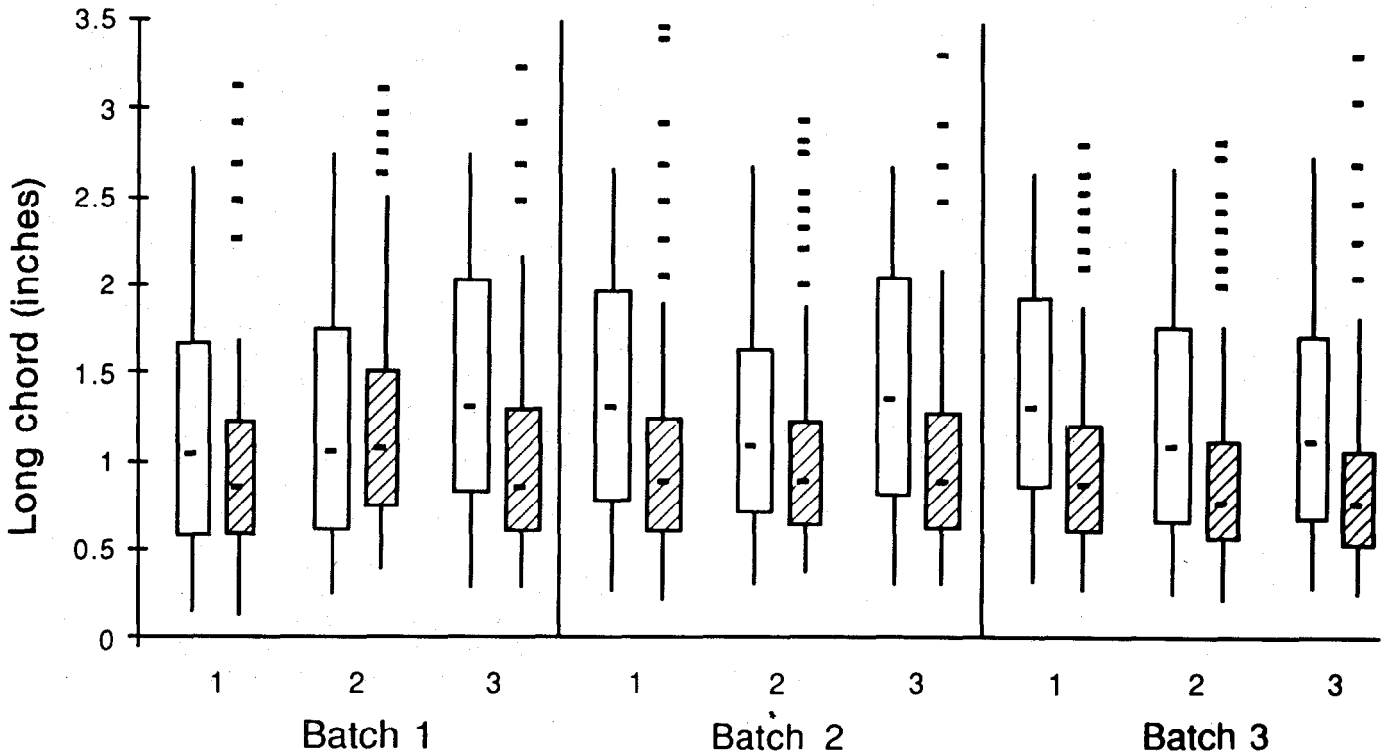


Figure 9—Variability in long chord; Type I □ and Type II ▨ flakes. (ML87 5407)

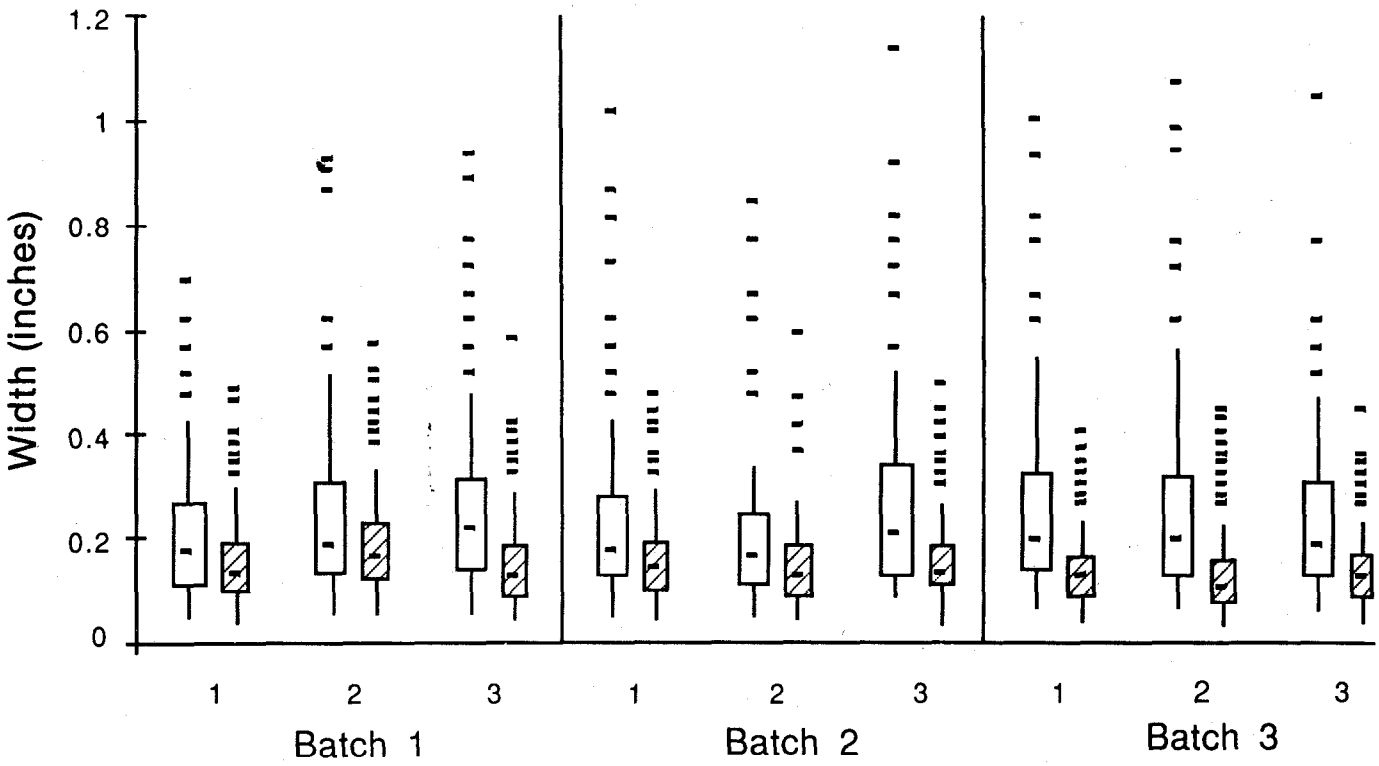


Figure 10—Variability in width; Type I □ and Type II ▨ flakes. (ML87 5408)

Within the constraints of this study, we found that a sample size of 150 flakes per group enabled us to distinguish a 0.003-inch difference in average thickness, a 0.26-inch difference in average long chord, a 0.05-inch difference in average width, and a 0.13-square-inch difference in average flake area. Increased variability in commercial furnish due to changes in tree quality, species, and lower machine tolerances will necessitate larger sample size. An extensive initial investigation is normally required to establish the variability of the flake measurements in question as well as the difference in average flake measurements that has practical significance.

The best graphical way we have found to visualize the characteristics of a flake furnish is to plot the cumulative distribution functions of the variables (Chambers et al. 1983). The flake data are first sorted by the variable in question and arranged in ascending rank from the smallest to the largest. The data are then split into the desired number of equal groups or percentiles. The measured value of the variable corresponding to the percentile point is then recorded and plotted against its respective percentile. Cumulative distribution functions for flake area of both Type I and Type II flakes are shown in figure 11. Whereas 80 percent of the Type II flakes had total surface areas of less than 0.2 square inch (i.e., the 80th percentile of the Type II flakes ranked by total surface area equaled 0.2 in^2) only 50 percent of the Type I flakes were this small. In a cumulative distribution function plot, each observation has equal weight. Just as we obtained means of the descriptor variables, weighted by flake volume, we also obtained a weighted cumulative distribution function for area (fig. 11b). Here, the percentile flake area data are plotted against the accumulative volume occurring at that point. Note that the curves are pushed towards the right because the smaller flakes have less "weight" than before. Plotted in this way, approximately 58 percent and 15 percent of the volume of Type II and Type I flakes, respectively, had areas less than 0.2 square inch.

A direct comparison of the flake furnishes can be obtained by plotting percentile values of Type II flakes against percentile values of Type I flakes. This graph is termed a Quantile-Quantile (Q-Q) plot (Chambers et al. 1983). A Q-Q plot of flake area is shown in figure 12a. There are nine X's on each plot, representing the 10th to 90th percentiles of each flake type. If the flake furnishes are the same, the plot will be a straight line having a slope of 1. If the furnishes are different, the Q-Q curve will deviate from this 45° line. Practical application of this format to a flakeboard operation would require establishing descriptive data for a best or optimum flake furnish. Proper quality control or operational procedures would need to be taken when the deviation exceeded some preset limit as established by experience.

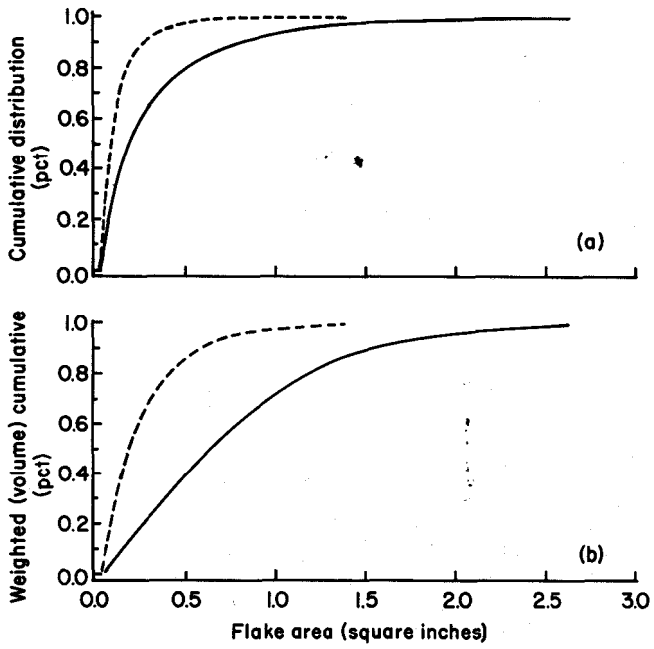


Figure 11—Cumulative distribution of Type I (---) and Type II (–) flake area. (a) Area; (b) weighted volume. (ML87 5512)

Again, Q-Q plots can be made from cumulative or weighted cumulative distribution functions. A Q-Q plot comparing flake area of the two furnish types weighted by volume is shown in figure 12b. The actual plot of the data does not appreciably change from the unweighted data (fig. 12a). What does change is the location of the percentile points. Figure 12a indicates that 20 percent of the Type I flakes (above 80th percentile) had areas larger than 0.5 square inch, whereas figure 12b shows that these flakes contained 60 percent of the volume. Likewise, figure 12 shows that approximately 5 percent of the Type II flakes were larger than 0.5 square inch but contained 15 percent of the volume. Because of the similarity in weighted and unweighted Q-Q plots and the importance of the weight in flakeboard fabrication, all Q-Q plots presented forthwith are shown for weighted (by volume) data. One must realize that three times as many Type II flakes were needed to equal the volume contained in a representative sample of Type I flakes. In reality, a distribution change in any geometric variable caused by dull knives, different raw material, etc., is usually accompanied by some change in both the volumetric distribution and flake count per unit volume.

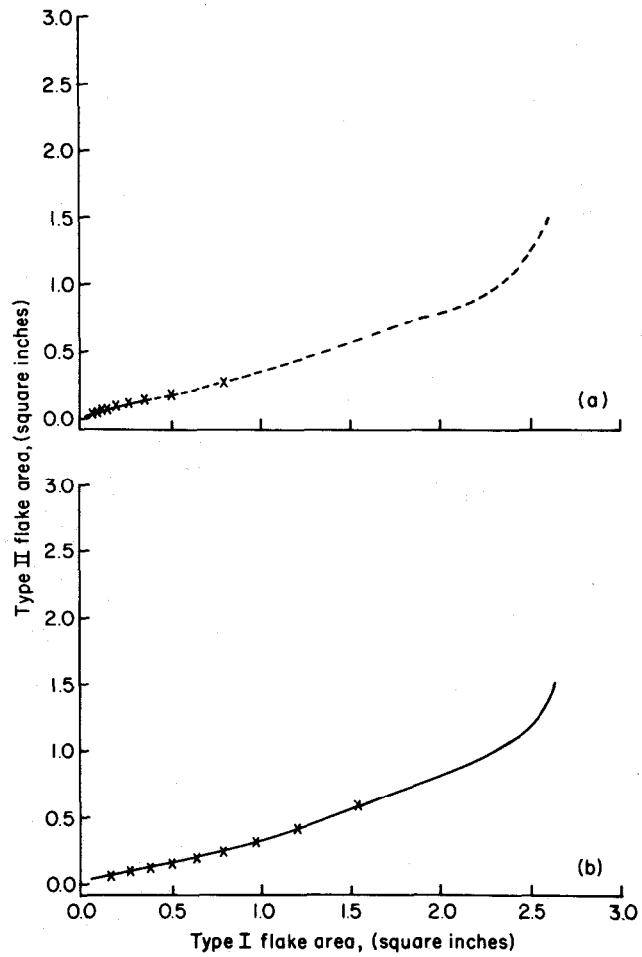


Figure 12—Q-Q plots of (a) area and (b) weighted (volume) area. (ML87 5513)

Q-Q plots of flake long chord, width, thickness, total surface area/volume, edge ratio, slenderness ratio, and aspect ratio are shown in figures 13-19. Long chords of the smaller Type II flakes were shorter than the long chords of corresponding Type I flakes (fig. 13). However, the top 10 percent of the volume of Type II flakes had long chords which approached or exceeded those of the Type I flakes. This was caused by the unrestricted upper limit of the Type II flakes, as shown previously in figure 9. The Q-Q plot of width (fig. 14) is similar to that of area (fig. 12). However, the Q-Q plot for thickness (fig. 15) is characterized by an S-shaped curve, indicating that Type I flakes were similar to Type II flakes in the first 10 percent of the volume, and in the remainder, Type I flakes were thicker than Type II flakes. As mentioned previously, this could have been caused by breakup of some large (usually thicker) Type II flakes due to internal damage.

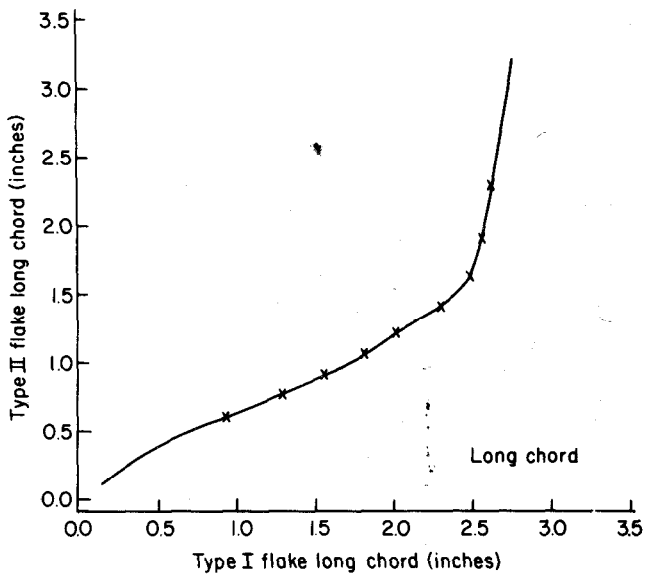


Figure 13—Q-Q plot of weighted (volume) long chord. (ML87 5514)

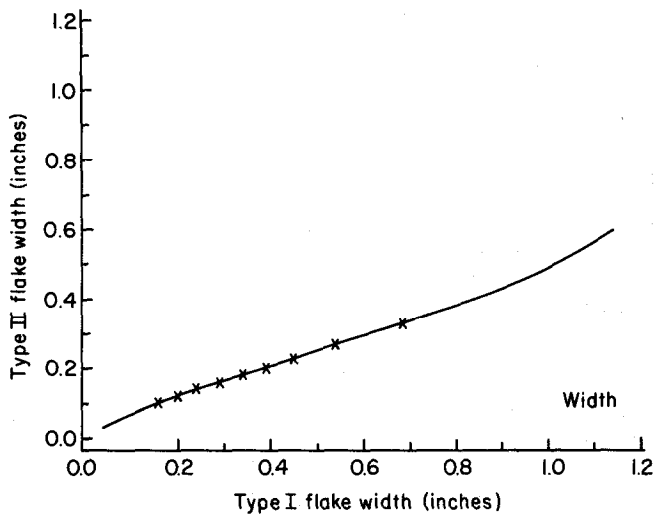


Figure 14—Q-Q plot of weighted (volume) width. (ML87 5515)

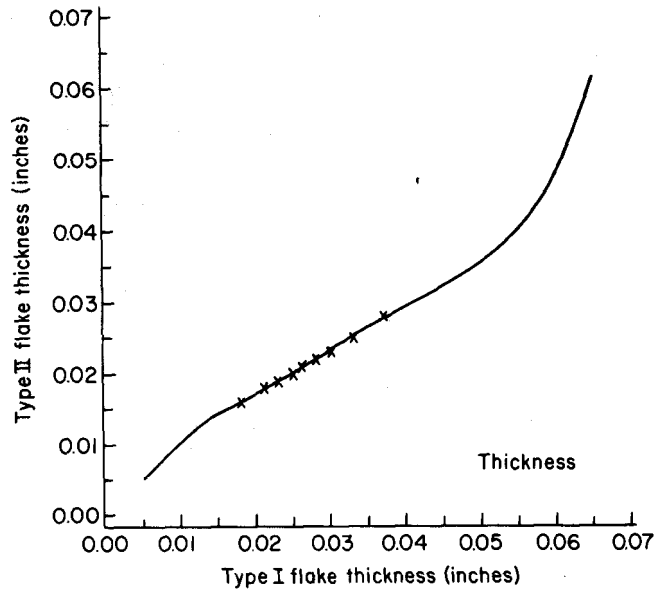


Figure 15—Q-Q plot of weighted (volume) thickness. (ML87 5516)

Q-Q plots show little difference in the two furnishes for surface area/ volume ratios and edge ratios (figs. 16 and 17). In both cases, Type II flakes had only slightly greater values than their Type I counterparts. In other studies, ratios such as these have been used to establish factors that affect board properties (Brumbaugh 1960, Hill and Wilson 1978, McMillin 1971, Rackwitz 1963). If one assumes that adjacent flakes within a flakeboard make contact only on the knife-cut surfaces, then edge ratio is an indicator of the effective bonding area. Surface-to-volume ratios, on the other hand, indicate total resin efficiency or relative glue spread. Flakes with lower surface/volume ratios require less adhesive.

Except for the extreme tails, Q-Q plots show very little difference in slenderness and aspect ratios between flake types (figs. 18 and 19). Type II flakes had a slightly higher aspect ratio and a slightly lower slenderness ratio than corresponding Type I flakes. As indicated by the relationship presented in table 1, the larger flakes tended to have the highest slenderness ratio and the lowest aspect ratio. Note that 20 percent of the volume of Type I flakes had slenderness ratios above 100 compared to only 10 percent of the volume of Type II flakes. Slenderness ratio is related to bending properties (Walter et al. 1979). It is highly desirable that flakes used in making structural flakeboard have ratios above 100 (Post 1961). Aspect ratio in conjunction with long chord indicates ability to align flakes.

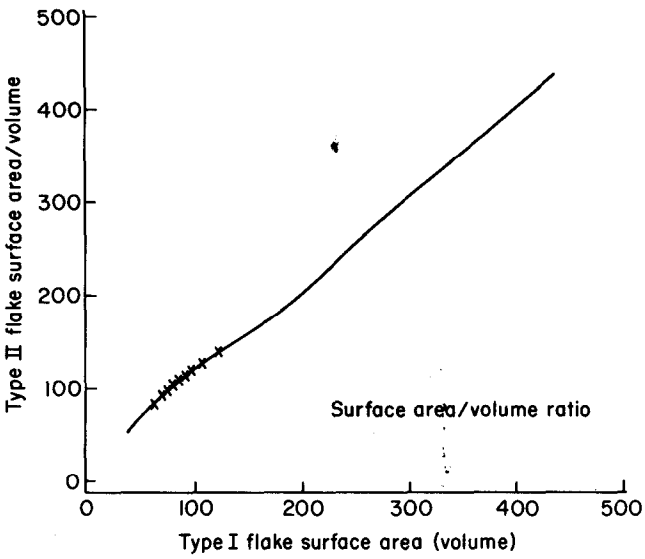


Figure 16—Q-Q plot of weighted (volume) total surface area/volume. (ML87 5517)

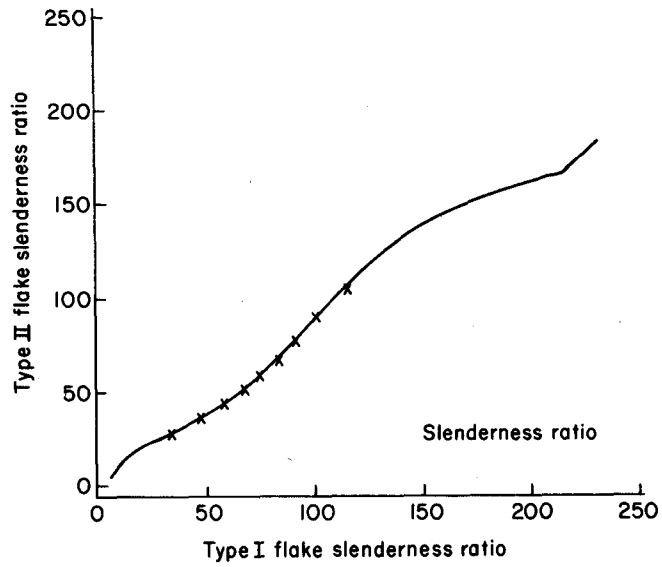


Figure 18—Q-Q plot of weighted (volume) slenderness ratio. (ML87 5519)

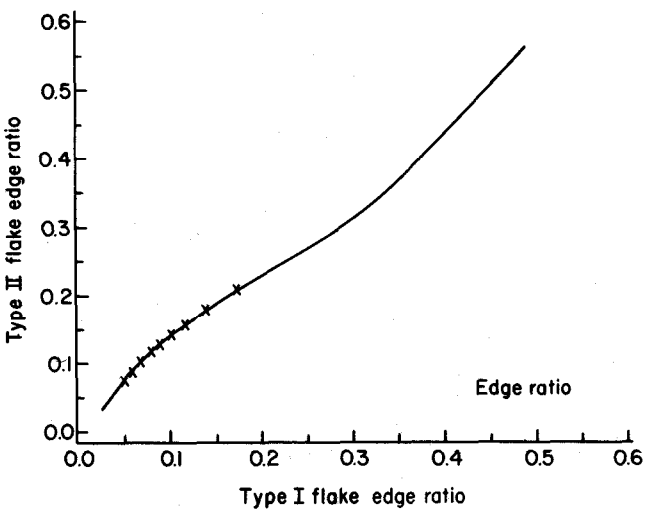


Figure 17—Q-Q plot of weighted (volume) edge ratio. (ML87 5518)

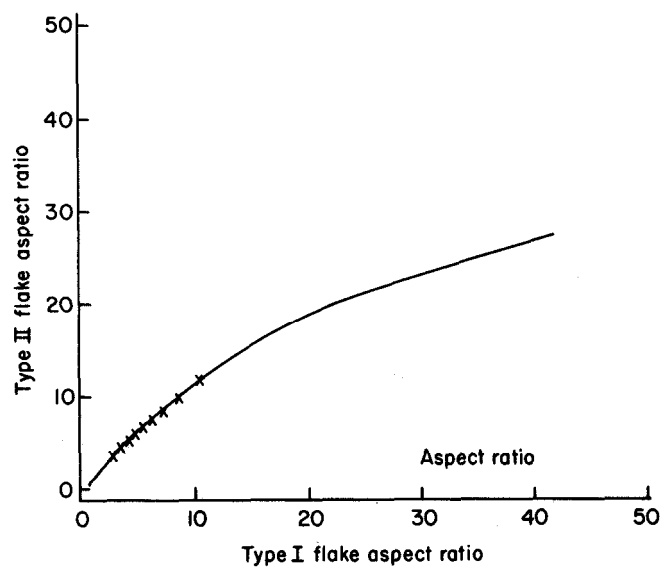


Figure 19—Q-Q plot of weighted (volume) aspect ratio. (ML87 5520)

While the Q-Q plots conveniently compare any one geometric descriptor between flake types, it is well to be aware of the association existing between the various descriptors and volume (figs. 20-23). A plot of the Type I long chord versus volume (fig. 20) illustrates the variability of volume for any given long chord. Note that volume was only partially dependent on long chord, which is understandable when one compares a long slim flake with a long wide flake. A plot of width versus volume (fig. 21) shows a somewhat stronger pattern. Thickness, while still showing a limited relation to volume, was extremely variable, especially in the smaller flakes (fig. 22). The edge ratio versus volume plot (fig. 23) tends to follow a decreasing curvilinear path with increasing volume. As with many of the other descriptive factors, the edge ratio-volume relationship contains a large amount of scatter. Plots comparing descriptor variables to volume were similar for both types of flakes.

Board Properties

As stated previously, a very important factor in establishing a flake classification system is the choice of appropriate descriptive variables that can be related to board properties. However, establishing these relations is the most difficult part of the problem. Screen classification simplifies the choice of descriptive variables but does not measure flake dimensions and the interactions between those geometric descriptors that affect the performance of structural reconstituted products.

Boards made in this study provided a cursory look at the performance of two flake furnishes that had been characterized by both screen fractionation and image analysis techniques. Flakes for board production were sorted by screening as this was the only practical technique for providing the quantity of material needed. It must be emphasized that the comparative performance values lack any statistical significance, having been derived in some cases from only a single board.

Bending properties of MOE and MOR for boards made from Type I and Type II flakes, and the screen fractions thereof, are compared in table 5. Data were adjusted for differences in SG and flake alignment according to equations and methods described by Geimer (1986). Strength and stiffness were greatest in the boards made with the larger flakes (retained on or above a 1/2-inch mesh screen) and diminished approximately 20 percent for both flake types in boards made from the fraction passing through the 1/4-inch screen and retained on the 1/8-inch screen. The similarity of Type I and Type II flakeboard properties obtained with the - 1/2 + 1/4 and - 1/4 + 1/8 inch screen fractions was expected. As discussed previously, the screen image analysis data set revealed statistical differences

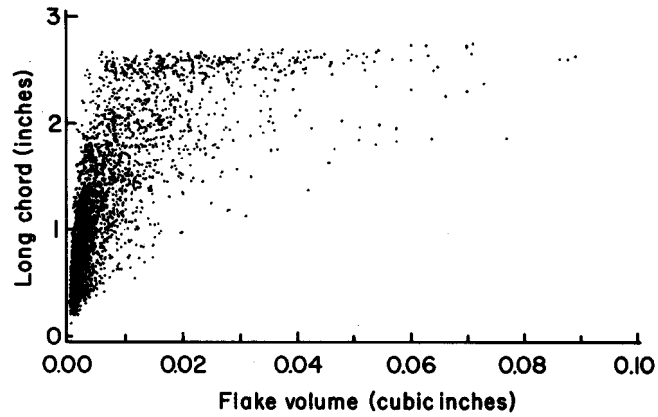


Figure 20—Long chord versus volume of Type I flakes. (ML87 5521)

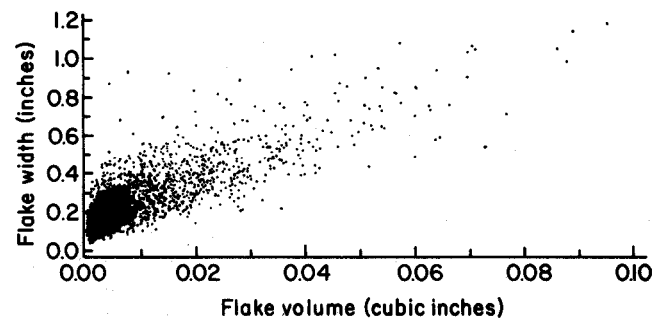


Figure 21—Width versus volume of Type I flakes. (ML87 5522)

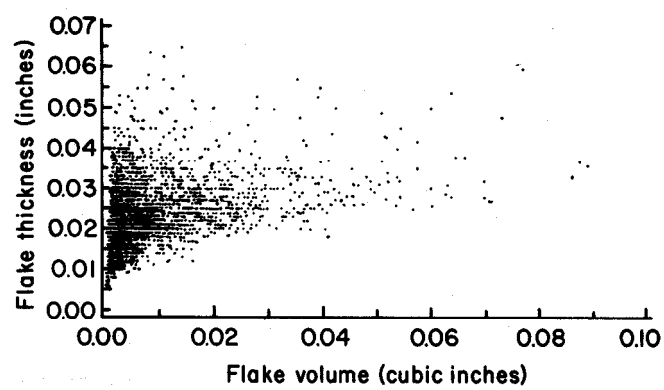


Figure 22—Thickness versus volume of Type I flakes. (ML87 5523)

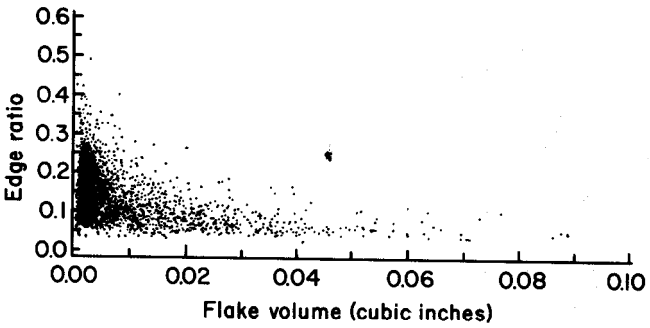


Figure 23—Edge ratio versus volume of Type I flakes. (ML87 5524)

between the geometry of the flake types only for flakes retained on or above a 1/2-inch screen. Apparently even these differences were not enough to drastically affect the bending properties of those boards made with the fractions retained on the 1/2-inch screen.

The similarity between Type I and Type II boards made with the combined fractions is not surprising if board properties are a function of the form factor or aspect ratio, as these values were similar in the two furnishes. However, if board properties are a direct function of flake length and width, then one would expect differences because the Type I furnish contained a much greater portion of the larger flakes retained on the 1/2-inch screen (41 pct compared to 5 pct for the Type II furnish), and it would seem reasonable that the high bending properties attained with this fraction would be reflected proportionally in the boards made with the combined fractions. Using an estimated MOE of 250,000 pounds per square inch (lb/in^2) and an MOR of 2,000 lb/in^2 for the - 1/8 + 1/32 inch screen fraction, the difference between bending properties of the two combined flake types based on the mean MOE and MOR values of each fraction weighted by the screen retention percentages was calculated to be approximately 16 percent. Boards produced from the Type II combined flakes, however, were only 5 percent lower in MOE than those made from Type I combined flakes. Bending strength was nearly the same for both sets of these boards.

The problem faced in any continuation of this work will be to find a relationship between the geometric measurements made in the image analysis and the final board properties. Inspection of table 4 shows that there are notable differences in some of the mean geometric descriptors for each flake type. It may be possible to relate the 30 percent difference in long chord measurements of the fraction retained on or above the 1/8-inch screen to the actual 5 percent difference in bending properties of boards made with the fraction retained on or above the 1/32-inch screen. It is more likely that property predictions will be made on interactions of several geometric descriptors.

Bending properties for the aligned boards followed the same general pattern as that of the random boards. After adjusting for SG and alignment, no practical difference could be observed between boards made from the two types of flakes. The different screen fractions again produced boards with different bending properties. Strength and stiffness declined with decreasing particle size. We attribute a major portion of the bending property difference between boards from each of the screen fractions to our ability to achieve flake alignment.

The MOE and MOR values (measured parallel to alignment and adjusted for SG only) for the Type II boards made with the combined flakes were 75 and 81 percent, respectively, of those values measured for the Type I boards. We attribute the reduced performance of these Type II boards to a decrease in flake alignment, from 52.1 to 35.9 percent. (See Geimer (1976) for description of flake alignment measures.) The screen analysis of the two furnishes showed a large. difference in volume of the highly alignable flakes retained on the 1/2-inch screen (40.1 pct for the Type I flakes vs. 5.7 pct for the Type II flakes). It is interesting to note that the mean Type II long chord of 0.92 inch, shown for the + 1/8-inch material, was 70 percent of the 1.32 inches calculated for the Type I furnish (table 4). It is not unreasonable to assume that the long chord by itself would make a good predictor for flake alignment.

Additional board properties, including tension, IB, and dimensional stability, are shown in table 6. No attempt was made to adjust these values for differences in SG. Tensile maximum stress averaged 47 percent of the original values obtained for bending MOR. Tensile MOE (not shown) averaged 90 percent of unadjusted bending MOE.

Internal bond values shown in table 6 are averages of the combined values of both aligned and random boards. Except for boards made from the smaller - 1/4 + 1/8 inch mesh fraction, IB averaged slightly higher for the Type II flakeboards. This strength difference is attributed to the smaller average flake dimensions of the Type II flakes in those screen fractions.

Thickness swelling properties were very similar for both sets of random boards. As with bending properties, linear expansion of the aligned boards was a function of flake alignment. Finally, no major difference was noted in the performance of the two types of flakes when boards were exposed to a VPS treatment and tested wet (data not shown). Both bending MOE and MOR property retention based on thickness at test averaged 38, 30, and 38 percent for random, parallel to alignment, and perpendicular to alignment tests, respectively.

Summary

Two flake furnishes differing substantially in the volume of large flakes retained on a 1/2-inch screen (40.2 vs. 5.2 pct) were characterized with both screen fractionation and image analysis techniques. In addition, image analysis data were obtained on the separate screen fractions to provide a basis for comparing the two classification methods.

A screen mesh sequence of 1, 1/2, 1/4, 1/8, 1/16, and 1/32 inch did not cleanly separate the flakes by any one of the geometric descriptors measured with image analysis. In general, flake measurements in the upper and lower 25th percentile of one screen fraction were also present in the adjacent screen fraction. Stepwise discriminate analysis showed no single combination of geometric descriptors to be best in predicting screen classification, and the prediction accuracy was limited to 70 percent. Distinction of individual flakes by furnish type was also difficult and only partially successful for those larger flakes retained on or above a 1/2-inch mesh screen. Form factors were not useful in classifying flakes.

Cumulative distributions of the image analysis data proved to be an excellent method to describe flake furnishes. Q-Q plots are useful in comparing two flake furnishes and can readily be adapted to an industrial plant quality-control program.

No practical means were available to separate the flakes by size descriptors in the quantity necessary for board productions. However, boards made from different screen fractions provided a cursory look at the potential of using geometric dimensions as predictors of both board properties and flake alignment levels. Board properties may be closer related to aspect ratios than to individual flake length or width measurements. Average flake length, on the other hand, appears to have a direct relation to flake alignment.

Image analysis provides the means to define a furnish by geometric flake measurements. With the advent of video scanning equipment and computers this technique can be practical on a commercial scale. To increase the usefulness of image analysis flake classification, it will be necessary to define the best geometric flake descriptors and relate them to board properties.

Literature Cited

Arnold, D. 1986. The advantages of digital image processing for partial analysis. Holz als Roh und Werkstoff. 44(1986): 249-252.

Brumbaugh, J. 1960. Effect of flake dimensions on the properties of particleboard. Forest Products Journal. 10(5): 243-246.

Chambers, J. M.; Cleveland, W. S.; Kleiner, B.; Tukey, P. 1983. Graphical methods for data analysis. Belment, CA: Wadsworth, International Group. 395 p.

Geimer, R. L. 1976. Flake alinement 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. L. 1979. Data basic to the engineering design of reconstituted flakeboard. In: Proceedings, 13th annual particleboard symposium. Pullman, WA: Washington State University.

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

Geimer, R. L. 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.

Hill, M. D.; Wilson, J. B. 1978. Particleboard strength as affected by unequal resin distribution on different particle fractions. Forest Products Journal. 28(11): 44-48.

May, H. A. 1978. Optimizing the manufacturing conditions of phenolic bonded particleboard; Part I: Studies on various factors affecting bonding quality. Holz als Roh und Werkstoff. 36(1978): 441-449.

May, H. A. 1982. Relations between properties, raw-material, and the density distribution in particleboards; Part II: Applicability of common industrial sorting procedures for evaluating particle mixtures. Holz als Roh und Werkstoff. 40(1982): 303-306.

May, H. A.; Keseru, G. 1982. Relations between properties, saw materials, and distribution of density in particleboards; Part I: Sifting of particle mixtures and methods for evaluating their applicability for particle manufacturing. Holz als Roh und Werkstoff. 40(1982): 105-110.

May, H. A.; Stegmann, G. 1966. Methods for the determination of particle dimensions and the evaluation of screening processes. Holz als Roh und Werkstoff. 24(7): 305-311.

McMillin, C. W. 1971. Aspects of wood and particle characteristics affecting the properties of aggregates from southern pine flakes. FS-50-3201-3-10. Alexandria, LA: U.S. Department of Agriculture, Forest Service, Southern Forest and Range Experiment Station; Nov. 23.

McMillin, C. W. 1982. Application of automatic image analysis to wood science. Wood Science. 14(3): 97-105.

Neusser, H.; Krames, U. 1969. Determination of some impactional wood chip indexes. Holzforschung und Holzvewerrung. 21(4): 77-80; Aug.

Neusser, H.; Krames, U.; Hardinger, K.; Serentschy, W. 1969. The particle character and its influence on the surface quality of particleboard. Holzforschung and Holzvewerrung. 21(4): 81-90; Aug.

Post, P. W. 1961. Relationship of flake size and resin content to mechanical and dimensional properties of flakeboard. Forest Products Journal. 11(1): 34-37; Jan.

Rackwitz, G. 1963. Influence of chip dimensions on some properties of wood particleboards. Holz als Roh und Werkstoff. 21(6): 200-209.

Rackwitz, G. 1964. Sifting of wood particles; Part II: Evaluation of chip blends and sifting processes. Holz als Roh und Werkstoff. 22(10): 365-371; Oct.

Vorreiter, L. 1964. Particle physics as the basis for the processing of (minute) wood chips. Holz-Zentralblatt. 89(5): 53-56 Part I; 89(11): 153-156 Part II; 89(47): 707-710 Part III.

Walter, K.; Keiser, J.; Wittke, T. 1979. Effect of chip form on some strength properties of oriented structural board. Holz als Roh und Werkstoff. 37(5): 183-188; May.

Table 1 – Screen fraction means

Descriptor	Type I flakes						Type II flakes					
	Screen size (in)						Screen size (in)					
	1	1/2	1/4	1/8	1/16	1/32	1	1/2	1/4	1/8	1/16	1/32
	SCREEN WEIGHT DATA SET											
Screen analysis, retention by weight[a] (pct)	6.7	33.5	40.0	8.7	5.3	3.6	0.4	4.9	35.5	23.8	16.8	12.8
	SCREEN FLAKE COUNT DATA SET											
Original count (No/ hectogram)	330	680	2,990	17,650	112,500	330,000	740	900	3,500	14,470	57,500	240,000
	SCREEN IMAGE ANALYSIS DATA SET											
Image analysis, sample size (No. flakes)	40	40	40	59	60	60	39	40	40	60	60	60
Ovendry weight (g)	10.423	5.450	1.827	0.529	0.149	0.025	5.745	3.755	1.594	0.617	0.209	0.060
Specific gravity	0.306	0.277	0.265	0.223	0.202	0.224	0.322	0.295	0.275	0.261	0.250	0.305
Mean long chord (in)	2.56	2.43	1.91	0.955	0.528	0.326	2.72	2.36	1.70	0.970	0.567	0.340
Mean width (in)	0.673	0.454	0.244	0.107	0.069	0.043	0.418	0.332	0.228	0.123	0.079	0.047
Mean thickness (in)	0.0304	0.0284	0.0241	0.0230	0.0197	0.0113	0.0248	0.0238	0.0244	0.0212	0.0207	0.0119
Mean perimeter (in)	6.91	5.85	4.44	2.15	1.19	0.71	7.03	5.74	3.92	2.16	1.25	0.75
Mean top surface area[b] (in^2)	1.660	1.040	0.440	0.107	0.036	0.013	1.130	0.810	0.362	0.113	0.040	0.016
Mean total surface (area/volume ratio)	73.7	83.8	103.6	133.0	164.7	271.5	89.3	94.6	98.0	130.4	152.6	272.4
Edge ratio (edge surface/total surface)	0.06	0.07	0.11	0.19	0.24	0.24	0.07	0.08	0.12	0.17	0.24	0.22
Slenderness ratio (long chord/thickness)	84	85	79	41	27	28	109	99	69	45	27	28
Aspect ratio (long chord/width)	3.8	5.4	7.8	8.9	7.6	7.6	6.5	7.1	7.5	7.9	7.2	7.2
Form factor[c]	0.84	0.92	0.89	1.02	0.99	0.99	0.79	0.91	0.91	0.97	0.96	1.05

[a]2.2 pct of Type I flakes and 5.8 pct of Type II flakes passed through 1/32-in screen.
[b]Surface as viewed on sonic digitizer (top surface of flat flake).
[c]Form factor = $4A(1 + E)^2/P^2E$, where A = top surface area, E = long chord/width, and P = perimeter.

Table 2–Multiple comparison of screen fractions

Variable	Transformation	Multiple comparisons[a,b] Type I flakes	Type II flakes
Thickness	None	1, 1/2, 1/4, 1/8, 1/18, 1/32	1, 1/4, 1/2, 1/8, 1/16, 1/32
Area	Logarithm	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Perimeter	Square root	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Long chord	Square root	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Width	Logarithm	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Volume	Logarithm	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Total surface area	Logarithm	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Edge surface area	Square root	1, 1/2, 1/4, 1/8, 1/16, 1/32	1, 1/2, 1/4, 1/8, 1/16, 1/32
Surface area/volume,	Logarithm	1/32, 1/16, 1/8, 1/4, 1/2, 1	1/32, 1/16, 1/8, 1/4, 1/2, 1
Edge ratio	Logarithm	1/16, 1/32, 1/8, 1/4, 1/2, 1	1/16, 1/32, 1/8, 1/4, 1/2, 1
Slenderness ratio	Square root	1/2,1,1/4,1/8,1/32,1/16	1, 1/2, 1/4, 1/8, 1/32, 1/16
Aspect ratio	Logarithm	1/8, 1/4, 1/16, 1/32, 1/2, 1	1/4, 1/8, 1/2, 1/32, 1/16, 1
Form factor	Logarithm	1/32, 1/8, 1/16, 1/2, 1/4, 1	1/32, 1/8, 1/16, 1/4, 1/2, 1

[a]Averages are arranged from high to low.
[b]Screens showing a common underline are not considered statistically different at 0.05 level.

Table 3–Discriminant analysis-predictions of flake retention (in percent) using area, long chord, and width as predictor variables

	Screen size	Predicted 1	1/2	1/4	1/8	1/16	1/32
	-In-	Pct					
		Type I flakes[a]					
	1	78	22	0	0	0	0
	1/2	30	50	20	0	0	0
Actual	1/4	0	28	60	12	0	0
	1/8	0	0	10	68	22	0
	1/16	0	0	0	18	65	17
	1/32	0	0	0	2	12	86
		Type II flakes[b]					
	1	79	18	3	0	0	0
	1/2	25	70	5	0	0	0
Actual	1/4	5	22	61	12	0	0
	1/8	0	0	15	72	13	0
	1/16	0	0	0	18	62	20
	1/32	0	0	0	0	18	82

[a]Average correct prediction of 69 pct.
[b]Average correct prediction of 71 pct.

Table 4–Image analysis–average flake descriptors

Variable	Numerical average Type I	Type II	Weighted (volume) average Type I	Type II
Total number of flakes	2,749	6,664	2,749	6,664
Total ovendry weight (g)	109.267	89.073	109.267	89.073
Long chord (in)	1.325	0.923	1.918	1.341
x distance (in)	1.33	0.931	1.927	1.357
Width (in)	0.235	0.149	0.387	0.202
y distance (in)	0.335	0.199	0.520	0.270
Thickness (in)	0.023	0.020	0.027	0.022
Perimeter (in)	3.080	2.053	4.644	3.009
Top surface (in^2)	0.329	0.132	0.763	0.272
Total surface area (in^2)	0.732	0.306	1.654	0.610
Edge surface area (in^2)	0.074	0.042	0.128	0.066
Volume (in^3)	0.008	0.003	0.026	0.006
Surface/volume ratio	113.3	88.9	126.7	112.4
Edge ratio	0.138	0.165	0.102	0.137
Slenderness ratio	62.9	48.1	75.7	63.7
Aspect ratio	6.7	0.978	6.2	7.3
Form factor	0.954	0.978	0.961	0.976

Table 5–Flakeboard bending properties

Screen fraction	Random				Aligned									
	Number of boards	SG	MOE adjusted for SG[b]	MOR adjusted for SG[c]	Number of boards	SG	Align sonic velocity ratio[d]	Align MOE:R[e]	MOE:R	MOE Pa adjusted for SG[b]	MOE Pa adjusted fpr SG and ALN[b]	MOR:R	MOR Pa adjusted for SG[c]	MOR Pa adjusted for SG and ALN[c]
			k lb/in²	*Lb/in²*			- - - - -*Pct* - - - - -			- -*Lb/in²* x *10³* - -			- - - - *Lb/in²* - - - -	
							TYPE I FLAKES							
Combined[f]	4	0.631	585	4,110	4	0.604	52.1	49.0	4.9	1,238	1,266	3.8	7,700	7,730
+ 1/2	2	.677	684	5,100	3	.655	58.9	52.0	5.4	1,355	1,319	3.9	8,560	8,560
– 1/2 + 1/4	2	.644	582	4,040	2	.635	52.2	50.0	5.1	1,182	1,182	4.1	7,830	7,640
– 1/4 + 1/8	2	.632	537	3,960	1	.600	37.7	37.3	3.4	917	1,096	2.8	6,110	7,020
							TYPE II FLAKES							
Combined[f]	5	.622	554	4,130	4	.626	35.9	33.7	3.0	924	1,191	2.4	6,250	7,860
+ 1/2	1	.624	677	5,240	1	.654	62.7	61.5	7.4	1,517	1,306	5.8	10,470	8,930
– 1/2 + 1/4	2	.656	630	4,620	2	.624	50.0	45.5	4.4	1,129	1,195	3.1	7,280	7,900
– 1/4 + 1/8	2	.627	552	3,880	2	.626	36.8	33.0	3.0	855	1,064	2.5	5,850	7,090

NOTE: SG = specific gravity; MOE = modulus of elasticity; MOR = modulus of rupture; Pa = test in parallel-to-alignment direction; ALN = alignment.

[a]4 test samples were cut from each board, 2 in the parallel direction and 2 in the perpendicular direction.

[b]Adjustment to 0.640 SG. MOE random = $e^{\mu 1}$ $SG^{\alpha 1}$, MOE Pa = $e^{\mu 1} SG^{\alpha 1}$ $MOE{:}R^{\delta 1}$ where μ_1 = 13.77, SG = 0.640, and MOE:R = 5.1.

[c]Adjustment to 0.640 SG. MOR random = $e^{\mu 2}$ $SG^{\alpha 2}$, MOR Pa = $e^{\mu 2}$ $SG^{\alpha 2}$ $MOE{:}R^{\delta 2}$ where μ_2 = 8.9, SG = 6.40, and MOR:R = 3.87.

[d]Percent align = 75.8 ln sonic velocity ratio (Geimer 1981).

[e]Percent align = 30.7 ln MOE:R where MOE:R = modulus of elasticity ratio = $\frac{\text{MOE Pa}}{\text{MOE Pe}}$ (Geimer 1981).

[f]Includes + 1 to + 1/32-in screen fractions.

Table 6—Flakeboard mechanical and physical properties

Screen fraction	Modulus of rupture tensile stress: Random	Modulus of rupture tensile stress: Parallel perpendicular ratio	Modulus of rupture tensile stress: Parallel to alignment direction	Internal bond: SG	Internal bond: Stress	Dimensional stability[a]: MC	Dimensional stability[a]: Linear expansion random	Dimensional stability[a]: Linear expansion test: Parallel to alignment direction	Dimensional stability[a]: Linear expansion test: Perpendicular to alignment direction	Dimensional stability[a]: Thickness swell
	Lb/in²		*Lb/in²*		*Lb/in²*	*Pct*				
					TYPE I FLAKES					
Combined	1,710	3.3	3,100	0.628	52	15.6	0.193	0.129	0.558	10.9
+1/2	2,340	5.3	4,240	.633	52	15.6	.205	.107	.723	10.7
−1/2 +1/4	1,960	4.4	3,560	.629	46	15.0	.217	.112	.567	10.8
−1/4 +1/8	1,730	2.2	2,710	.623	63	15.7	.222	.180	.373	12.9
					TYPE II FLAKES					
Combined	1,790	2.2	2,770	.593	67	15.8	.198	.137	.377	11.4
+1/2	2,360	5.7	5,340	.620	59	15.8	.179	.091	.621	12.0
−1/2 +1/4	2,360	3.3	3,180	.633	54	15.4	.205	.097	.436	12.0
−1/4 +1/8	1,900	2.3	2,000	.607	60	15.5	.208	.122	.344	12.6

NOTE: SG = specific gravity; MC = moisture content.

[a]All dimensional stability data refer to condition following exposure to 90 pct relative humidity and are shown as a percent of ovendry condition.

Appendix A
Factors for comparing a two dimensional object to a rectangle.

Formula 1

For a rectangle whose width is defined as a and its length as b

Perimeter = P = 2(a + b) (1)

Then $a = \frac{P}{2} - b$ (2)

But area = A = ba (3)

Substituting (2) into (3) $A = b(\frac{P}{2} - b)$ (4)

Since $\frac{A}{b(P/2 - b)} = 1$ for a rectangle (5)

Form factor = FF $= \frac{A}{b(P/2 - b)}$ (8)

Formula 2

Let aspect ratio = E $= \frac{\text{long chord}}{\text{width}} @ \frac{b}{a}$ (7)

Then $a = \frac{b}{E}$ (8)

From (1) P = 2a + 2b (9)

Substituting (8) into (9), $P = 2\frac{b}{E} + 2b$ (10)

Multiplying each term by E, PE = 2b + 2bE (11)

And $b = \frac{PE}{2(1 + E)}$ (12)

Substituting (8) into (3), area = A $= \frac{b^2}{E}$ (13)

And substituting (12) into (13), $A = \frac{(PE)^2}{(2(1 + E))^2/E}$ (14)

And $A = \frac{P^2E}{4(1 + E)^2}$ (15)

As in (5) and (6) since

$\frac{A}{P^2E/4(1 + E)^2} = 1$ for a rectangle (16)

Form factor = FF $= \frac{4A(1 + E)^2}{P^2E}$ (17)

Appendix B
Calculation of weighted and unweighted means.

$$\text{Furnish mean}_{(\text{weight})} = \frac{\sum \text{Screen mean x screen weight}}{\sum \text{screen weight}} \quad (1)$$

where screen weight divided by ∑ screen weight equals the percentage of total weight retained on each screen.

$$\text{Furnish mean}_{(\text{number})} = \frac{\sum \text{screen mean x screen number}}{\sum \text{screen number}} \quad (2)$$

where screen number (screen fraction flake count per hectogram multiplied by the proportion screen fraction weight) divided by ∑ screen number is the relative number of flakes in each screen fraction.

Example: Weighted and numerical means of long chord for Type I material retained on and above 1/8-inch screen.

Screen	1-inch	1/2-inch	1/4-inch	1/8-inch	Total
Mean long chord	2.56	2.43	1.91	0.955	
Percent weight	6.7	33.5	40.0	8.7	88.9
Count/100 g	330	680	2,990	17,650	
Screen number	22.11	227.8	1,196	1535.55	2981.46

$$\text{Mean long chord}_{(w)} = \frac{(2.58 \times 6.7 + 2.43 \times 33.5 + 1.91 \times 40.0 + 0.955 \times 8.7)}{88.9} = 2.06$$

$$\text{Mean long chord}_{(N)} = \frac{(2.56 \times 22.11 + 2.43 \times 227.8 + 1.91 \times 1{,}196 + .955 \times 1535.55)}{2981.46} = 1.46$$

2.0-6/88